The Interbank Money Market in Portugal: Liquidity Provision and Monetary Policy

by

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Declaration

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Abstract

This thesis consists of a series of three papers on risk management in banking industry and the liquidity insurance function performed by interbank markets. It is widely agreed that banks cooperatively use the interbank money market to compensate for expected and unexpected short-term liquidity shocks. Yet, we do not have a complete and detailed picture of its behaviour and how it can be connected to the conduction of monetary policy. We link banks' strategic behaviour to the monetary policy transmission mechanism, and explore the impact of interbank market microstructure on the monetary policy transmission mechanism. We extend mainstream literature on banks liquidity risk management developing a model of the interbank market in which banks trade at a range of maturities rather than simply overnight. The rational expectations solution to the model implies that maximizing profit banks impose a smoothing effect on interbank market interest rates. Using a unique dataset frequency data set of trade flows and interest rates for the Portuguese interbank money market, we analyse the micromechanics of the interbank market and model the co-movement of money market rates. We document banks trading at a range of maturities – mainly from over-night up to one week loans – and a seasonal pattern on market participation and interest rates. Further, failure to support the martingale hypothesis on interest rates can be tracked to banks specific characteristics and its share in market participation. An error correction model of the interbank market term structure provides evidence that rates respond to shocks originating either in banks' demand for liquidity or monetary policy, although reactions vary across monetary policy regimes. Our results emphasise two blocks of interest rates moving together: the short end on one hand, with maturities up to 2 weeks; and the longer end, on the other, comprising the remaining maturities The rational expectations theory of interest rates does not hold in periods when there were institutional arrangements that prevented banks from yield curve arbitrage, and when there is uncertainty regarding the commitment of the central bank to pre-announced monetary policy targets.

This work is dedicated to those I love,

my wife, Manuela, my daughter Catarina, and

my parents.

Chapter 1

Introduction and Summary

This thesis consists of a series of three papers about risk management in banking industry and the liquidity insurance function performed by interbank markets. Banks cooperatively use the interbank market to compensate for expected and unexpected short-term liquidity shocks. Authors of previous research in the area agree on the importance of a well functioning interbank market for banks' reserve management and for the monetary policy transmission mechanism. But little is known about the microstructure and the mechanics of this market. In fact, despite a burgeoning theoretical literature, empirical research is scarce mainly due to the paucity of data.

The contribution of this thesis is twofold. First, we add to theory by developing a model of the interbank market in which banks trade at a range of maturities rather than simply overnight. Most research, both theoretically and empirically, concentrates on analysing the overnight market alone. We extend mainstream literature on banks liquidity risk management models by allowing banks to borrow funds in the interbank money market for overnight and maturities beyond. We argue that banks can to a certain extent forecast short-term needs for funds, and as a result they borrow from their peers for a different range of maturities up to one year. In fact, a great proportion of foreign and stock exchange market transactions are settled at a deferred date and most banks chose to borrow in advance to meet expected liquidity shortages. The overnight borrowing and lending is only a fraction of total interbank bilateral exposures, and from a regulatory perspective this whole range of investments should not be ignored. Particularly, if one is concerned with systemic risk threats, the payments system stability and overall interbank market exposures, the extended network of relationships has to be considered.

The second contribution of this thesis is to add to empirical knowledge by analysing the micromechanics of the interbank market in Portugal, and modelling the co-movement of money market rates, using a unique high frequency data set of trade flows and interest rates. This helps bridge a gap in the literature exploring the relationship between banks liquidity management behaviour and the monetary policy implemented by central banks. Empirical research shows interbank interest rates are anchored on monetary policy instruments, and thus are tightly linked to the monetary transmission mechanism. We emphasise that the institutional features of interbank money markets are of surmounting importance to assess the effectiveness of monetary policy and the ability of central banks to achieve monetary goals. Modern central banks implement monetary policy by setting an intermediate target for some short-term interest rate and aiming ultimately at price stability. Operationally they intervene in financial markets through open market operations, thus affecting overnight and other short-term interbank rates, which they expect to be able to control. Several tools are used to achieve the target while stabilizing interest rates. The efficacy in pursuing such targets is subject to much discussion, to which we expect to contribute with this research.

Empirically, we use a unique dataset recording the characteristics of all individual loans in the Portuguese interbank money market from the 1st of January 1989 to 31st December 1998. This dataset offers a multitude of opportunities to do empirical research in interbank money markets and payments system related issues.

In the background of this research are the financial innovation and liberalization trends that we find globally in financially developed markets. Over recent decades, and largely due to reduction in reserve requirements ratios and shifts towards quasi-contemporaneous reserve requirement systems, attention has focused on interbank interest rate volatility and its implications to achieve monetary policy goals. It is argued that a large proportion of interest rate fluctuations is due to the payments system, i.e., short-term expected and unexpected liquidity shocks face by banks. If banks do not hold enough cash reserves at the central bank they can borrow from their peers in the interbank market, and in doing so they prevent the payments systems from stalling while allowing for the smooth functioning of the financial system.

Banks hold reserves deposited with the Central bank either for regulatory and safety purposes. However, because reserve holding is costly, risk-neutral profit-maximizing agents will pursue cost minimization strategies to increase profits. Interbank money markets allow banks to economize on central bank funds through borrowing short-term funds from other banks to finance transitory imbalances in the reserve account. To what extent this private arrangement succeeds in allocating liquidity is a matter of discussion as the benefit comes at a cost, and credit-rationing may imply the market fails to achieve an efficient distribution of central bank reserves.

The ability of interbank money markets to provide adequate liquidity insurance to banks is widely discussed in two basic dimensions. On one hand, what are the implications for banks reserve management problem? And on the other hand, to what extent does the market mitigate or exacerbate financial fragility and systemic threats to the banking system? Interbank exposures make banking systems more fragile, with potential systemic risks arising and fuelling contagion through real channels. These two issues draw our attention to the institutional features of the interbank money markets, i.e., the micro-mechanics of interbank markets and, as explained below, its interaction with monetary policy.

The interbank money market is at the very beginning of the monetary policy transmission mechanism. Monetary policy targets are achieved through controlling interest rates in the very short-term end of the yield curve. Central banks continuously monitor short-term interest rates and impose fluctuation limits. When effectively controlling short-term rates, the central banks is able to condition individuals' expectations regarding the longer-term rates and, in turn, affect real variables in the economy, such as inflation.

Modern central banks have developed a set of instruments to intervene in this market, ranging from periodic refinancing operations to standing facilities, while keeping track of their monetary policy goals. Without central bank intervention, fluctuations in the demand for reserves have implications for interest rate volatility, which might put in jeopardy the chosen target. The standing facilities, providing credit and accepting deposits from interbank market participants in response to wide fluctuations in demand for reserves, is an attempt to curb asymmetric information and credit rationing effects upon interest rate volatility and systemic risks. In general the corridor established by standing facilities is able to reduce interest rate volatility not only in the overnight market but also at longer maturities. But a lot depends on how market participants perceive the effectiveness of central bank actions and its ability to prompt intervention as lender of last resort. Interest rate volatility might therefore be reduced while liquidity shocks are sterilized.

These two questions – banks' reserve management on one hand and monetary policy on the other – have implications for both to regulators and the conduct of the monetary policy. Recent developments stressed new dimensions of banking financial fragility, which is being incorporated in the most recent amendment to the Basle accord, and reinforced the systemic risks threat, which might arise from a complex network of bilateral exposures, where failure of an individual bank may trigger a chain reaction and produce losses on otherwise sound banks in the financial system. A bank might be trapped in an unwinding process where credit risks play little role, and liquidity risks are the main reason for default. Either, banks fail to settle payments or postpone redemption of interbank loans just to buy time to be kept in business, and the market might gridlock. From the monetary policy side, the ability of the central bank to control intermediate targets depend on the timing and reaction of banks in interbank money market, mainly how they absorb shocks to interest rates and how these are propagated to the longer end of the term structure of interest rates. It is of particular interest to know to what extent the central bank can affect 6-month interest rates, which serve an indexing role to floating rate notes and other financial instruments.

In short, a liquid interbank money market is critical for monetary policy transmission and systemic threats to financial system stability. A frictionless interbank money market reduces transaction costs and lowers interest rate volatility when liquidity shocks are bank specific and sum up to zero for the whole banking system. It may also reduce the costs faced by central banks who act as lenders of last resort, as a smaller amount of funds has to be lent to those banks needing funds, and liquidity poured into the market through main refinancing operations is more effectively redistributed when banks lend to each other. Despite this importance, little research has examined the development of liquidity in interbank markets. In particular, with a few exceptions, little is known about the relationship between interbank interest rates and monetary policy, and how do banks of different sizes lend to each other.

The plan of this thesis is as follows. In Chapter 2 we describe the institutional setup, reviewing regulatory and legal constraints imposed on interbank money markets and the Portuguese monetary policy for the 10-years period starting on the 1st January 1989. We divide the period in four regimes, which stand for the changing stances observed in the monetary policy and the institutional changes dictated by the exchange rate mechanism of European Monetary Union process. These regimes are then used in the empirical research that follows to ensure robustness of results, and test for structural change. Chapter 2 also describes the unique dataset used to model the Portuguese interbank money market rates. Availability of daily data was possible for the Portuguese banking system and for the decade ending on the 31st December 1998[1]. The data set is important per se as it might shed some light on the institutional features of interbank markets, and add to the scarce research in this area.

Chapter 3 describes the micro-mechanics of the interbank money market. It starts with a "stylized facts" approach to undercover the most important institutional features in interbank markets, which in turn motivate the theoretical model. The empirical evidence that banks trade at a range of maturities in the interbank market justifies the modelling approach of chapter 4. We find that overnight loans settling on day of trading are dominant, which might be justified by the fact that the overnight market is more liquid and, hence less costly than other maturities. However, banks also use up to one-week

[1] We use a unique interbank money market dataset, made available by The Banco de Portugal only after due diligence to obtain permission from the banks with transactions recorded on it. After a long process as to ensure confidentiality of data, we eventually got access to all interbank money market loans recorded between the 1st January 1989 and the 31st December 1998, just before the inception of the Euro. The dataset is quite comprehensive and records all interbank transactions among domestic banks within this period, and all the payment systems data, though for a shorter 3-year period ending on the 31st December 1998.

loans for purposes of reserve and liquidity management, mainly when there are expected liquidity shocks lying ahead. Also we observe a seasonal pattern on borrowing and lending and market participation rates. Usually banks attempt to top required reserves at the very beginning of the reserve holding period, which might be due to risk aversion and to a quasi-contemporary reserve regime that allows banks to partially know their liquidity needs in advance. Seasonality is only observed for maturities up to one week, i.e., above the reserve holding period length. An abnormal amount of trading is found two days before the last day of the reserve-holding period, i.e., the date when banks know exactly the amount of reserves they must hold, and the overnight market is more active around the day required reserves become known to all banks. Prior to that they prefer to borrow and lend for a period length of up to one week.

Consistent with other studies, we do not find support to the martingale hypothesis of interbank market interest rates. However, the overnight interest rates spike on the first day of the reserve maintenance period and plunge on the last day, contrary to the U-shaped pattern found in studies on the Federal funds market in the US. Overnight rates are systematically lower than tom/next and spot/next trades. The effect is robust to reserve holding period effects, although the same cannot be said about the longer rates. Banks do seem to effectively arbitrage interest rates across the different maturities available, as very early in the maintenance period interest rates are pressed up across all maturities. Banks also borrow value date funds, anticipating next-period liquidity shocks.

Credit rationing considerations suggest that there are reasons for large banks to be more active in interbank money markets than small banks, which we find both in number of trades and volume. The conclusion applies whether we consider the overall market or restrict the analysis to overnight trades only. Yet, while the top 5 large banks are on average selling funds daily, the remaining are buyers for most of the time. Also, small banks are responsible for a larger share of overnight lending when approaching the end of the reserve-holding period, while large banks are more active at the beginning of the period. This might reflect small banks' aversion to liquidity shocks, preferring to secure funds at the beginning of the maintenance period in order to avoid unexpected shocks to interest rates. This strategy is likely to cause accumulation of excess reserves, which banks attempt to sell overnight close to the end of the reserve holding period. We find that banks have a preference for trading within the same group. We find that in the short-term banks restrict trading to a reduced number of partners, with the number increasing at longer time horizons (when virtually everyone trades with everyone). No bank seems to be excluded from borrowing or lending in the market. But we find evidence that credit rationing might occur via interest rate discrimination, as small banks pay usually higher interest rates than small banks when borrowing funds. Conversely, as compared to large banks they receive a lower interest rate when lending.

Chapter 4 extends reserve management models, including a richer set-up that allows banks to borrow for longer maturities beyond the single overnight term assumed in mainstream literature. Our model emphasizes the network of bilateral exposures that emerges from banks' optimising behaviour. We propose a dynamic formulation that allows explicitly for time, accommodates for persistency in liquidity shocks, and encompasses both bank specific and industry wide liquidity shocks. We then analyze potential systemic risks arising from the persistency of liquidity shocks, but also due other factors, such as the behaviour of banks when arbitraging interest rates amongst different maturities, and its perception regarding overall market shocks, and the central bank commitment to operational monetary policy targets. Using a rational expectations framework we find that banks follow a profit smoothing behaviour, which in turn imposes a smoothing effect on interest rates. Banks might anticipate future shocks to a certain extent and, consistently, they start hoarding central bank reserves before they are effectively needed, creating persistence in individual interbank money market exposures. The extent to which early hoarding happens, depends on how banks perceive the liquidity and the depth of the interbank money market at its different maturities. Shall the overnight market alone be able to withstand all liquidity shocks, and the hoarding behaviour will disappear. The interbank money market equilibrium supports a rational expectations explanation for the term structure of interbank money market rates, and links interest rates to current and expected liquidity shocks and banks expectations regarding the ability of the market to clear out the shocks.

Chapter 5 looks empirically at the link between interbank money markets and the monetary policy. We provide a useful background to analyse the effectiveness of central bank's monetary policy operations, given its objective is to minimize deviation of interest rates from target, while at the same time permitting the interbank money market to regularly function as a private arrangement to insure participating institutions against specific liquidity shocks. We model the term structure of interbank money market rates using a multivariate error correction model. We find that interbank money markets react to shocks originating either in demand for liquidity or monetary policy, and that these reactions change across monetary policy regimes. The rational expectations theory of interest rates does not hold in periods when there were institutional arrangements that prevented banks from yield curve arbitrage, and when there was uncertainty regarding the commitment of the central bank to pre-announced monetary policy targets. When the central bank changed the monetary policy operational framework as to include standing facilities interest rate volatility decreased and the lag responses to shocks shortened. In sum, when the Central bank shifted to credible commitment to the monetary policy target interest rates did seem to follow the rational expectation hypothesis. Prior to that, investors were reluctant to arbitrage the term structure of interest rates.

Most research uses a single cointegration vector to show that interest rates are cointegrated with the spread over the target. However, by neglecting the effect of other maturities' spreads over the interest rate adjustment, the approach is missing a richer framework. The argument that a spread between any two long rates can be decomposed into a combination of two spreads with the short rate is misleading, because each one of these shortest spreads has a different adjustment coefficient, making the decomposition not feasible. Therefore, we might gain additional insight into interest rates dynamics by looking at broader decomposition of the yield curve. In fact, we find that interest rates respond to several long run factors, thus validating our model. Though each interest rate is more responsive to its own cointegration vectors, it is also affected by neighbouring maturities. Our results emphasise two blocks of interest rates moving together: the short end on one hand, with maturities up to 2 weeks; and the longer end, on the other, comprising the remaining maturities.

Chapter 6 concludes discussing results and policy implications. We also refer to alternative formulations and methodologies and propose some avenues for future research. The extensions to the theoretical model incorporate some institutional features resulting from the empirical investigation. Issues such as credit rationing, banks preference for a given loan structure and reserve maintenance periods can be accommodated into our formulation. On the empirical side, the interbank loans data set and its payments system companion is still to be explored on several dimensions, such as intraday trade and interest rate dynamics and the relationship between the payments shocks and banks' use of the interbank money market. Also, using panel data we might undercover other institutional features such as pricing and trading persistency on an individual basis.

Chapter 2

Institutional Background: Interbank Money Markets and Monetary Policy in Portugal

1. Introduction

The use of the interbank market for liquidity management purposes is an important feature of the banking system. However, its use also has implications upon the monetary policy transmission mechanism, and vice-versa. Economic literature says institutions place a constraint on monetary policy effects and theoretical modelling should take into consideration restrictions as such, because its impact upon the final results is far from irrelevant. Hence, completely understanding how do models work under different institutional backgrounds and what are the limits of their applicability is essential.

We use this chapter to discuss the Portuguese financial system institutional and historical background. A brief description of the Portuguese interbank money markets and general historical issues regarding the monetary and exchange rate policies adopted over the last ten years in Portugal is presented in order to picture out the constraints that should enter into our models. Section 2 describes the institutional features of the Portuguese interbank money market and major changes occurred during the second and third phase of European Monetary Union. Section 3 discusses monetary and exchange rate policies. We identify 4 regimes emphasising changes in monetary policy final and intermediate targets. There is however a common final goal of exchange rate and price stability, aiming at the introduction of the European single currency in 1999. Section 5 concludes presenting a summary of the data used in this research, while describing the procedures used for its collection. We expect to show the reader the existing bonds between interbank money markets, liquidity provision, and monetary and exchange rate policies.

2. A Brief History of Portuguese Interbank Money Markets

Aiming at developing an efficient system for banks' reserve management and in order to implement the monetary policy, The Banco de Portugal formally established the interbank money market[1], in 1977, and the interventions market, in 1978. Though subject to renovation and regulatory

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[1] Also known as MMI, the initials stand for *mercado monetário interbancário*.

reforms over time, mainly those required when ECB[2] was set up, their basic functions remain unchanged. The former serves as a private arrangement for liquidity insurance amongst banks, while the latter is reserved to The Banco de Portugal to implement open market operations.

Table 2.1 presents the most relevant facts related to the Portuguese interbank money markets since inception. There are no major institutional changes. Yet, there are important monetary policy facts that impinge on the effectiveness of these markets in allocating liquidity amongst banks. Financial system modernisation along with gradual implementation of open market operations – switching the monetary policy focus from credit growth restrictions to indirect control of liquidity and money growth via interest rates – are the underlying trends over the 10 year period under investigation.

Table 2.1 – Interbank Money Market Milestones

Date	
01-08-77	The Interbank Money Market is created mainly devoted to banks' reserve management.
01-02-78	The Interbank Securities Market is created. This is essentially a primary market, used by The Banco de Portugal to trade central bank funds with money institutions.
00-00-80	Banks are allowed to use the Interbank Securities Market to record collateralized loans and repurchase agreements. In fact, a secondary market is created.
12-07-1993	Changes in the functioning of the Interbank Money Market as banks are allowed to trade deferred and same day value date loans.
12-07-1994	The Banco de Portugal announces marginal lending and deposit facility rates regularly.

Source: The Banco de Portugal.

[2] Formally, the ECB – European Central Bank took over the monetary policy in January 1999, when the Euro was introduced. Money markets had to be adapted, while new regulations to implement monetary policy were being set up.

2.1. The Interbank Money Market

At first, banks were allowed to trade among themselves in the interbank money market uncollateralized funds only. In 1980, an interbank securities market was created as to accommodate transaction of collateralized central bank funds. However, the rapid development soon turned the interbank money market the most important system for trading short-term funds, as banks seem to prefer interbank uncollateralized loans for reserve management purposes. Possibly, banks are not willing to pay the extra cost of collateral arrangements, because short living loans do not entailing much credit risk. Also, the absence of operational regulations and procedures to settle securities deterred a faster development. Alternative platforms for trading securities developed after stock market reorganization in the 90's, against which the interbank securities market was unable to compete.

Table 2.2 compares transactions among banks in each of these two markets. According to The Banco de Portugal officials, the amount of transactions dealt outside the system is negligible[3]. Interbank market turnover increased dramatically: 80% of total banks' assets in 1989 to almost 350% in 1998.

[3] This is not however the case after introduction of the Euro, as freed from exchange rate risk banks started buying and selling funds with banks situated in active European financial centres.

Overall, end of the year interbank exposures amounted to approximately 4% of banks' total assets in 1998, while this ratio was only 2% in 1989[4].

Table 2.2 – Interbank Money Market: Aggregate Turnover

	1989	1992	1995	1998
Uncollateralized transactions	8 131	23 900	34 800	79 800
Collateralized transactions	381	3 906	136	83
Uncollateralized transactions as percentage of banks' total assets	80%	206%	240%	349%

Values are as billion PTE.

Source: Interbank Money Market databases.

Overnight transactions are dominant. Though and due to earlier restrictions imposed upon banks' activity, longer maturities achieved and abnormal share of market turnover. Table 2.3 presents market turnover breakdown by maturity.

During the early years, a considerable amount of loans were made for purposes other than over-night reserve management. One must recall the extensive privatization programme of the banking system and the establishment of new privately owned banks to explain this odd feature of the money market. The global excess liquidity made it possible to banks with excess reserves to lend money on a weekly basis – approximately the time length of the reserve holding period – to newly established banks, which in turn used interbank loans

[4] This figure is quite stable and end of the year effects are negligible. Only interbank money market exposures, i.e., with up to one year maturities, are considered. Credit to other financial intermediaries and long-term loans are excluded. The Portuguese Bankers Association reports aggregate credit exposures having financial intermediates as counterparties to be up to 12% in 1989 and 25% in 1998. Similarly, interbank exposures double over the same period.

to expand activities beyond the limit imposed by a small deposit base. Gradually, financial market liberalization and removed this bias, and the market share of overnight transactions increased to stabilize around 80% of total market turnover[5]. Up to one-week loans are still dominant, yet the reserve management purpose is of the interbank market is now reinforced.

Table 2.3 – Interbank Money Market: Maturity breakdown

	1989		1992	1995	1998	
Over-night	3 333	41%	11 700	20 000	40 700	51%
Tom-Next	–		–	3 631	18 800	24%
Spot-Next	–		–	1 013	1 677	2%
1-week	3 278	41%	4 578	5 303	9 160	12%
2-weeks	400	5%	808	991	2 222	3%
1-Month	542	7%	767	1 679	3 007	4%
3-Months	307	4%	322	1 292	2 603	3%
6-Months	157	2%	96	481	771	1%
12 Months	35	0%	10	239	698	1%

Values are as of billion PTE.

Source: Interbank Money Market databases.

On 12 July 1993 The Banco de Portugal introduced major changes in the interbank money market, allowing banks to trade for delayed settlement, i.e., trade date and value date are different[6] [7]. This change was responsible for a

[5] This figure includes both same day and deferred settlement trades, i.e., Over-night, Tom-Next and Spot-Next loans.

[6] Until then banks using the SISTEM could trade for overnight settlement only. We hypothesise that this operational shift may have caused a breakdown in the series. Eventually, demand for liquidity could be planned ahead and banks could choose whether they wanted funds to clear immediately or at a later date.

halt in the exponential upward trend observed on overnight trading volumes. Banks switched to tom-next and spot-next transactions, which are more adequate to cover the liquidity exposure initiated in stock markets and spot foreign exchange transactions, which are usually settled within two working days.

2.2. The Intervention Market

The institutional features of the intervention market are important for monetary policy implementation, which we discuss next. The Interbank Securities Market – MIT – was firstly established in February 1978 to be used by The Banco de Portugal to conduct the monetary policy through open market operations[8]. Eventually, by 1980 and before the formal development of a repo market banks were granted permission to use the MIT for purposes of recording repo transactions and other collateralized transactions[9].

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[7] Until July 1992, overnight trades accounted for an average 63% of total trading. This percentage decreased to 53% afterwards, when value date transactions were introduced. Furthermore, overnight loans with deferred value date respond for 21% of total interbank money market turnover for all maturities. This evidence partially supports of our argument that banks manage liquidity days ahead before the liquidity shock is expected.

[8] The market name has been changed to open market – *mercado de operações de intervenção* – in 1994, more acordingly to its actual functions.

[9] One must bear in mind that the formal establishment of these markets had in mind, first the establishment of rules allowing banks to trade short term funds, and secondly the development of favourable conditions for trades settled using the mechanism devised by The Banco de

The Banco de Portugal used seldom the intervention market to sell funds due to structurally high excess liquidity in the banking system. The monetary policy stance offers a good description of the size and direction of intervention transactions over the entire period. Rarely, the central bank was called to sell liquidity, except during some ERM turmoil episodes. Most banks, would seek to sell The Banco de Portugal funds at the offered interest rate[10]. And the central bank responded offering to sell central bank notes – TRM and TIM[11] – maturing within 1 to 52 weeks. Firstly auctioned at a fixed interest rate, they were replaced in 1990 by variable interest rate tender auctions. TRMs had the shortest maturities – between 1 and 14 days – and were used as fine tuning operations, while TIMs – maturing in 4, 9, 13, 26 and 52 weeks – were designed to absorb liquidity for longer periods. Open market loans without collateral have been rarely used during this period. The central Bank used preferred and reverse repos to achieve immediate targets.

Portugal. Banks were, nevertheless, allowed to trade using alternative trading and settlement platafforms though at an additional cost.

10 The Banco de Portugal was the leader organizer of Treasury bill auctions. Also, regularly it issue short term notes with maturities from 2 days to 7 weeks to absorb excess liquidity.

11 TRM stands for money regulation notes – "Títulos de Regularização Monetária". TIM are the initials for money intervention notes – "Títulos de Intervenção Monetária".

Progressively, as excess liquidity decreased[12], the market became more active on both directions and in July 1994 the Banco de Portugal introduced changes in the operation of the intervention market, announcing daily marginal lending and deposit facilities on a regular basis. This monetary operational procedure imposed a cap and a floor on overnight interest rates. As the day ends, banks are free to deposit idle excess reserves at the bid rate, or to borrow overnight to meet liquidity shortages paying the offer rate. However, borrowing through the standing facility has to be contracted until 2:00 noon, before the interbank market closes. In case a bank waits until the end of the day, it can still borrow at a penalty rate, but using a discount window facility instead.

3. The Portuguese Monetary Policy in the 1990s

From 1975 until late 1980's a great proportion of government budget deficits were financed through expanding the monetary base. This produced an excess liquidity in the banking system, which has been removed using a big sterilization operation, aiming firstly at implementing a new monetary policy, which became to be known as indirect monetary control, and lately at full participation of the Portuguese Escudo in the European Monetary Union.

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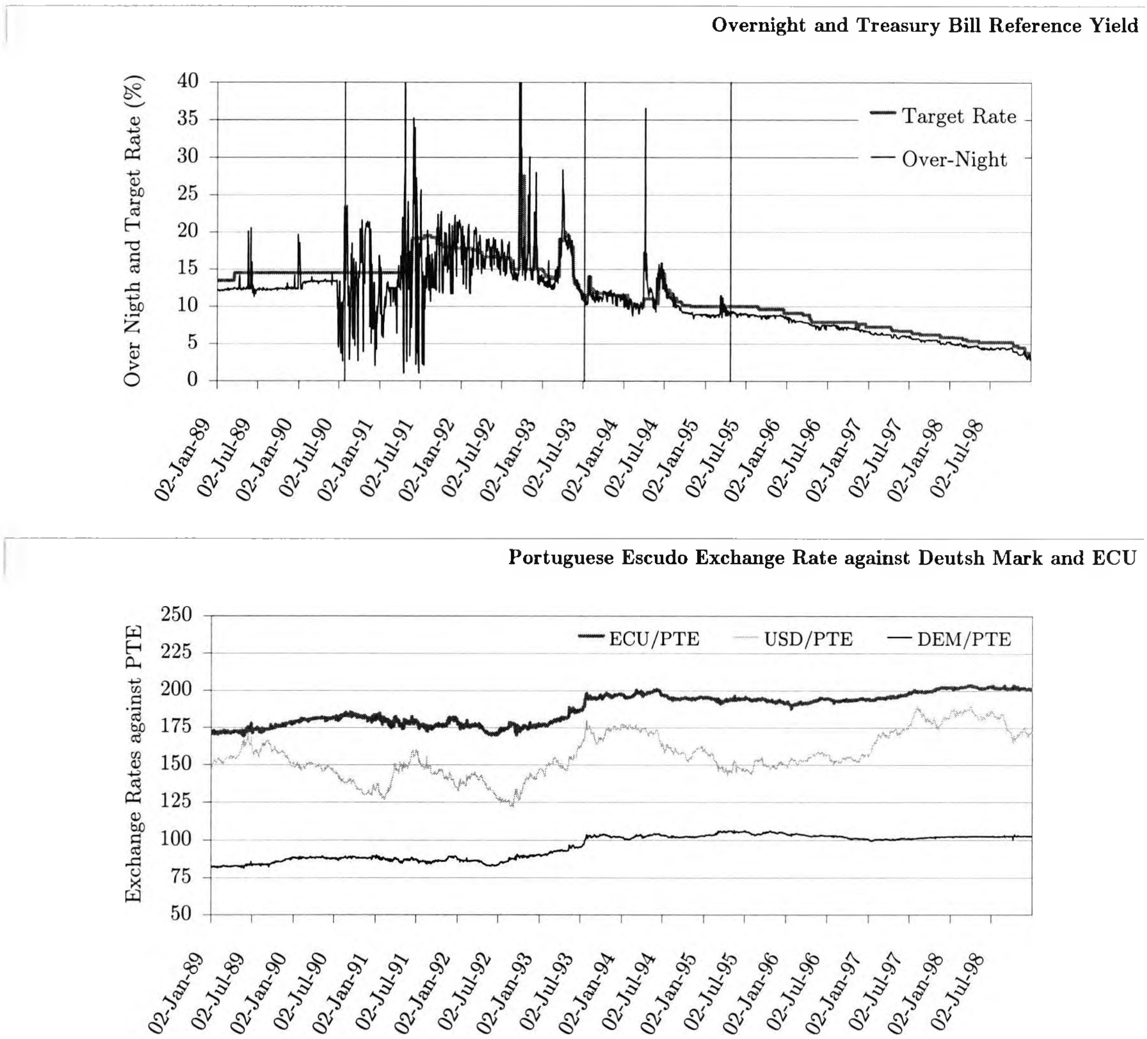
[12] It has been of surmount importance the big sterilization operation initiated by The Banco de Portugal on the early 1990s, as we discuss in the next section.

Consequently, and until 1994 there were successive operational changes in the monetary policy, interbank, and intervention markets subordinated to this objective of excess liquidity withdrawal. A significant effort begun in the mid 1980's to reduce monetization of budged deficits through securitization of government debt. Treasury bills – i.e., short-term debt instruments – started to be issued in 1986, while Treasury bonds primary market, with longer maturities, achieved momentum in 1993. The monetary policy in the 1990s has been subordinated to the main objective of joining the single currency in the European Union. Hence, regarding the exchange rate policy, The Banco de Portugal first imposed a crawling peg devaluation of the Escudo against a basket of currencies, which included the USD. Later, it started to shadow the exchange rate mechanism of the ERM aiming at exchange rate stability and inflation convergence as to ultimately introduce the Euro as a substitute to the Portuguese Escudo.

During the whole period, interbank money market rates exhibited a downward trend mainly driven by the convergence criteria. A tight monetary policy subordinated to the target of foreign exchange rate stability eventually succeeded in decreasing inflation and interest rates to European Union average. The overnight rates, trading volume and the Treasury-Bill reference yield (TBRY), commonly taken as intermediate targets and reflecting the stance of monetary policy and early indicators of target achievement are depicted in Figure 2.1. The tight monetary and exchange rate policies were subordinated to price stability in the long run. The target was set as the average inflation of international trading counterparties. Within the context of European Union, that meant the European Countries and, in particular, the German inflation.

Figure 2.1 –Interest Rates and Foreign Exchange



Source: Interbank Money Market databases and The Banco de Portugal.

Exchange rate stability was binding, and The Banco de Portugal has always been active in both the domestic interbank and foreign markets as to achieve stabilization of the Escudo during this period, which was taken as a pre-requisite to enter the Monetary Union as wrote down in the Maastricht Treaty. A credible commitment to exchange rate stability under free capital mobility triggered the desired effects and, eventually, interest rates and inflation converged to European average.

In the meantime The Banco de Portugal was able to pursue an autonomous monetary policy in the very short term. Forssbaeck et Oxelheim (2003) use a panel of countries, where Portugal is included, to analyse the degree of monetary policy autonomy over the 80s and 90s. They do not find much difference in the degree of monetary policy autonomy between countries that pursue flexible exchange rates and those committed to keep exchange rates fixed. Setting an independent monetary target that is independent though correlated with the targets of those countries to which we are financially integrated is as binding as locking the exchange rate. Market imperfections and other institutional constraints allow central banks a certain degree of autonomy, as only under strong conditions do fixing exchange rates imply full loss of monetary policy autonomy, what is not clearly the case in most real world situations.

Though, ERM made The Banco de Portugal committed to exchange rate stability through buying or selling Escudos against other ERM currencies, the effects upon liquidity can be sterilized through changing central bank marginal rates and open market operations. But they can also be left without any compensation, and often the central bank decided not to counterbalance foreign exchange intervention forcing the interest rate differential to escalate against other currencies. There are however certain episodes when the central bank decided autonomously to keep interest rates and liquidity levels constant.

We choose to breakdown the period in different monetary policy regimes. This is particularly useful considering we want to analyse the effectiveness of monetary policy over time modelling interest rates over a 10-year period[13]. The classification is three-dimensional, and it is based on the degree of capital mobility; the allowed exchange rate flexibility; and the way monetary policy is implemented by The Banco de Portugal. The classification captures the changing speed in the monetary policy transmission mechanism and in the operational targets also. It is highly plausible that The Banco de Portugal shifted the emphasis of the monetary policy over time and this might have affected the speed of adjustment of interest rate variables.

The basic argument is that when setting monetary policy targets, central banks take into consideration price developments and inflation in the medium long term, though, in the short term, interest rates and exchange rates fluctuate with market sentiment. Therefore, the main issue about monetary policy is credibility and commitment, and that was certainly achieved during this

[13] This is pursued in Chapter 5.

period[14]. Portugal benefited from participating in the European Economic Monetary Union. It took advantage of trade interdependency through currency stability, and imported a low inflation regime. This long-term objective allowed minor deviations from parity at certain moments in time, which anchored on time-specific institutional features.

3.1. Monetary Policy Regimes

Structural breaks are identified based on anecdotal evidence and empirical research on the Portuguese monetary and exchange rate policy under the ERM, such as in Adão (2003) and Braga de Macedo et al. (2002). Applying this methodology we end with 4 monetary policy regimes. A thorough historical reconstruction procedure is used to identify the most relevant events presented in Table 2.4. Structural breaks are marked with "*".

Table 2.4 – Monetary Policy and Exchange Rate signing posts

Date	Open Market and Monetary Policy	Foreign Exchange Market
09-05-1989	New reserve requirements regime: deposit ratio is increased up to 17%.	
30-06-1989	Investment caps on Government Bonds are removed.	

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[14] As said by the Governor of The Banco de Portugal Vitor Constâncio at the governing council of ECB in 2003, in BIS Review (2003,47):

> "Markets and economic agents in general have learned to understand the underlying framework of our monetary policy with the important result that we have become a more predictable institution. This implies that we can better manage expectations and implement monetary policy while maintaining smooth function of money markets."

Date	Open Market and Monetary Policy	Foreign Exchange Market
20-09-1989		The Escudo enters ECU "basket".
01-03-1990	Credit rationing is eliminated, and banks are recommended to gradually phase out administrative credit limits.	
28-03-1990	The Banco de Portugal starts auctioning TIM, and interest rates are allowed to fluctuate.	
04-06-1990	A quasi-contemporaneous reserve regime is introduced to replace the one week lagged regime. Interest is paid on banks' minimum reserves deposited at The Banco de Portugal. *Interest rates vary according to composition of banks' liability portfolio. Reserves held against short-term deposits are not paid any interest. In 1990, average interest rate paid was 7.5%.*	
25-06-1990 *	The Banco de Portugal starts auctioning TRM in auctions, and interest rate are allowed to fluctuate.	Limits to curb foreign capital imports. Swaps are ruled out, and borrowing abroad requires a compulsory deposit of 40% at The Banco de Portugal.
01-10-1990		The Escudo joins the ERM of EMS 'informally'.
07-12-1990	Structural sterilization of excess liquidity in the banking system – phase I. *The Banco de Portugal and the Government agree on a structural operation to sterilize excess liquidity in the financial system. The Government issues medium to long-term bonds to banks internally and uses the proceeds to redeem foreign debt.*	
01-02-1991		Restriction on imports of capital are reinforced, as banks are required to place a deposit at The Banco de Portugal of 40% of all foreign deposits in Escudos as collateral.
01-03-1991	Structural sterilization of excess liquidity in the banking system – phase II. *The operation is to last for the entire month of March, and to complete the structural intervention in the financial market.*	
01-04-1991	The structural sterilization is completed.	
01-07-1991		Foreign investors are forbidden from buying variable rate debt instruments in Portugal.
22-07-1991	TRM's maturity is extended to 14 days. REPOS with the Banco de Portugal using government securities have their maturity extended to a maximum of 26 weeks.	
05-08-1991	The Banco de Portugal widens TIM maturity to up to 52 weeks.	
27-08-1991	Main refinancing and deposit interest rates are disclosed regularly.	
01-09-1991		The Banco de Portugal suspends daily fixing of quotes.

Date		Open Market and Monetary Policy	Foreign Exchange Market
06-04-1992			The Escudo enters the ERM of EMS, at a central rate of 178.735.
01-09-1992			Imports of foreign capital are liberalized gradually. *Residents can borrow foreign funds freely.*
13-09-1992			Attack to the ERM of EMS. The Lira devalues by 7%.
23-11-1992			The Portuguese Escudo and The Peseta are realigned in the ERM of EMS.
16-12-1992			Complete liberalization of international capital flows.
13-05-1993			Realignment of the Escudo within the ERM of the EMS: devaluation of 6.5% against the central parity.
12-07-1993	*	Changes in the functioning of the Interbank Money Market split the market in deferred and same day value date transactions.	
13-08-1993			Fluctuation bands of the ERM are widened to 15%.
01-01-1994			Second phase of EMU starts, and the European Monetary Institute is established.
12-07-1994		The Banco de Portugal announces marginal lending and deposit facility rates regularly.	
04-11-1994		Reserve requirements ratio is dropped to 2%, and interest ceases to be paid on minimum reserves.	
06-03-1995	*		The Escudo is realigned in the ERM together with the Spanish Peseta.
01-02-1996		The SPGT (real time gross settlement system) starts operations, but for transactions with The Banco de Portugal only.	
19-02-1996		Refinancing operations rules are changed: Either the Banco de Portugal announces the amount and the interest rate, or chooses an auctioning mechanism indicating the maximum amount of funds available.	
03-05-1996		Main refinancing operations rules for the next reserve holding period are changed. Funds are auctioned on the last day of the reserve-holding period with value date the following working day. Quotas on the marginal lending facility are eliminated, and a maximum amount of daily lending is established instead. The Banco de Portugal allows regular overnight funding on the last day of the reserve holding period. That means that main refinancing operations occur in two days. On the first day and on the last day of the reserve holding period.	

Date	Open Market and Monetary Policy	Foreign Exchange Market
01-07-1996	The Banco de Portugal accepts non-government securities as collateral in refinancing operations. Securities must be traded in the Portuguese Exchange market and subject to credit conditions (rating and liquidity) established by The Banco de Portugal.	
15-07-1996	Banco de Portugal facilitates intraday liquidity to banks participating in the SPGT	
30-09-1996	The SPGT (real time gross settlement system) is fully implemented.	
02-05-1998		The Escudo is confirmed as integrating the Euro Area from January 1999 onwards. The Euro bilateral conversion rates are established on this date.
01-06-1998	The European System of Central Banks starts operations.	
02-11-1998	A transitory reserve requirements regime is implemented. There are two one-month reserve-counting periods.	
22-12-1998	First main refinancing operation of the Eurosystem. The base rate was set at 3%.	
31-12-1998		Exchange rates are fixed irrevocably in the Euro area.

a. Regime 1: Liberalization of interbank rates | from 01/01/89 to 25/06/90.

The period starts with an increase in the reserve requirement ratio and ends when The Banco de Portugal liberalizes open market interest rates. A few episodes explain the spikes in volatility during this period. First, major changes are introduced to the reserve requirement regime on 09/05/89, as the reserve ratio is raised to 17%, and on 04/06/90, when The Banco de Portugal starts paying 7.5% interest on banks' reserve deposits. Second, starting on 30/06/89, bank loans, which used to be rationed by The Banco de Portugal, are freed on 01/03/90 from any administrative controls completely. The Portuguese Escudo shadows a basket o European currencies committing to exchange rate stability, though a slight devaluation was allowed under a crawling peg rule, as to allow a smooth adjustment of the long lasting structural imbalance both in inflation and balance of payments due to lack of competitiveness of the Portuguese economy.

b. Regime 2: Banking liberalization | 25/06/90 to 12/07/93.

This period corresponds to highly volatile interbank money market rates, as The Banco de Portugal drains excess liquidity from the banking system through a series of structural operations between 07/12/90 and 01/04/91, and attempts to implement a monetary policy taking the money aggregate liquidity as the intermediate target. A tight monetary policy starting in 1990 and aiming at inflation reduction is then implemented. Mateus (1997:3) says that during the first half of the year The Banco de Portugal raised the minimum reserve requirements to 17%, well above the 2% common in banking systems across Europe. Later, and given the huge burden imposed upon banks due to high opportunity costs, it is forced to issue long-term notes in order to offset the excess liquidity for a 10-year period[15].

Stabilization of the Escudo exchange rate[16] over this period pushes domestic money market rates downwards, while at the same time the Banco de

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[15] The Banco de Portugal issued notes of varying maturities in an attempt to gradually restore liquidity levels in the banking system, accompanying money requirements from economic growth.

[16] The Banco de Portugal announced the escudo would shadow the ERM from 01/10/90.

Portugal is committed to absorb funds at a given interest rate[17]. In August The Banco de Portugal ends the regular exchange rate fixing session[18]. The Escudo enters the ERM close to the upper limit on 06/04/92. During the whole period afterwards, interest rates are shaped by episodes of foreign exchange market turbulence, driving up interest rates and volatility when the Portuguese Escudo approached the ERM fluctuation bands together with the Spanish Peseta and Italian Lira. During the summer the ERM is attacked undermining the credibility of the central bank's monetary policy. Consecutive attacks result in the devaluation of the Italian Lira on 13/09/92 and the Portuguese Escudo and Spanish Peseta on 13/04/93. Eventually, the British Pound and the Italian Lira abandon the mechanism and in November the Banco de Portugal triggers a tremendous interest rate increase while devaluating the Escudo as to prevent the exchange rate from sliding outside the fluctuation bands. The ERM turmoil continues during the first half of 1993 until a new devaluation of the Escudo, together with the Spanish Peseta, on the 13th of May and, finally, to widening fluctuation bands to 15% above or below central parity on the 13th August 1993.

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[17] Liquidity sterilization was announced on 07/12/90, and despite the limits imposed on foreign funding on 25/06/90 and 01/12/90, banks were able to circumvent restrictions and pumped liquidity through swap operations having the Escudo Euromarket as counterpart. The Banco de Portugal completes sterilization by 01/04/91. Restrictions on foreign funding are reinforced on 01/07/91, when foreign investors are forbidden of buying variable rate bonds.

[18] Until 01/09/91 The Banco de Portugal used to conduct a daily session every morning with the banks to fix the official exchange rate of the escudo against the US dollar.

c. <u>Exchange rate stability | from 02/08/93 to 09/05/95.</u>

This is the final stage before a perfectly credible commitment to the single currency. Mateus (1997: 4) says it took The Banco de Portugal until the end of 1992 to assemble a completely new monetary regime. Following the complete liberalization of capital flows in December 1992 the Portuguese Escudo was devalued in April 2003. In August that year, The Banco de Portugal switched the intermediate target to exchange rate stability, while arguing that under free capital mobility it was not feasible to implement a monetary policy subordinated to liquidity growth, as it has been until then[19]. Interest rates are allowed to fluctuate within the limits imposed by the Exchange Rate Mechanism of European Monetary Union.

The Banco de Portugal overvalued the Escudo during the 1992-1995 period due to imperfect credibility of the exchange rate policy[20] [21]. Demand of foreign

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[19] Mateus (1997: 9).

[20] Mateus (1997: 23).

[21] The central bank behaviour is according to Krugman (1991), who supports that when the monetary policy is credible there is a smooth pasting effect when the currency deviates from its fundamentals. Intra-marginal interventions in the foreign exchange market are quite effective and do not require the central bank to dispend much reserves on keeping exchange rate policy. In practical terms, the exchange rate process exhibits a mean reverting property if there are no shocks to the economy's fundamentals. However, when credibility is incomplete the smooth pasting effect is not present and the central bank must spend huge amount of reserves when the currency is close to the lower limit bound to devaluation.

currency was steeper when the escudo approached the inferior devaluation band, requiring massive interventions from the central bank. This effect is less pronounced when the currency is in the upper limit bound to valuation, turning intra-marginal interventions more effective than otherwise. Hence, the Banco de Portugal made an effort to keep the currency next to the ERM upper band. This allowed the central bank to adopt an almost independent monetary policy in the short run.

In the long run domestic interest rates target German interest rates, and at the same time open market lending rates – the repo rates – become the most important instrument to signal monetary policy targets[22]. New monetary policy instruments are introduced as the central bank essays regular disclosure of marginal deposit and borrowing facilities rates, placing a lower and upper limit for the repo rate. But, exchange rate stability is continuously under market scrutiny and on some occasions The Banco de Portugal is forced to let the exchange rate fluctuate freely. Supporting the escudo – the monetary policy intermediate target – produced wide interbank interest rate fluctuation in an attempt to mitigate arbitrage opportunities and neutralize speculative investors.

There are significant changes in the interbank money market architecture, and new procedures are implemented at the onset of this period. SISTEM, the

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22 Mateus (1997:13).

automatic settlement system for interbank transactions, is upgraded as to accommodate value date loans at the very beginning of the period, and a new active segment emerges encompassing tom/next and spot/next transactions. Interest paid against deposit reserves is swept out on 04/11/94. The period ends with the last realignment of the Escudo before the final stage to EMU.

d. Regime 4: Convergence towards EMU | from 10/05/95 to 31/12/98.

The transition period is concluded with a credible commitment to join the EMU. During the first half of 1994 the Escudo was again subject to speculative attacks when foreign investors reduced their Portuguese Treasury Bonds exposures massively. However, The Banco de Portugal succeeded in keeping the Escudo stable, and in March 1995 together with the Spanish Peseta a new realignment was agreed. From 1992 to 1996 the volatility of Escudo dropped dramatically[23]. The intermediate target of interest rate stability converging towards EU average is pursued with renewed strength without jeopardising long-term foreign exchange rate stability[24]. No devaluations of the Escudo occurred during this last period and The Banco de Portugal practically does not

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[23] Escudo participation in the ERM can be subdivided in two periods. The first, ending in August 1993 corresponds to the highest turmoil ever seen in the ERM; and the second phase post-1993 with increasing credibility of monetary policy and commitment to EMU (Mateus, 1997: 25).

[24] The Escudo and the Spanish Peseta are realigned for the last time on 06/05/95, enhancing the credibility of the monetary policy regarding interest rate decrease and stability.

buy or sell funds in the foreign exchange market as to support the Escudo. Mateus (1997) estimates the maximum credibility of exchange rate stability is achieved in 1996.

4. Data set description

The dataset of daily interbank transactions for the 10-year period ending on the 31st December 1998, at the inception of Euro in the European Union and the formal establishment of the European Central Bank is of independent interest. Its construction involved the processing of approximately 296 000 transactions.

The Banco de Portugal allowed access to these datasets only after permission has been obtained from inter-bank market participants[25]. Further, individual bank's transactions are coded as so to remain anonymous[26]. Additional variables regarding banks' size and investment portfolio are also available for each bank, allowing the construction of proxies for banks' risk and market size, though we are committed to maintain individual trades confidential.

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[25] Each of the 20 banks involved in this study was requested to write an authorization letter to Banco de Portugal allowing the disclosure of proprietary information for the purposes of this research.

[26] Though authorization was obtained from the 20 banks, the dataset contains all the banks in the Portuguese banking system. Nevertheless, banks for which authorization was not requested are grouped under the same code, and no individual treatment is allowed for these.

Three additional data sets containing the payment system flows and the daily cash reserves position held by each individual bank at The Banco de Portugal were also made available, though for a shorter period, covering the last three years of our dataset only. The first payment system database contains the flows of the daily netting system, while the second comprises all flows recorded in the real time gross settlement system.

Table 2.5 – Characterization of banks

	1989	1992	1995	1998
Caixa Geral de Depósitos	2 448	4 857	6 898	9 827
Banco Comercial Português	511	1 527	5 405	6 423
Banco Pinto & Sotto Mayor	774	1 266	4 747	5 092
Banco Espírito Santo e Comercial de Lisboa	904	1 527	2 926	5 056
Banco Português do Atlântico	975	2 248	3 003	3 935
Banco Totta & Açores	617	2 319	3 175	3 481
Banco Português de Investimento	120	1 081	1 389	3 123
Banco Fonsecas & Burnay	436	794	982	2 946
Banco de Fomento Exterior[a]	356	1 382	1 683	
Banco Borges & Irmão[a]	507	729	947	
Banco Nacional Ultramarino	555	1 019	1 180	1 603
Crédito Predial Português	384	621	880	1 184
Banco Mello		92	222	692
Banco Internacional do Funchal	116	259	341	669
ABM AMRO	0	84	283	601
Banco Comércio e Indústria	107	345	336	576
Banco CISF			302	334
Banco Santander Negócios			129	216
Banco Comercial dos Açores	51	79	122	148
Banco Comercial de Macau		228	328	24
Total banking industry	**10 135**	**22 837**	**40 406**	**56 383**

Values are as of billion PTE

[a]– These two banks merged with Banco Fonsecas & Burnay in 1995. Its name has been changed to Banco BPI. These are the only three banks that effectively merged in this period. Several other banks are integrated in financial conglomerates, though they remain independent companies at least from a formal perspective.

Source: APB – Associação Portuguesa de Bancos (Portuguese Bankers Association), and banks' reports.

Summary statistics for banks involved in this study are as presented in Table 2.5. The dataset is highly representative of the Portuguese banking industry and allows for a thorough investigation of the micro-mechanics of interbank money markets. Selected banks represent more than 80% of industry's assets and comprise more than 80% of interbank market trades.

The interbank market data set comprises individual observations for all trades in the Portuguese interbank money market and the intervention market[27], though transactions for non-identified institutions are coded under the common notation "OUT". The observations are collected from the SISTEM[28], a trading platform developed by Banco de Portugal to trade and settle interbank money market transactions amongst monetary institutions operating in Portugal[29].

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[27] The interbank money market accommodates bilateral loans both with and without collateral and serves banks to allocate short-term liquidity. The intervention market is used by Banco de Portugal to conduct monetary policy through open market operations. Also, the Banco the Portugal used to underwrite primary market T-bill and T-bond. Marginal lending and borrowing is requested individually by banks and it is not comprised is this data set.

[28] SISTEM stands for telephone based trading system, "SIStema TElefónico de Mercado".

[29] The SISTEM comprises a computer based settlement platform and a telecommunications network linking Banco de Portugal and financial institutions authorized to operate in the interbank money market, mostly banks (Instrução n° 37/96).

Interbank money market transactions are contracted bilaterally and both counterparts enter the trade details into the SISTEM. Following, the SISTEM generates automatically settlement instructions for two different moments in time: *firstly*, when funds are lent (contract opening); and *secondly* when the loan expires (contract closing) and the borrowing bank has to return funds to the lending bank. Once keyed into the SISTEM, the opening flow is settled immediately except if the lending institution is short of central bank cleared funds. At maturity, the closing flow is settled overnight and funds are made available to the lending institution early in the morning before the interbank money market opens.

One should bear in mind that banks were free to have trades settled through other means but the SISTEM. The SISTEM worked as a kind of "organised exchange" offering operational benefits to banks. Hence, the SISTEM accounted for the bulk of Portuguese interbank money market transactions over the 1989-1998 period. There is a very small fraction of interbank trades not captured in our database[30]. It covers the period 1 January 1989–31 December 1998, and consists of 295 918 observations.

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[30] The SISTEM has the comparative advantage of economising in the settlement procedures of interbank market trades. The low operational costs lead banks to use this system simple one-step procedure instead of, *first*, trading bilaterally and, *secondly*, using the payments system to settle transactions at the onset (delivery of funds) and at the outset (loan redemption).

Table 2.6 – Data set description. 1 January 1989 – 31 December 1998

	Number of records	%	Trading value[a]	%
Interbank Money Market, MMI	**260 062**	**88%**	**394 533**	**72%**
Interbank loans with no collateral[b]	*233 519*	*79%*	*364 528*	*67%*
Outright loans[c]	190 955	65%	256 312	47%
Value-date loans[d]	42 564	14%	108 216	20%
Interbank collateralised loans[e]	*26 543*	*9%*	*30 005*	*5%*
Treasury bills	26 161	9%	29 033	5%
Central bank term deposits	37	0%	57	0%
Central bank intervention bills	345	0%	915	0%
Interventions Market, MIT	**35 856**	**12%**	**151 023**	**28%**
Open market, primary market (new issues)	*28 407*	*10%*	*95 909*	*18%*
Treasury bills	13 887	5%	20 994	4%
Central bank term deposits	1 056	0%	1 766	0%
Central bank intervention bills	13 464	5%	73 149	14%
Open market, secondary market	*7 449*	*2%*	*55 114*	*9%*
Main absorbing operations	6 956	2%	54 206	9%
Main refinancing operations	493	0%	908	0%
Total	**295 918**	100%	**545 556**	100%

a– Trading value is as of billion PTE.

b– Maturities range between 1 working day and 1 year. In case of same day settlement, loans with maturity 1 day are usually referred as overnight. When, delivery of funds to the trading counterpart occurs later into the future, loans with maturity 1 day might either be tom/next or spot/next.

c– Trades settled overnight.

d– Trades with deferred settlement.

e– Central bank certificates of deposit represent term deposits banks held at Banco de Portugal, while the central bank intervention bills include two types of short term instruments with different maturities: TRM– "Títulos de Regularização Monetária", and TIM – "Títulos de Intervenção Monetária".

The data set comprises observations for all trades in the Portuguese interbank money market and the intervention market. It covers the period 1 January 1989–31 December 1998, and consists of 295 918 observations.

Table 2.6 describes the contents of the original data set. The Portuguese interbank money market comprises two segments: *first*, the interbank money market where banks borrow and lend bilaterally short-term central bank funds[31]; *second*, the interventions market where The Banco de Portugal administers monetary policy, and interacts with banks buying and selling securities against central bank funds.

4.1. Interbank Money Market

The Interbank money market, denoted by MMI[32], accounts for both secured and unsecured loans. Unsecured loans is by far the most representative segment, and contains information on 233 519 trades for which nominal value, interest rate, counterparts, trading hour; delivery date, and maturity date are known on a daily basis for the entire period[33].

It was not until July 1993 that loans going through MMI could be settled at a deferred date. Banks using SISTEM are required to communicate trades to Banco de Portugal, and settlement occurred overnight. In 1998, 38.7% of all

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[31] The objective is to improve allocation of liquidity. This issue is detailed elsewhere.

[32] The MMI capitals stand for interbank money market. In Portuguese, "Mercado Monetário Interbancário".

[33] The data set can be further decomposed, if we analyse the funds delivery date in detail. Usually, the interbank money market transactions are settled on the very same day. However, there are some mitigating circumstances. In several occasions, banks prefer to contract funds for delivery into the future. This is also the case in the Portuguese interbank money market. Hence, the data set contains records on trades with deferred date value. The most common case is when funds delivery date is two working days after the trading date.

interbank market transactions were settled at date value different from trade date. Interbank secured loans used mostly Treasury Bills as collateral. All the remaining instruments have been used only marginally. But, in 1994 banks seem to have lost interest and collateralised transactions plunged and became almost irrelevant by 1998. The formal introduction of a repo market in 1997 is partially responsible for this change[34].

4.2. Interventions market

Banco de Portugal conducts the monetary policy through an adequately named intervention money market (MIT). Instruments used to buy and sell funds to banks comprise main lending and borrowing operations, structural lending and borrowing, and fine-tuning operations. Table 2.8 shows descriptive statistics for the intervention market from 1989 to 1998.

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[34] The repo market was formally created by Bolsa de Derivados do Porto and approved by Banco de Portugal on 8 March 1997 (Aviso nº 1/97). The features of the contract are based on the global master repurchase agreement (UK) and the "convention cadre relative aux operations de pension livrée (France).

Table 2.7 – Interbank Money Market value turnover, 1989–1998

		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Interbank Money Market, MMI		**8 512**	**13 712**	**23 232**	**27 806**	**36 481**	**45 229**	**34 936**	**56 786**	**67 807**	**79 883**
	Number of observations	14 474	21 215	25 308	31 510	29 509	32 577	24 322	27 113	27 978	26 056
Interbank loans with no collateral		*8 131*	*13 100*	*18 200*	*23 900*	*28 391*	*34 175*	*34 800*	*56 500*	*67 400*	*79 800*
	Number of observations	*13 598*	*19 074*	*22 355*	*27 662*	*22 791*	*23 145*	*24 148*	*26 964*	*27 777*	*26 005*
Outright trades[a]		8 131	13 100	18 200	23 900	24 900	25 700	23 200	33 500	36 600	48 900
	Number of observations	13 598	19 074	22 355	27 662	20 628	17 773	17 996	18 722	16 773	16 374
Value-Date trades[b]		0	0	0	0	3 491	8 475	11 600	23 000	30 800	30 900
	Number of observations	0	0	0	0	2 163	5 372	6 152	8 242	11 004	9 631
Interbank collateralised loans		*381*	*612*	*5 032*	*3 906*	*8 090*	*11 054*	*136*	*286*	*407*	*83*
	Number of observations	*876*	*2 141*	*2 953*	*3 848*	*6 718*	*9 432*	*174*	*149*	*201*	*51*
Treasury bills		354	582	5 010	3 769	7 589	10 800	136	286	407	83
	Number of observations	855	2 113	2 921	3 710	6 580	9 407	174	149	201	51
Central bank term deposits		22	25	9	0	0	0	0	0	0	0
	Number of observations	14	15	8	0	0	0	0	0	0	0
Central bank intervention bills		5	4	13	137	501	254	0	0	0	0
	Number of observations	7	13	24	138	138	25	0	0	0	0
CPI, except housing		*100.00*	*113.80*	*123.77*	*134.21*	*142.86*	*148.62*	*153.66*	*158.70*	*162.30*	*167.67*
	Annual Inflation	*11.7*	*13.8*	*8.8*	*8.4*	*6.4*	*4.0*	*3.4*	*3.3*	*2.3*	*3.3*

Value turnover is as of billion PTE.

[a] Trades cleared overnight. Funds are made available to the borrowing counterpart on the very same day of trading.

[b] Trades with deferred settlement. Funds are cleared on the agreed date value. The number of days between the trading date and the value date spans from 1 to 4 working days.

Table 2.8 – Intervention Market value turnover: 1989 – 1998

		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Intervention Market, MIT		**15 067**	**11 121**	**4 176**	**4 241**	**4 387**	**10 338**	**22 827**	**15 316**	**18 916**	**14 031**
	Number of observations	5 165	4 599	2 091	2 421	2 059	2 830	4 228	2 874	2 926	1 841
Primary market		*14 895*	*10 093*	*3 261*	*3 774*	*3 352*	*2 200*	*2 427*	*4 816*	*11 221*	*9 329*
	Number of observations	*5 026*	*4 390*	*1 612*	*2 191*	*1 837*	*1 702*	*1 583*	*1 718*	*2 142*	*1 984*
Treasury Bills[a]		1 813	2 508	2 745	1 941	1 635	2 150	2 427	2 639	2 345	791
	Number of observations	1 427	2 266	1 378	1 479	1 407	1 700	1 583	1 280	998	369
Banco de Portugal term deposits[b]		874	851	41	0	0	0	0	0	0	0
	Number of observations	546	479	31	0	0	0	0	0	0	0
Banco de Portugal intervention bills[c]		12 208	6 734	475	1 833	1 717	50	0	2 177	8 876	8 538
	Number of observations	3 053	1 645	203	712	430	2	0	438	1 144	1 015
Open market		*173*	*1 028*	*915*	*467*	*1 035*	*8 138*	*20 400*	*10 500*	*7 695*	*4 702*
	Number of observations	*139*	*209*	*479*	*230*	*222*	*1 128*	*2 645*	*1 156*	*784*	*457*
Liquidity absorbing operations		0	812	418	464	1 030	8 129	20 400	10 500	7 695	4 697
	Number of observations	0	156	196	227	215	1 121	2 645	1 156	784	456
Refinancing operations		173	215	497	3	5	10	0	0	0	5
	Number of observations	139	53	283	3	7	7	0	0	0	1
CPI, except housing		*100.00*	*113.80*	*123.77*	*134.21*	*142.86*	*148.62*	*153.66*	*158.70*	*162.30*	*167.67*
	Annual Inflation	*11.7*	*13.8*	*8.8*	*8.4*	*6.4*	*4.0*	*3.4*	*3.3*	*2.3*	*3.3*

Value turnover is as of billion PTE

[a] – Banco de Portugal underwrites short-term government debt. Hence, floatation is chosen according to the stance of monetary policy and Banco de Portugal targets.

[b] – Banks were allowed to choose between 180 days deposits with or without renewal option feature, and 365 days deposits, both earning a competitive interest rate.

[c] – Intervention Bills issued by Banco de Portugal comprise two very short-term financial instruments: TRM – "Títulos de Regularização Monetária" – and TIM – "Títulos de Intervenção Monetária".

A caveat must be made about the functioning of the intervention market. Banco de Portugal has been responsible for organising placement of Treasury Bills and Government Bonds. New issues were first underwritten by Banco de Portugal, and then auctioned to financial banks and other monetary institutions afterwards[35]. Our database comprises short-term public debt only. No information is available relating to new issues of Government Bonds.

The main refinancing and liquidity absorbing operations, equivalent to open market operations conducted by the Fed, where central bank funds are auctioned to participating banks represent the bulk of transactions[36]. Central bank funds are withdrawn both through new issues of short–term securities, and trading of securities from The Banco de Portugal portfolio. Term deposits were issued in 1989, 1990 and 1991 by Banco de Portugal to absorb excess liquidity in the banking system, which was considered incompatible with monetary policy intermediary objectives[37]. Introducing a contemporaneous reserve requirement

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[35] The procedures have changed since then. Currently, auctions are prepared and organised directly by Treasury.

[36] Except for given periods, when Banco de Portugal had to use long term operations do face structural liquidity imbalances.

[37] During most of the 1989–1998 period, liquidity was structurally high and funds had to be drawn out of the banking system. Banco de Portugal both issued new central bank intervention bills and the sold out securities from its portfolio to achieve this target. On a certain moment in time, when a shock therapy was set up, banks were requested to make term deposits at Banco

system and to achieve exchange rate stability and decreasing inflation required a structural approach that reduced dramatically interbank liquidity. Thus the potential for bank credit growth was mitigated as well. Further, banks were not allowed to on their own to trade central bank funds against this deposits neither could they exercise early redemption.

At the same time, the lack of enough short-term government debt to implement a tight monetary policy, lead Banco de Portugal to issue new securities with very short maturities: TRM and TIM[38] were then issued and sold to banks, regularly as to achieve interbank market stabilization.

Refinancing operations were conducted through repurchase agreements and redemption before maturity of previously issued securities. Regarding the structure of these open market operations over the 1989–1998 period, funds were bought and sold through either fixed rate tenders or variable rate tenders[39].

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de Portugal for 180 days and 364 days. The main objective was to reduce inflation and, at the same time, to prepare the Escudo and the Portuguese financial system to join EMU. Reserve management policy was also changed, as interest rates were changed more than one to introduce a modern reserve management policy.

[38] TRM, "Títulos de Regularização Monetária" in Portuguese, have maturities ranging from 1 to 14 days. On the other hand, TIM – "Títulos de Intervenção Monetária" – live longer and can have the following alternative maturities: 4, 9, 13, 26, or 52 weeks.

[39] In practice, procedures are equivalent to those currently in place after introduction of euro, except that under the European Central Bank, maturities are far longer as the reserve requirement periods last for one month, in contrast with the one week reserve holding periods for the time span under analysis.

4.3. Marginal lending and deposit facilities and other official rates

Though not very regularly till 1992, Banco de Portugal kept a marginal lending and deposit facility that banks could use daily, in order to reduce interbank money market rate fluctuations. In practice this policy has been equivalent to setting a cap and a floor on money market rates fluctuations. In practice this target has been achieved most of the times. We collected information on these and other official rates as well for the entire period under analysis. End o period figures are reported on Table 2.9. However there are not any statistical figures indicating the frequency of use of borrowing and lending facilities over the entire period by banks. Nevertheless, we can infer this from the reserve balances banks hold at Banco de Portugal on each day.

Table 2.9 – End of period official rates.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Discount rate	14.50	14.50	14.50	14.50	13.00	10.50	9.50	7.00	6.00	3.25
Marginal lending rate	–	–	–	–	12.00[a]	11.50	10.50	8.30	6.90	3.25
Deposit rate	–	–	–	–	–	8.50[b]	7.75	6.20	4.90	2.75
Refinancing operations	–	–	20.00[c]	26.55[d]	11.00	8.88	8.50	6.70	5.31	3.00
Absorbing operations	–	–	15.63[e]	14.00	9.88	8.50	7.75	6.20	4.90	2.75
Reserve deposits	–	–	15.75[f]	13.25	9.88	8.75[g]	–	–	–	–
Inflation	*11.7*	*13.8*	*8.8*	*8.4*	*6.4*	*4.0*	*3.4*	*3.3*	*2.3*	*3.3*

Banco de Portugal establishes the discount rate, the marginal lending rate, and the deposit rate unilaterally. Interest rates of refinancing and absorbing operations are, either, fixed by Banco de Portugal or resulting from auctions. Banks' reserves at Banco de Portugal used to pay interest until 1994, when the binding reserve ratio was kept at very high levels due to existing excess liquidity in the Portuguese financial system. Hence, banks were receiving a compensation for not being able to expand their loan portfolio.

a – On 12 July 1993 Banco de Portugal implemented a regular marginal (daily) lending facility.

b – The deposit facility was introduced on 19 January 1994. Banks were given the option to daily deposit funds at a fixed rate till the end of the reserve counting period.

c – Banco de Portugal started regular refinancing operations on 24 May 1991 (21.65%).

d – 2 October 1992. Refinancing operations were suspended afterwards until 1993.

e – Banco de Portugal started regular liquidity absorbing operations on 24 May 1991 (16.50%).

f – Since 2 January 1991, interest was paid on banks' reserves deposited at Banco de Portugal.

g – 4 October 1994. From then onwards reserves deposited at Banco de Portugal ceased to earn interest.

Records on the official interest rates database are mainly hand collected, and checked against Banco de Portugal notices and instructions to the banking system. Although there exists a point in time when a given official interest rate or central bank facility – borrowing or lending – was first introduced, there were periods for which the facility or interest rate was suspended for monetary policy purposes. We identify those cases in the database, though they are not relevant for the purposes of describing the data here. Main refinancing and liquidity absorbing operations are auctioned at the onset of each holding period and mature on the very last day[40].

Before the introduction of daily lending and deposit facilities, Banco de Portugal used to fine tune refinancing and liquidity absorbing operations. Therefore, within the reserve holding period banks were still allowed to access central bank facilities. There is a difference however as the daily facilities are requested by banks unilaterally, while the refinancing and absorbing operations were auctioned to banks after assessment of market conditions by Banco de Portugal and accordingly to the stance of monetary policy.

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[40] Notice Banco de Portugal run sequentially a one week long approximately reserve holding period after another. Funds are paid back on the first day of the next reserve holding period.

4.4. Minimum reserve requirements

Additionally, we hand collected the reserve holding and counting periods and money market reference rates for the whole period, from the official sheets[41] published by the Central Bank. For most of the period under analysis Banco de Portugal had in place a *quasi*-contemporaneous reserve holding policy.

From 1989 to 1998 there were two regimes regarding reserve requirements. Until end 1994 a lagged reserve policy was in place. According to the regime set up in place, minimum reserve requirements were determined weekly for each bank[42], and the corresponding reserves deposited at Banco de Portugal were assessed immediately the following week[43]. To compute the minimum reserve requirements for each bank, weighted liabilities were averaged daily over the

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41 "Avisos", "Instruções", and "Cartas Circular" from Banco de Portugal.

42 These periods are known as *reserve counting periods*. In Portuguese, these is known as "períodos de apuramento da base de incidência". There are four weekly periods every month, as established in Aviso nº 900/84 of 1 July 1984, ending on days 8, 15, 22 and last day of the month.

43 This is known as the *reserve holding period,* in Portuguese the "período de constituição de reservas". Reserve holding periods used to be one week long and they were defined as equivalently to the reserve counting periods.

counting period[44]. Subsequently, the following week banks were requested to hold a daily average reserve balance not less than the minimum requirement.

On 1 November 1994, Banco de Portugal implemented a quasi-contemporary reserve requirement regime with partially overlapping reserve counting and reserve holding periods. The reserve requirement ratio was also reduced to 2% uniformly[45]. Reserve counting and holding weeks have variable length. Each month reserve counting periods are as follows: *first*, from day 1 to day 8; *second*, from day 9 to day 15; *third*, from day 16 to day 22; and *fourth*, from day 23 to the last day of the month. Reserve holding periods are: *first*, from day 4 to day 11; *second*, from day 12 to day 18; *third*, from day 19 to day 25; and *fourth*, from day 26 to day 3 next month[46].

Following the previous discussion, reserve counting and holding periods were identified accordingly and the number of calendar days and the operational

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[44] Liabilities were weighted according to how they were redeemable on demand. Thus, sight deposits carry more weight then term deposits. Until 1994, the following weights were applied to banks' liabilities: (a) up to 180 days deposits: 12%; (b) between 180 days and 1 year deposits: 9%; (c) over 1 year deposits: 6%.

[45] Aviso nº 7/94 and Instrução nº 28/94.

[46] Recently, after the inception of Euro, the reserve requirements policy was changed according to the newly established European Central Bank rules. There are two holding periods with 24 and 38 working days, immediately before transition to Euro.

procedures needed to daily average liabilities and reserve balances were reconstituted for the interbank money market and payments system data sets.

Table 2.10 – Time span of reserve counting and holding periods

	Before 1 November 1994				After 1 November 1994			
	Calendar days		Working days		Calendar days		Working days	
Time span (Number of days)	Number of counting periods	Number of holding periods	Number of counting periods	Number of holding periods	Number of counting periods	Number of holding periods	Number of counting periods	Number of holding periods
3			5	5			5	3
4	2	1	27	33			15	25
5	1		173	158			124	107
6	5	7	56	68	2	3	35	46
7	180	169	19	17	130	119	14	11
8	44	59			30	41		
9	19	20			10	12		
10	17	18			13	13		
>10	12	7			8	6		2
Total observations	**280**	**281**	**280**	**281**	**193**	**194**	**193**	**194**

Working days were reconstituted from Banco de Portugal dataset.

Reserve counting and holding periods were identified accordingly and the number of calendar days and the operational procedures needed to daily average liabilities and reserve balances were reconstituted for the interbank money market and payments system data sets.

Following the previous discussion, reserve counting and holding periods were identified accordingly and the number of calendar days and the operational procedures needed to daily average liabilities and reserve balances were reconstituted for the interbank money market and payments system data sets.

Table 2.10 tabulates the number of counting and holding periods for the entire sample by calendar days and working days. There are 473 and 475 reserve counting and reserve holding periods respectively. The variable time length of each period is clear. Yet, reserve counting and holding periods are predominantly 7 calendar days long, both before and after the inception of a major change in the reserve requirement policy in 1994. If we exclude weekends and bank holidays the periods range between 3 and 7 days, with 5 days being the most frequent observation.

4.5. Price deflators

Real figures are reported after scaling by the consumer price index excluding housing, as published by Instituto Nacional de Estatística, interpolated daily[47]. Figure 2.2 plots daily change in prices. The characteristic function of this series derives from the procedure used to interpolate daily changes in prices.

Inspection of Figure 2.2 shows prices decreasing steadily and, eventually, stabilising after 1993. This is not surprising if we take into consideration the final goals established for the monetary policy pursued by Banco de Portugal over this period, mainly after 1991. Decreasing inflation and exchange rate

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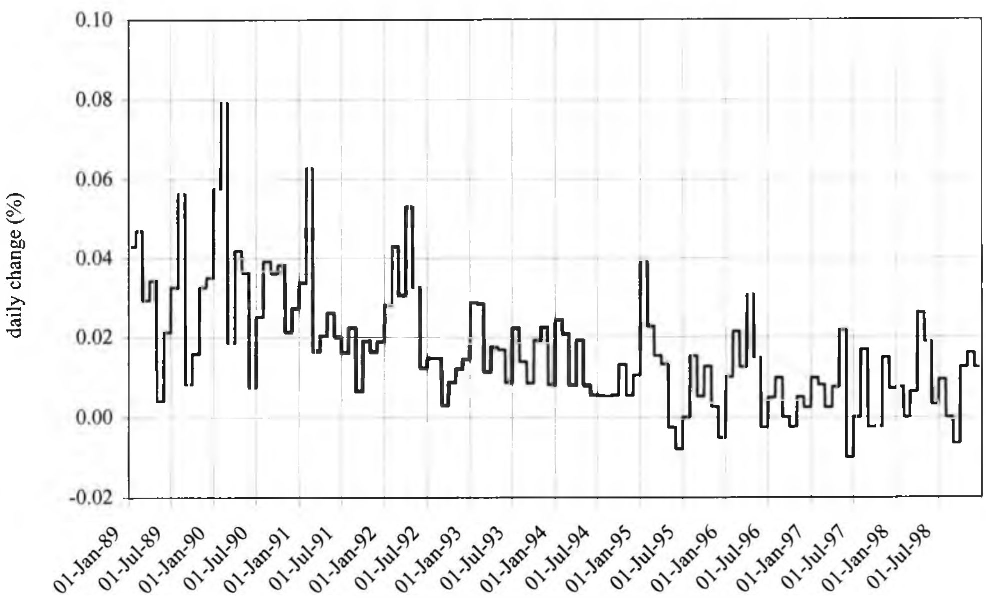
[47] In order to deflate daily trading volumes, the daily CPI was interpolated from end of month inflation figures assuming daily compounding. If $g = CPI_T/CPI_{T-1} - 1$ is reported as the monthly inflation rate for calendar month T, which consists of N days, the interpolated CPI value for the t-th calendar day of the month is $CPI_{T-1}(1+g)^{t/N}$

stability were endeavoured in order to create the necessary conditions for the Portuguese Escudo to enter the ERM in 1991 and join the Euro in 1999.

Figure 2.2 – Daily change in Consumer's Price Index (CPI) except housing



INE – Instituto Nacional de Estatística. Daily changes are interpolated as described in footnote 47.

Chapter 3

Portuguese Interbank Money Markets: Stylized Facts

1. Introduction

The flow of funds stemming either from the payments system itself or from opening positions over the day leaves some banks with a deficit at the central bank reserve account, while others are in surplus. When short of funds a bank needs to borrow to avoid costly overnight overdrafts and prevent transactions to halt. In contrast, those with excess reserves find it costly to hold idle funds and are willing to lend to others. Overnight and intra-day same-day-settlement markets serve the interest of both counterparts. Unsecured loans can be arranged between market participants to distribute liquidity at a primary level. Considering that banks are able to forecast with more or less accuracy future liquidity needs uncollateralized loans with longer maturities and settling at value date might also be used for reserve management purposes.

We investigate uncollateralized daily money market transactions and interest rates in the Portuguese Interbank Money Market over a 10-year period ending in December 1998. We expand previous research using a unique dataset, which has not yet been used for these purposes, and explore transaction volume and counterpart behaviour features in markets for liquidity insurance. The dataset allows for a complete characterization of the functioning of the Portuguese interbank money markets, and its interaction with monetary policy instruments and banks' behaviour in the interbank market. We split the sample in two periods according to institutional changes in interbank money market operational procedures, which are found to have implications on banks' behaviour.

In summary, interbank market loans have very short maturities. Overnight loans represent about 50% of interbank money market transactions, while spot-next and tom-next trades account for another 25%. Limited trading observations for longer maturities suggest the uncertainty of future liquidity shocks hinders arbitrage opportunities, as the associated adjustments costs might be quite large. We find evidence that banks are risk averse regarding liquidity and interest rate shocks, and have a tendency to hoard funds at the beginning of the reserve-holding period. Also, and reinforcing the risk aversion behaviour, banks borrow for long maturities at the beginning of the reserve holding period. Eventually, they are left with excess reserves that they are willing to sell towards the end of the period, thus forcing interest rates down. Calendar effects, such as reserve maintenance period impact on interest rates level and volatility. However, and contrary to main empirical research we find that overnight rates are higher and more volatile on the first day of the reserve-holding period as compared to the last. At the bank level we find that large banks are mainly lenders in interbank money market, while small banks are usually borrowers, and they might as well operate as market makers for different maturities, while profiting from positive bid-ask spreads.

The plan of this chapter is as follows. The next section explains why and how do banks use interbank money markets to manage liquidity positions. Theoretical model implications and empirical research is briefly reviewed. Empirical research using disaggregated data is very scarce due to paucity of data, making the description that follows highly useful for policymakers, market participants and regulators. Section 3 describes the general properties of interbank loans. A range of different loans' maturities, interest rates and settlement procedures is analysed at the aggregate level, while investigating for the presence of calendar effects. Section 4 extends the discussion and breaks down the data by bank size. This allows a complete description of the micro mechanics of the interbank markets, such as banks' preferences regarding trading, which are the basis for credit rationing and market making behaviour.

2. The use of interbank money markets

The ability of interbank markets to provide complete insurance depends on market efficiency. Only when markets are complete and there is no asymmetric information or moral hazard do interbank markets operate efficiently to provide adequate insurance against liquidity risks to banks. Otherwise, transaction costs and other market imperfections make the interbank market a sub-optimal arrangement for liquidity insurance, which might require the central bank to step in as a lender of last resort. There are several reasons why interbank money markets fail model predictions, which we describe in the following sections. In general, they are related to market microstructure and individual behaviour of market participants.

Quite a number of studies focus on the aggregate behaviour of interbank interest rates, however, little is known about aggregate and individual market liquidity and what are the implications from its behaviour to conducting monetary policy. In particular, some basic questions remain unanswered: How much does liquidity and trading vary on a day-to-day basis? Can we find any regular patterns in daily trading and interbank exposures? For example, can we detect day-of-week and end-of period effects? How do banks' risk management determine bilateral exposures? For instance, can we find signs of credit rationing in the interbank money market, or are there any discernible patterns on trading and counterpart choice? What causes changes in the in the movements of trading and interest rates?

These questions can only be analysed using data on trading by banks. The answers are directly related to the institutional features of interbank money markets, and are of central importance for treasury managers and central bankers, who aim at controlling financial risks, understand how interest rate shocks spread across the term structure of interest rates and, ultimately, the systemic risk in the financial system. Unfortunately, researchers seldom get access to examine such detailed trading data. An interesting note about this market is the absence of trading volume information. Therefore, empirical studies often look at aggregate data, analysing pricing behaviour and volatility.

The subject gained renewed interest in Europe since the introduction of the euro and after monetary policy control was handed in to the European Central Bank. A few papers have been published on liquidity management, banks' behaviour in interbank money markets, and the relationship of these with the conduct of monetary policy and European Central Bank refinancing operations.

We have very detailed data on the trading behaviour of banks in the Portuguese interbank market. This data has not been used before and its access data was only possible for a small country like Portugal. The Banco de Portugal runs a proprietary trading system, known as SISTEM, use by national banks to book interbank money market loans. Until the introduction of Euro in January 1999, almost all interbank money market transactions were carried through the SISTEM. Since then, and according to The Banco de Portugal, transactions passing through this market are decaying, as banks trade increasingly with other European institutions and choose alternative settlement procedures[1].

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[1] Nevertheless, for transactions with national counterparts the SISTEM maintains a cost advantage, and entangle simple procedures for banks back-office, as the repayment flow is instructed automatically early morning – i.e., before market opening – on the expiration day.

To the extent of our knowledge the use of individual transaction data is restricted to the United States and a few isolated studies in Europe. Furfine (1999, 2000) infers overnight transactions from transactions recorded in Fedwire[2] and using a short time horizon he presents several properties regarding the overnight interbank market. Using a similar procedure to identity overnight loans Demiralp et al. (2004) investigate transactions and interest rates on brokered and directed trades in federal funds, Eurodollar transactions, and repurchase agreements, all of which are used by banks in overnight funding. Very recently, and using a more restrictive data set, Cocco et al. (2004) explore relationship lending and credit rationing in the Portuguese interbank money market. Our data set does not have as many cross sectional observations as Furfine (2000), because the number of banks compatible to a small country is necessarily smaller. However, it covers a 10-year period of daily observations, and is longer and more representative of the Portuguese interbank money market than the one used by Cocco et al. (2004). The long extension of the data set allows one to analyse the time dynamics of interbank money markets mechanics and possibly its relationship with the monetary policy stance.

On a related way, several authors use aggregate data to explain money market rates, relating its behaviour to banks liquidity management problem.

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[2] Fedwire is a book-entry electronic system operated by the Federal Reserve to transfer funds between institutions with accounts at the Federal Reserve Bank.

Hamilton (1996), Winters (1995), and Spindt and Hoffmeister (1988) demonstrate that the Federal Funds market calendar effects are related to the reserve maintenance period, holidays and other specific end of period dates. Hamilton (1996) demonstrates that interbank interest rates do not exhibit a martingale property and, hence, funds on different days of the reserve period are not perfect substitutes. Interest rates over the maintenance period are U-shaped and spike when approaching the end-of-period. Volatility also increases on settlement Wednesdays. Griffiths and Winters (1997) explain end-of-the year effects in monetary instruments with investors' preferred habitat for liquidity on the turning of the year. Others propose window dressing arguments. Lee (2003) shows that Eurodollar overnight rates exhibit calendar effects which are similar though less pronounced to Federal Funds rates. Regulatory restrictions and incomplete arbitrage arguments explain the observed different behaviour.

In this chapter we investigate the functioning of the Portuguese interbank money market and how do banks lend to each other short-term funds. We are interested in knowing if there is any bank size effect in this market, as if small and large banks behave differently regarding the amount of trading and the choice of counterparts. We also want to know how do possibly banks arbitrage the interbank market yield curve, while buying and selling funds of very different maturities simultaneously. Calendar effects and other institutional features of the market, such as trade size and pricing patterns are analysed.

A methodological note is required here. Chapter 3 identifies 4 monetary policy regimes, corresponding to different stances of monetary and exchange rate policies. Though this partition is important for modelling banks' behaviour regarding pricing of loans, as we show in chapter 6 next, they remain not as significant for analysing individual bank's use of the interbank money market. On contrary, institutional changes on how does interbank money market operate are more important than The Banco de Portugal policy constraints. As such the analysis is broken down in two periods, the first until 12th July 1993, and the second afterwards[3]. The bond with monetary policy stance is not broken completely. The first period covers regime 1 and 2, while the most recent starts exactly at the same moment as regime 3 and it is extended to cover regime 4. We end up with two periods related to changes in the interbank money market architecture. In general and for simplicity we will report figures for the most recent period only, except when results are useful for matter of comparison.

3. Aggregate Stylized Facts

Trading value has increased steadily over the research period to level at approximately 100 daily trades[4]. At first, the borrowing bank would have access

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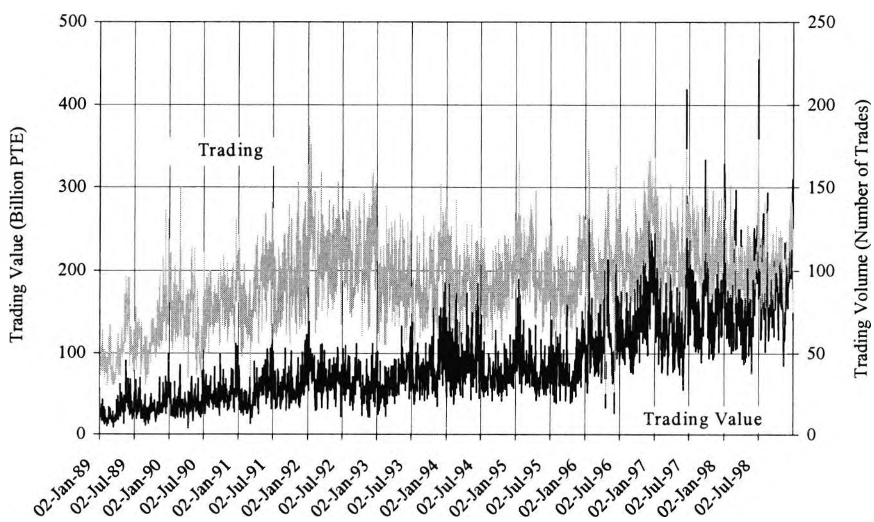
[3] The choice is not arbitrary and stems from preliminary tests suggesting how results might change if an alternative partition of data is used. We did not find a statistically significant difference when comparing regimes 1 and 2, on one hand, and regimes 3 and 4, on the other.

[4] We restrict the analysis to interbank market loans with no collateral, as the remaining trades represent only 5% of total and are irrelevant from 1994 onwards.

to the contracted amount of funds on the same day of trade. The market trading platform did not allow banks to make forward rate agreements and negotiate a different delivery date. Transactions with value date deferred from trade date were introduced in 1994. This was a major improvement in the functioning of interbank money market, permitting banks to cover liquidity exposures opened in foreign exchange and stock markets, which are known a couple of days in advance. Banks are allowed to fix the interest rate on their loans the day before the flow actually happens in case they do not have enough central bank funds. A wider choice of maturities permits a better matching of the expected inflows and outflows stemming from payments system and bank's activities.

Figure 3.1 – Daily trading in the interbank money market: Value and Volume



Daily trading values are obtained after summing up one leg of all interbank money market trades. Only unsecured loans were considered. Values are deflated using the CPI index interpolated daily.

Settlement when the transaction is initiated occurs mostly within two working days, i.e. the lender delivers funds to the borrowing bank with a two days delay at most. This feature is also observed in overnight trades, which trade at a range of settlement dates. The bulk of transactions settle overnight, but there is a considerable amount of loans that make overnight funds available at a later date only – i.e., the date value exceeds the transaction date, identical in all respects to a forward rate agreement, except that it is for the shortest overnight maturity. A closer inspection of the importance of the option to trade loans with the same maturity and different settlement dates is detailed next.

3.1. Overnight and deferred settlement

Until 1993 interbank lending for different maturities was settled overnight. When banks became allowed to trade overnight loans with value date different from trade date on 12 July 1993, settlement has been deferred into the future. The proportion of trades settling overnight stabilized just below 60%. They are at most overnight loans, as longer maturities settle preferably at deferred value-date. Yet, it is interesting to note that about 15% of loans settling on trading day have maturities above or equal to one week. This suggests that banks might in fact arbitrage the interbank money market term-structure, and longer-term loans are alternative to overnight loans in meeting shortage of funds.

Table 3.1 exhibits summary statistics for the entire period. Daily trades are settled mostly overnight, but there is a considerable amount of trading settling a few days ahead.

Table 3.1 – When are daily trades settled? Summary statistics (12/07/93 – 31/12/98)

Value date	Obs	Mean	Std. Dev.	*t-statistic*	Median	Skewness	Kurtosis
t	1365	64.89	14.53	165.00 **	65.34	-0.35	3.39
T+1	1365	22.07	13.54	60.22 **	21.07	0.51	3.18
T+2	1365	11.80	9.67	45.08 **	9.07	1.38	5.58
T+3	1365	1.08	4.61	8.66 **	0.00	5.69	43.70
T+4	1365	0.09	1.13	2.94 **	0.00	13.46	192.02

The figures shown are mean percentages of day *t* total turnover settling on each value date. The number of observations stands for the number of trading days during each period.

Value date is the number of working days by which settlement is delayed. Trading is supposed to happen at time t. Thus, if value date is *t+1*, delivery of funds is lagged by one working day, i.e., the loan effectively begins at time *t+1*. Means significantly different from zero at the one percent (five percent) level are indicated by ** (*).

The percentage of same-day-settlement trades is decreasing steadily since value date transactions were allowed in 1993. A year-by-year detailed analysis is presented in Figure 3.2. One-day loans with deferred settlement – i.e., tom-next and spot-next transactions – and are increasingly important as banks use this facility to avoid uncertain moves in overnight interest rates when the liquidity shock is foreseen[5]. Longer maturity interbank loans settle within two working days, and might represent banks loans backed by securities trades, either with clients or other market participants, whose reverse operation is known in advance.

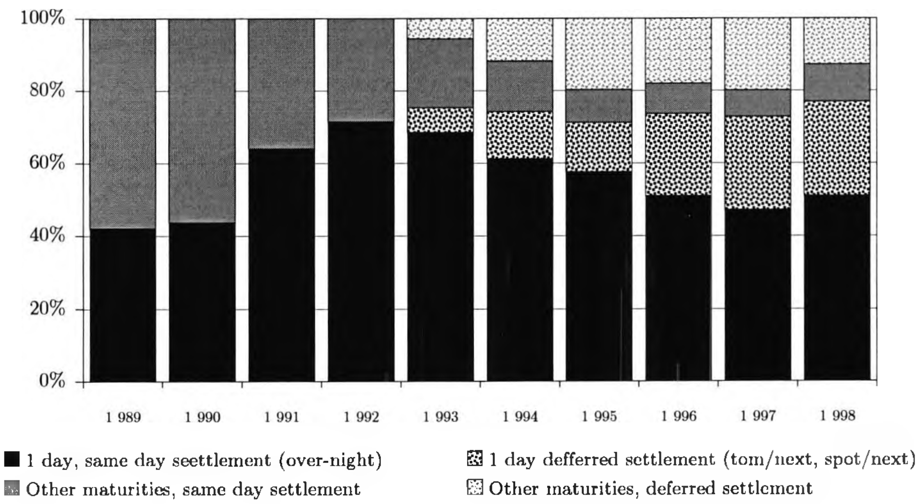
A formal relationship between trades and settlement using [1] was estimated in order to understand the dynamics and preferences of banks' lending behaviour in this market.

[5] Trades settling within 2 working days might be originated in foreign exchange and stock markets transactions, whose settlement is known in advance.

$$S_t = A(L)V_t \quad [1]$$

where $A(L)$ is the $n-th$ order lag polynomial to be estimated

Figure 3.2 – When are daily trades settled? One-day versus longer maturity loans



Values are presented as percentages of total interbank money market loans. Loans with deferred settlement were introduced for all maturities in 1993 only. Solid blocks stand for loans with funds made available immediately, while the patterned ones represent loans for which the borrower is granted access to the funds at a previously agreed future date – i.e., the value date.

The conclusions are that daily settlement is mainly driven by current trades, and lagged 1 and 2 working days. There are very few trades with value date beyond two working days. The choice of this lag structure was driven by the analysis of aggregated data for the entire period. Table 3.2 presents regression results[6]. Estimated slope coefficients also add up to one suggesting

[6] Other variables, such as calendar effects have been neglected.

that the lag structure[7] captures the entire dynamic of loan and settlement activity.

Table 3.2 – When are daily trades settled? Regression results (12/07/1993–31/12/1998)

Explanatory Variables	Coefficient		t-statistic	[95% confidence interval]	
V_t	0.539	**	31.08	0.505	0.573
V_{t-1}	0.307	**	16.26	0.270	0.344
V_{t-2}	0.157	**	9.10	0.123	0.191

Dependent variable is S_t : interbank money market value settled daily. Explanatory variables are V_t : interbank money market trading value, current and lagged. Regression was run imposing the no-intercept constraint. Coefficients significantly different from zero at the one percent (five percent) level are indicated by ** (*). Adjusted R-squared is 0.9637.

The relationship between daily settlement and daily trading confirms our opinion. Interbank market loans are mostly settled overnight. The regression also suggests that settlement occurs mostly within two working days. Regarding lagging settlement relative to the trading date, only lags of one and two days are statistically significant at the 1% level. Existing trades settling 3 and four days ahead are quite noisy, and do not exhibit a regular pattern. Each day settlement is broke down in about 54% from current day trading, 31% and 16% from the previous day and 2 days before, respectively.

Further, we cannot reject the null hypothesis that coefficients add up to one, and therefore settlement at time t is a weighted average of current and

[7] The lag structure illustrates value date and trade date loans. One day lag stands for trades that settle next day corresponding to the tom/next transaction.

previous days trading activity. Results are consistent to the distribution of daily trades by value date[8].

3.2. Loan maturity and volume

One important feature of interbank money markets is that bilateral contracting allows banks to choose specific maturities according to their special needs, and in particular those related to liquidity management purposes[9]. A detailed analysis of how do banks overall choose amongst different maturity loans and how do they change behaviour on different days of the reserve holding period is presented next.

a. Loans maturities and volume

A wide spectrum of maturities is often found when we analyse raw data. Making the data tractable requires concentrating out the sample using maturity brackets, which we do next. Intervals are described in Table 3.3.

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[8] This issue deserves the attention of central banks when forecasting settlement and trading activity into the future as to determine system liquidity needs, and also for the purposes of conducting the monetary policy.

[9] Markets usually trade loans with standardized maturities, such as one week or one month. Interbank markets, however, show a wider range of maturities as bilateral contracting permits a wider choice to banks. Market microstructure theory suggests this compromises market depth while fragmenting market orders which, being split by different market segments and under positive transaction costs, reduce investors' ability to arbitrage and might increase the cost of funding. On the other hand, we might argue that interbank money markets serve the main purpose of liquidity management, and therefore this cost is equal to the banks' benefit of choosing a maturity that matches its specific interests.

Table 3.3 – Description of maturity intervals

	1 day	1 week	2 weeks	1 month	3 months	6 months	1 Year
Interval, days	[1, 1]	[2, 9]	[10, 17]	[18, 60]	[61, 135]	[136, 225]	[226, 366]
Outright Loans							
– Number of days…							
… mean	1	5.63	13.41	31.34	87.94	148.73	345.87
… weighted mean	1	5.49	13.41	30.36	87.05	181.30	333.24
– Standard deviation	0	1.99	2.08	8.61	15.67	11.86	35.55
– p50	1	7	14	30	91	182	364
– p95	1	8	17	54	120	188	365
Value-date Loans							
– Number of days							
… mean	1	6.52	13.73	32.10	86.36	179.87	341.92
… weighted mean	1	6.48	13.41	31.68	86.53	179.28	341.48
– Standard deviation	0	1.38	1.56	7.82	15.41	11.25	38.56
– p50	1	7	14	31	91	182	365
– p95	1	8	16	55	119	187	365

The weighted average number of days is computed using loan's nominal value as weights. Standard deviation is the sample standard deviation with no adjustment for trade size. The intervals were chosen as to have the trades distributed symmetrically around the median. Notice the one-year loans show quite a noisy behaviour.

We set the median value of each interval equal to the maturity tag posted in the bracket. For each bracket, transactions whose maturity is 10% above and below the median fall mainly within the 5 and 95 percentiles. Those transactions that do not are not representative and mostly serve the purpose of hedging positions opened in other market segments, e.g., collateralised loans or foreign exchange transactions.

A few interesting results emerge when we sort the data this way. Table 3.4 presents aggregate results. Overall 1-day maturity loans are prominent representing almost 80% of total interbank market turnover. About two thirds of these loans are settled on the same day of trading – which are often referred as overnight loans – while the remaining funds are made available at a future date – this are tom/ next and spot/next trades, which deliver funds on the next working day or two working days ahead, respectively.

The intense use of overnight loans emphasises the issue that flows in the interbank market are mainly driven by unexpected liquidity shocks and reserve management reasons, as it is supported by empirical research. Yet, the data in uninformative on why some liquidity shocks are hedged in advance as when banks contract loans for overnight at a date into the future. The tom/next and spot/next operations represent 22% of transactions after July 1993, which we can hypothesise stem from opening positions at the stock and foreign exchange markets. Overall, outright – i.e. same day settlement – and value date funds represent almost three quarters of interbank market loans. Banks strive to keep daily positive reserve balances at the central bank in order to avoid penalties, and also to prevent the payments system to halt due to shortage of cleared funds in its reserve account[10]. On the other hand overnight and intra-day loans are profitable alternatives to keep idle funds at the central bank.

Table 3.4 shows that longer maturities are also important. We might therefore hypothesise that banks are able to some extent to forecast future inflows and outflows of central bank funds and, accordingly, choose to borrow or lend for long maturities. There is at least one source of predictability, which is

[10] There were periods in the past when banks used interbank money market loans to finance loans activities. Credit constraints explain this behaviour. Newly established banks did not have a wide deposit base to finance loans, and they took deposits from other banks through interbank money market loans, to finance personal and corporate loans. This funding feature is reflected long maturities in the early years, which eventually disappeared after 1993 as other sources of funding developed. Eventually, the interbank money market resumed its liquidity insurance function.

related to minimum reserve requirements policy. The Banco de Portugal runs an almost one week long reserve holding period, and as so one week investments are expected to represent an important stake in interbank flows, while banks attempt to borrow for the whole reserve requirement period in case reserves fall bellow he required level. Additionally, this is consistent with our first results showing one-week long loans as the second most important source of trading in the Portuguese interbank money market. Other maturities are less important, and delaying the date funds are settled may have two interpretations: banks choose unsecured interbank money market loans either to hedge foreign exchange and derivatives exposures, or to arbitrage on interest rates[11].

Previous regression results and Table 3.4 figures emphasise that interbank loans for liquidity management purposes is active mainly at maturities up to one week and clearing date (value date) within two working days ahead of trading. Quite rightly overnight loans, identified in literature as the most relevant source of funding and that empirical research treats as the only instrument available for daily reserve management purposes, represent more than half of interbank loans in our database. Yet this should obscure alternative

[11] We consider two sorts of arbitrage opportunities here. The *first* consists of arbitraging between spot and forward markets, along the yield curve and possibly using the foreign exchange market. The *second*, is more like expectations or uncovered arbitrage, such as banks have behave strategically, contracting in advance funds they know they will need in the future to compensate for expected flows should they expect interest rates to rise. This might happen as empirical literature suggests that interest rates increase towards the end of the reserve holding period.

long-term interbank market investments, as they are equally important and might produce an interest rate smoothing effect when banks finance liquidity shocks across different maturity loans.

Table 3.4 – Unsecured interbank loan volume: agreed maturity and value date

Panel a. 1 January 1989 – 11 July 1993

Value date		Maturity Bracket							Total
		1 day	1 week	2 weeks	1 month	3 months	6 months	1 Year	
t	Value (billion PTE)	48 066	19 760	2 872	4 392	1 082	621	94	76 887
	% Total	63%	26%	4%	6%	1%	1%	0%	100%

Panel b. 12 July 1993 – 31 December 1998

Value date		Maturity Bracket							Total
		1 day	1 week	2 weeks	1 month	3 months	6 months	1 Year	
t	Value (billion PTE)	151 472	17 240	2 821	4 094	2 418	671	708	179425
	% Total	53%	6%	1%	1%	1%	0%	0%	62%
$t+1$	Value (billion PTE)	53 909	12 212	1 023	2 040	1 603	643	323	71 751
	% Total	19%	4%	0%	1%	1%	0%	0%	25%
$t+2$	Value (billion PTE)	8 091	14 202	2 922	5 236	3 671	1 662	680	36 465
	% Total	3%	5%	1%	2%	1%	1%	0%	13%
Total	Value (billion PTE)	**213 472**	**43 654**	**6 766**	**11 370**	**7 692**	**2 976**	**1 711**	**287 641**
	% Total	**74%**	**15%**	**2%**	**4%**	**3%**	**1%**	**1%**	**100%**

Panel c. 1 January 1989 – 31 December 1998

		Maturity Bracket							Total
		1 day	1 week	2 weeks	1 month	3 months	6 months	1 Year	
T	Value (billion PTE)	261 538	63 414	9 638	15 762	8 774	3 597	1 805	364 528
	% Total	72%	17%	3%	4%	2%	1%	0%	

Values are as of billion PTE, except where indicated otherwise. Nominal trade values are used. The transaction date is assumed to take place at time t. Therefore, where the value date equals t, transactions are cleared overnight on the very same day of trading. A value date of $t+1$ means the loan effectively begins at time $t+1$. T stands for total.

b. Loans volume

When we seek for calendar effects, we find that banks avoid borrowing in the last day of the reserve holding period. We find evidence that overnight loans are mainly used for reserve management purposes. Yet we cannot discard the argument that other maturities serve might be used with the same intent.

Table 3.5 – Loan volume on day-of-the-reserve-holding period

Panel a. Over-night loans

	Days of the reserve-holding-period						
	First day	2	3	-2	-1	Last day	p-value
Daily Loan Value	117.9 **	109.2	109.0	107.0	107.0	106.6	0.038
Standard deviation	49.2	44.7	54.5	52.8	49.4	48.6	
Average Loan Value	2.09 **	1.96 **	1.99 **	1.95 **	1.92 **	1.56	0.000
Number of Loans per day	56.3 **	55.6 **	54.7 **	54.9 **	56.1 **	68.3	0.000
Daily average interest rate (%)	7.99	7.93	7.90	7.9	7.8	7.7	0.007

Panel b. Tom-next and spot-next loans

	Days of the reserve-holding-period						
	First day	2	3	-2	-1	Last day	p-value
Daily Loan Value	42.2 +	44.9	50.5	49.0	45.4	48.1	0.231
Standard deviation	35.3	36.6	45.3	41.4	39.1	46.7	
Average Loan Value	3.18 *	2.97 **	3.12 **	3.10 **	3.00 **	3.51	0.001
Number of Loans per day	13.3	15.1 *	16.2 **	15.8 *	15.1 +	13.7	0.007
Daily average interest rate (%)	7.96	7.92	7.95	7.92	7.82	7.93	0.150

Panel c. One-week loans

	Days of the reserve-holding-period						
	First day	2	3	-2	-1	Last day	p-value
Daily Loan Value	46.5 **	27.9 *	20.8 **	20.6 **	33.7	32.8	0.000
Standard deviation	34.6	21.9	17.2	16.4	28.3	33.2	
Average Loan Value	2.44	1.99 **	1.78 **	1.77 **	2.52	2.90	0.000
Number of Loans per day	19.1 **	14.0 **	11.7	11.7	13.4 **	11.3	0.000
Daily average interest rate (%)	8.00	7.97	7.99	8.03	7.97	7.99	0.160

Panel d. Loans above one-week

	Days of the reserve-holding-period						
	First day	2	3	-2	-1	Last day	p-value
Daily Loan Value	23.4	20.7	20.6	20.5	21.7	22.2	0.014
Standard deviation	17.2	14.8	15.3	14.1	18.4	20.8	
Average Loan Value	1.36	1.24 **	1.34 +	1.34 +	1.43	1.54	0.000
Number of Loans per day	17.2 **	16.7 **	15.4 *	15.3 +	15.2 +	14.4	0.000
Daily average interest rate (%)	8.10	8.07	8.08	8.08	8.09	8.12	0.048

Figures are as of billion PTE, except where indicated. Results are presented for the period after 12 July 1993 only. Reserve holding periods are of different length and we consider the first and the last three days only. Each day is tested against the last day of the reserve holding period: a mean difference test for each day mean is produced and results are presented under the respective column. The one-tailed test checks whether the value of each day loan is significantly larger or smaller than the last day. Coefficients significantly different from zero at the one percent (five percent, ten percent) level are indicated by **(*,+). The p-value from an overall test of the restriction that means are equal across all days is also produced. Results are posted in the last column.

Results are presented in Table 3.5. Overnight loans are far larger on the first day, while tom-next and spot-next trading volume spike before and prior to before the last day of the reserve holding period, respectively. The number of overnight loans increases towards the end of the reserve period while average loan value decreases: the average loan size decreases 35% as compared to the first day, while we find an average 11% drop across all maturities. Banks are likely to borrow in advance to meet reserve requirements, and last trading is used to fine-tune the cash management policy. Whether this is consistent with market interest rates will be discussed later.

Fluctuation is less pronounced when we consider tom-next and spot next trades. Trading volume spikes towards the end of the reserve holding period for two different reasons. First, banks fearing interest rates to rise in the last day, secure interest rates trading at date value before end-period; and, second, due to a forward looking behaviour, banks anticipate next-period liquidity needs and accumulate reserves in advance.

One-week loans and longer maturities support the argument that banks attempt to answer the reserve requirement problem on the first day of the maintenance period. On average one-week loans are considerably larger in size on the first day, whereas the seasonal pattern is not observed for longer maturities. We suspect that after the first day of the maintenance period banks fulfill their reserve requirements only marginally, and then only when they face unexpected liquidity shocks requiring larger balances at the central bank account. Trading on the remaining days might stem mainly from cash management issues, such as the need not to deviate from the minimum balance target or to meet any overdrafts at the central bank. We could then hypothesize that, due to a quasi-contemporaneous reserve maintenance system, banks target the minimum reserve requirements at the onset of the reserve-holding period, or even before, borrowing at value date before the last period ends.

3.3. Interest rates

There are two important issues relating to interest rates behaviour. One is a known calendar effect, according to which interest rates might exhibit variations depending on the day of the week or reserve maintenance period. Authors report overnight interest rates exhibit a U-shaped pattern over the reserve maintenance period, which makes funds on different days of the reserve period not perfect substitutes for minimum reserve purposes. Evidence is contrary to rational expectations theories and might signal market anomalies, such as transaction costs and credit rationing. The other effect, not mentioned in literature, is a different time pattern observed between outright and value date loans. Comparing trades of equal maturities, we find for very short maturities that interest rates of same day settlement loans are usually smaller than the corresponding value date counterparts. In fact, value date loans with maturity less than one-week have larger interest rates rather than if they are settled overnight. Interestingly, the relationship reverses for longer maturities.

a. <u>Outright and value date interest rates</u>

We first look at the interest rate characteristics of outright and value date loans, in order to find whether market participants have a differential pricing behaviour for each type of loan. We compared trades of identical maturity on the value date, i.e. the date when funds were due to clear; and secondly, we used the trading day alternatively. The former tests the rates on funds clearing on the same day – i.e., funds originating in both outright loans and value date loans. Should interest rates be equal, and it would not make any difference contracting outright or deferred value date loans. Table 3.6 to Table 3.9 report results.

Table 3.6 – Outright versus value-date rates: observations grouped by value date.

	Num. Obs.	Outright Loans, percentiles				Value-date Loans, percentiles			
		5%	50%	95%	Mean σ	5%	50%	95%	Mean σ
1 Day	1332	4.237	7.533	11.909	7.752	4.279	7.536	12.010	7.828
Confidence Intervals:		[4.05 ,4.29]	[7.43 ,7.93]	[11.74 ,12.11]	2.744	[4.08 ,4.37]	[7.45 ,7.98]	[11.80 ,12.32]	2.852
1 Week	1234	4.280	7.581	11.942	7.802	4.350	7.468	12.000	7.838
Confidence Intervals:		[4.01, 4.38]	[7.45, 7.97]	[11.76, 12.15]	2.729	[4.00, 4.41]	[7.39, 7.84]	[11.75, 12.36]	2.714
2 Weeks	534	4.288	8.905	12.050	8.446	4.340	8.887	12.115	8.405
Confidence Intervals:		[3.88, 4.45]	[8.78, 9.04]	[11.80, 12.26]	2.596	[3.87, 4.42]	[8.80, 9.01]	[11.76, 12.50]	2.576
1 Month	1010	4.210	8.871	12.387	8.344	4.161	8.857	12.352	8.288
Confidence Intervals:		[4.00, 4.42]	[8.47, 9.00]	[12.00, 12.93]	2.802	[3.98, 4.40]	[8.48, 8.99]	[11.95, 12.85]	2.798
3 Months	721	4.301	7.875	11.925	8.015	4.251	7.789	11.814	7.967
Confidence Intervals:		[3.94, 4.33]	[7.37, 8.31]	[11.63, 12.13]	2.687	[3.92, 4.32]	[7.35, 8.35]	[11.60, 11.99]	2.656
6 Months	205	4.236	9.500	12.750	8.831	4.212	9.525	12.569	8.752
Confidence Intervals:		[3.97, 4.51]	[9.06, 10.00]	[12.04, 13.00]	2.615	[3.93, 4.39]	[8.89, 9.88]	[11.72, 13.00]	2.572
1 Year	28	4.041	8.625	11.638	8.038	3.958	8.615	11.602	7.989
Confidence Intervals:		[3.91, 4.41]	[5.39, 10.48]	[10.96, 11.75]	2.820	[3.80, 4.41]	[5.31, 10.47]	[10.71, 11.69]	2.800

The statistics have been estimated on the date the flow takes place, i.e., value date. First, classified loans in outright and deferred value date loans. Secondly, we weighted averaged each interest rate every day. Thirdly, we used only those days for which interest rates of similar maturity existed. Finally, interest rates were compared for trades settling on the same date but negotiated on different trading days. Because the percentiles have been computed for overlapping observations only, i.e., for those days where a pair outright/ value-date trade of same maturity could be found, the number decreases as we move to longer maturities. There are 1332 trading days after 12 July 1993.

Table 3.7 – Outright versus value-date rates: observations grouped by trade date.

	Num. Obs.	Outright Loans, percentiles 5%	50%	95%	Mean σ	Value-date Loans, percentiles 5%	50%	95%	Mean σ
1 Day	1333	4.237	7.546	11.902	7.762	4.277	7.553	12.010	7.839
	Confidence Intervals:	[4.05, 4.29]	[7.44, 7.97]	[11.74, 12.09]	2.750	[4.01, 4.36]	[7.45, 7.97]	[4.01, 4.36]	2.890
1 Week	1241	4.291	7.641	11.967	7.811	4.378	7.543	12.099	7.849
	Confidence Intervals:	[4.01, 4.38]	[7.45, 7.99]	[11.77, 12.20]	2.657	[4.00, 4.42]	[7.44, 8.00]	[11.79, 12.48]	2.718
2 Weeks	513	4.400	8.933	12.113	8.503	4.400	8.900	12.163	8.469
	Confidence Intervals:	[3.98, 4.46]	[8.81, 9.09]	[11.86, 12.38]	2.554	[3.98, 4.45]	[8.81, 9.03]	[11.80, 12.50]	2.569
1 Month	1010	4.236	8.878	12.469	8.350	4.133	8.862	12.413	8.303
	Confidence Intervals:	[4.00, 4.43]	[8.49, 9.01]	[12.08, 12.88]	2.805	[3.99, 4.39]	[8.48, 8.98]	[11.98, 13.00]	2.830
3 Months	735	4.310	8.000	11.875	8.075	4.267	7.920	11.792	8.013
	Confidence Intervals:	[3.96, 4.33]	[7.41, 8.77]	[11.63, 12.00]	2.679	[3.87, 4.32]	[7.36, 8.71]	[11.56, 11.99]	2.649
6 Months	197	4.277	9.500	12.202	8.680	4.217	9.375	11.54	8.588
	Confidence Intervals:	[4.21, 4.56]	[8.63, 9.92]	[11.25, 13.00]	2.519	[4.15, 4.30]	[8.47, 9.68]	[11.13, 12.82]	2.496
1 Year	29	3.695	7.150	11.969	7.455	3.700	7.150	11.921	7.387
	Confidence Intervals:	[3.50, 4.16]	[5.18, 10.08]	[10.80, 12.06]	2.920	[3.60, 4.07]	[5.09, 10.20]	[10.61, 11.97]	2.909

The statistics have been estimated on the trading date. First, classified loans in outright and deferred value date loans. Secondly, we weighted averaged each interest rate every day. Thirdly, we used only those days for which interest rates of similar maturity existed. Finally, interest rates were compared for loans trading on the same date but settling on different trading days, i.e., with different value date. Because the percentiles have been computed for overlapping observations only, i.e., for those days where a pair outright/ value-date trade of same maturity could be found, the number decreases as we move to longer maturities. There are 1332 trading days after 12 July 1993.

Overnight loans, clearing on the trade date itself have less volatile interest rates than the corresponding loans trading at value-date. Therefore, one-day loans might have different data generating processes, depending on whether they are settled overnight or at value date. The same is not true for longer maturities, as same maturity loans clearing on the same calendar date but negotiated on different days have similar interest rate distributions. This feature has implications on the interest rate modelling procedure we choose. Hence, we assume that loans with one-day maturity can be split into two different interest rates processes: overnight (loans clearing on the same day of trading) and tom/next (loans negotiated today but clearing the next working days)[12]. The remaining cases are assumed without loss of generality to share a single interest rate series, irrespective of when the flows of funds are cleared[13].

Table 3.8 reports pairwise tests of equal means for outright and value-date rates on the day of clearing funds, i.e., on value date, and on the transaction date. At first sight, outright and value-date overnight and beyond 1-month rates seem to be driven by different generating processes. Considering 1 and 2-week rates, there is evidence of a mean difference different from zero, but a less than 4 basis points spread attaches little important to this figure. Differences for longer maturities may stem from loan characteristics, as value date loans have longer maturities than outright trades within the same category. Also, maturity is more volatile for value date loans than for outright loans, which could explain why tests on interest rates fail to reject the null hypothesis that the mean interest rate difference is zero for maturities above one week[14]. In sum, overnight trades feature the largest and statistically most significant spread, close to 8 basis points.

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[12] Tom-next and spot-next loans are grouped under the same category, which we label tom-next as tom-next loans are dominant.

[13] We can take interest rates on clearing date, instead of trading date. This has no result implications, though it changes the time-position of date-valued loans.

[14] On average maturities are 2 days longer, with standard deviations ranging from 6 to 12 days for maturities between 1 and 6 months. One-week date value loans are almost two days longer than outright loans, and with standard deviation of 2 days. Two-weeks loans share the same characteristics whether they are date value or outright trades.

Interestingly, we also observe a spread reversion between outright and value date loans for maturities above one week, as loans contracted at date value show lower interest rates as compared to outright trades, but given the above discussion we do discard this result. Nevertheless, it is important to notice that banks are willing to pay a premium on the shortest-term value date loans, which might be explained by risk aversion. As we suggested before, banks are willing to secure liquidity just before the end of the reserve-holding period, as to avoid higher interest rates at the end of the holding period or having to borrow from the central bank at a penalty.

Table 3.8 – Pairwise tests of equal means for outright and value-date trades

	Pairwise test of equal mean interest rates …									
	…on settlement day					…on trading day				
	Num. Obs.	Mean rate of outright trades	Mean rate of value-date trades	Mean difference	t-statistic	Num. Obs.	Mean rate for outright trades	Mean rate for value-date trades	Mean difference	t-statistic
1 Day	1332	7.752	7.828	−.076	−3.12 **	1333	7.762	7.839	−.077	−7.16 **
1 Week	1234	7.802	7.838	−.036	−2.30 *	1241	7.811	7.849	−.038	−3.57 **
2 Weeks	534	8.447	8.406	+.041	2.18 *	513	8.502	8.469	+.034	+3.29 **
1 Month	1010	8.344	8.288	+.058	4.81 **	1010	8.350	8.302	+.048	+6.81 **
3 Months	721	8.015	7.967	+.048	3.68 **	735	8.075	8.013	+.063	+5.04 **
6 Months	205	8.831	8.751	+.079	3.44 **	197	8.680	8.588	+.092	5.11 **
1 Year	28	8.038	7.989	+.050	1.32	29	7.455	7.387	+.067	1.97

Coefficients significantly different from zero at the one percent (five percent) level are indicated by ** (*). Tests are applied to the period after 12 July 1993, when the new market was created. Results do not change much when we restrict the analysis to the interquartile range. The mean difference vector, for the various maturities becomes [i] on the clearing day: [-.043**, -.009*, +.032**, +.068**, +.049**, n.a., n.a.]; and on the trading day [-.036**, +.000, +.038**, +.071**, +.060**, n.a., n.a.]. Coefficients are still significantly different from zero.

As to gauge the accuracy of the proposed approach, we decomposed each interest rate series by day of the week, and reserve holding periods and searched for any departure from the proposed behaviour, such as we could not interpret results as reflecting day of the week or end of the reserve holding period effects.

Previous results are reinforced, as both outright and value-date loans show a similar pattern[15]. Table 3.9 display results using the clearing date only[16].

Table 3.9 – Pairwise tests of equal means for outright and value-date trades: decomposition by day of the reserve holding period

	5 working days reserve holding periods					All reserve holding periods			
	First day	2	3	4	5	–3	–2	–1	Last day
1 Day	–.055 **	–.091 **	–.082 **	–.078 **	–.037 *	–.034	–.035	–.181	–.114
1 Week	–.040 *	–.086 **	–.072 *	–.079 *	+.041	–.064 **	+.007	–.068 *	–.023
2 Weeks	+.000	+.013	+.077	+.020	+.091	+.004	+.098	+.088	+.051
1 Month	+.033	–.025	+.035	+.020	+.164 **	+.036	+.068 *	+.029	+.110 **
3 Months	+.052	+.010	+.061	+.039	+.064 *	+.053 *	+.052 *	+.057	+.033
6 Months	+.007	+.061	+.105	+.175	+.215 *	+.467	+.145 *	+.145 *	+.118 **

Figures are the mean difference between outright and value date interest rates. Comparisons are made on the clearing date, i.e., the date funds are transferred from the lender to the borrower. Coefficients significantly different from zero at the one percent (five percent) level are indicated by **(*). Tests are applied to the period after 12 July 1993, when the new market was created. Reserve holding periods are of different length We compared each data series –same day settlement and value date loans – with the joint data series created according to the methodology mentioned in the text. Results are unaltered.

Mean outright and value date rates in the last and previous to the last day of the reserve-holding period are globally statistically not different, while the remaining days show a distinctive behaviour between short and long maturities. We find that only one-day loans have persistently different interest rates accordingly to whether they are value date or outright trades. One-week loans

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[15] Two-sample Kolmogorov-Smirnov tests of the equality of distributions do not allow rejection of the null that distributions for outright and value-date rates are equal. Because equality may hide a similar interest rate pattern though lagged by the number of days between trade date and clearing of funds date, we performed pairwise tests of equal means for outright and value-date interest rates also. Results still support the hypothesis that processes generating interest rates are identical in both situations.

[16] Results using the date of trade are similar and, therefore, leaving conclusions unaltered.

are also significant, but to a lesser extent, whereas the remaining maturities show no evidence of any difference. Interest rate spreads between outright and value date loans preserve the aggregate properties, and it is still negative for one-day and one-week loans.

This suggests that when banks start hoarding funds early at the beginning of the reserve holding period, they drive value date interest rates above the corresponding clearing day rates for outright settlement. This is a puzzling result, as it suggests banks short of funds would do better entering in outright contracts rather then buying funds at value date. Further, if value date loans are used to hedge positions opened by other financial contracts, banks could design investment as strategies to appropriate the persistent interest rate differential between outright and value date market loans.

Given the above discussion, we assume value date and outright loans can be grouped under a single data series using the date of trade, except the very short maturity one day. This is equivalent to assuming above one-week interest rates processes for value date and outright trades to be identical, as if all these trades were cleared overnight. Loans with one-day maturity are thus subdivided into overnight and tom-next classes to capture the different dynamics and motivations driving trading. The spot-next loans are similar to tom-next, and are merged under the same series.

b. Reserve holding period effects on interest rates

Empirical literature recognizes calendar effects on interbank overnight rates. Hamilton (1996), Furfine (2000) and others report the Fed funds overnight rate displays a U-shaped behaviour along the reserve maintenance period. Previous tables discussing interest rates of different time horizons offer a first approximation to this problem in the Portuguese interbank money market, and suggest this behaviour might not be present.

In order to analyse day-of-the-week and reserve-holding-period effects, we computed the interest rate spread between each interest rate and the target, which is disclosed regularly by The Banco de Portugal. Results for reserve holding period effects are presented in Table 3.10. We controlled for day-of-the-week and end of the month effects.[17] Changes observed in target definition and monetary policy operations seem, however, to have a positive impact on results. We split the sample in two, corresponding to the institutional changes introduced in the interbank money market after value date loans were recorded in SISTEM. We do not find evidence of a significant shift in banks' behaviour during regimes 3 and 4, apart from a downward trend in interest rates and spreads. Also, regimes 1 and 2 bear a resemblance as related to banks' behaviour across the days of the reserve-holding period.

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[17] Results are not significant and, therefore not reported.

Table 3.10 – Day of the reserve holding period effects

Panel a. Regimes 1 and 2: 1 January 1989 – 11 July 1993

	Days of the reserve-holding-period						Target	p-value
	First day	2	3	−2	−1	Last day		
Over-night	0.980 **	0.656 **	0.633 *	−0.173	−0.061	−0.468	−1.396	0.012
Standard error	0.53	0.51	0.45	0.44	0.51	0.53	0.46	
1-week	0.648	0.457	0.458	−0.024	0.287	0.317	−0.964	0.602
Standard error	0.40	0.38	0.34	0.34	0.38	0.40	0.35	
2-weeks	0.449 +	0.120	0.211	−0.080	−0.161	0.020	−0.348	0.199
Standard error	0.29	0.27	0.24	0.23	0.28	0.29	0.25	
1-month	−0.258	−0.137	−0.101	−0.193	−0.276	−0.312	0.574	0.045
Standard error	0.21	0.20	0.17	0.17	0.20	0.21	0.18	
3-months	−0.460	−0.570	−0.249	−0.514	−0.706	−0.764	1.122	0.000
Standard error	0.29	0.27	0.24	0.23	0.27	0.28	0.24	
6-months	−1.235	−1.312	−0.767	−0.779	−1.181	−1.228	1.956	0.000
Standard error	0.36	0.36	0.31	0.31	0.35	0.37	0.32	

Panel b. Regime 4: 10 May 1995 – 31 December 1998

	Days of the reserve-holding-period						Target	p-value
	First day	2	3	−2	−1	Last day		
Over-night	−0.031 **	−0.046 **	−0.029 **	−0.075 +	−0.102	−0.123	−0.749	0.000
Standard error	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
Tom-next	−0.046	−0.059	−0.035	−0.071	−0.093 *	−0.039	−0.730	0.007
Standard error	0.03	0.03	0.02	0.02	0.03	0.03	0.03	
1-week	−0.084	−0.092	−0.055	−0.076	−0.090	−0.091	−0.685	0.011
Standard error	0.03	0.03	0.02	0.02	0.03	0.03	0.03	
2-weeks	−0.141	−0.112	−0.095	−0.062 *	−0.109	−0.130	−0.607	0.002
Standard error	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
1-month	−0.163	−0.163	−0.111	−0.080 **	−0.131	−0.157	−0.564	0.000
Standard error	0.03	0.03	0.02	0.02	0.03	0.03	0.03	
3-months	−0.149	−0.133	−0.096	−0.086	−0.109	−0.141	−0.624	0.006
Standard error	0.04	0.04	0.03	0.03	0.04	0.04	0.03	
6-months	−0.157	−0.175	−0.113	−0.128	−0.154	−0.198	−0.657	0.206
Standard error	0.08	0.07	0.06	0.06	0.07	0.08	0.07	

The spread is computed as the difference between each interest rate and the target set by The Banco de Portugal. The target is taken as the mi-point between bid and offer rates, except for regimes 1 and 2 when the interest rate was only indicative. Given arbitrage considerations, the banks cannot make profits from borrowing in the interbank market from other banks and selling funds to the central bank. Money market restrictions and transaction costs eroded any arbitrage opportunity. The target has changed over time and not always The Banco de Portugal has been willing to buy and sell funds at the target rate. Thus, we accounted for periods of foreign exchange turmoil whenever The Banco de Portugal suspended borrowing and lending in the interbank market and left rates to fluctuate freely. Results for those periods are under the column "Target", which is a dummy variable taking value one when The Banco de Portugal is willing to buy and sell funds at the pre-announced rates. Regime shifts occur as the central bank started targeting interest rate stability at the longer end of the maturity spectrum – anchoring the target to the Treasury bills market – and, eventually, moved to the shortest end of the interbank money market yield curve – open market and marginal deposit and lending facilities were introduced. In general, monetary policy regimes, identified in chapter 3, change with moving monetary policy targets. We do not find a different behaviour when we take two broad regimes: one before 12 July 1993 and the other afterwards. Yet, results for the post July period are restricted to regime 4 only, as they offer more clear cut conclusions. Each day is tested against the last day of the reserve holding period: a mean difference test for each day mean is produced and results are presented under the respective column. The one-tailed test checks whether the value of each day loan is significantly larger or smaller than the last day. Coefficients significantly different from zero at the one percent (five percent, ten percent) level are indicated by **(*,+). The last column "p-value" is a likelihood ratio test of the restriction that all coefficients excepting target are equal.

The episodes of exchange rate turmoil have been isolated. Mostly, we took special care identifying those periods when The Banco de Portugal withdrawn from buying and selling funds leaving interest rates to fluctuate freely. Usually, those events correspond to periods of high interest rates both in levels and volatility, and spreads were assumed to be equal to previous day[18].

Contrary to empirical evidence in the United States Federal funds market we find that, at least for the most recent period, overnight interest rates are higher at the beginning of the reserve holding period, and decrease as we approach the final day, when the average reserve deposit for each bank is assessed. For the remaining maturities we do not find significant calendar effects, except for two-weeks and one-week loans, which show higher rates two days before the end of reserve period. This supports our previous argument that banks attempt to secure funds very early at the beginning of the reserve-holding period and, if possible, they start hoarding before last period ends buying funds that are delivered on the first day of next period. For regimes 1 and 2, the decreasing interest rate effect is observed for over-night rates only, and no significant divergence between interest rates on a given day of the reserve-holding period and the last day is observed. The results could also signal that

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[18] This assumption seems reasonable as we observe that The Banco de Portugal resumes interest rates levels after turbulence comes to an end. Therefore, suspension is just a mechanism as not to work out as lender of last resort and mitigate any speculators from making profit arbitraging the domestic and the euro market of Escudo.

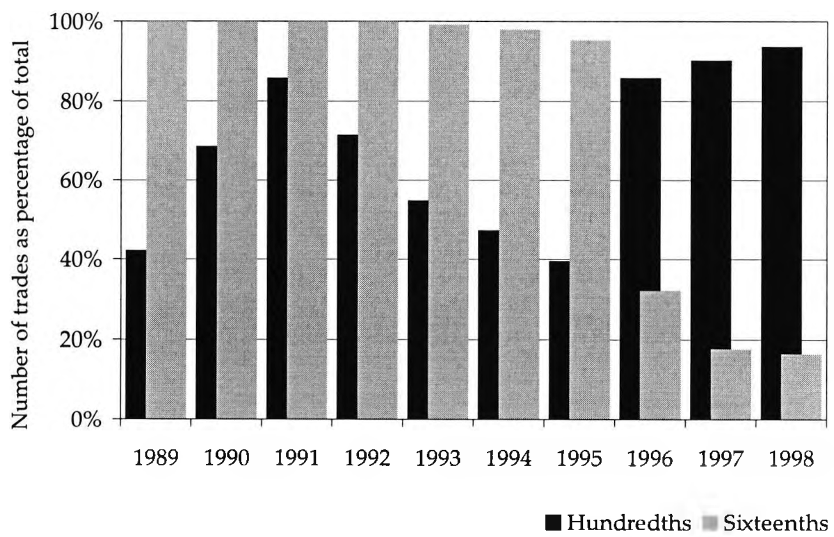
banks over-accumulate funds over the reserve holding period, which they seek to sell when they are pretty sure those are needed. This reinforces a previous argument of banks strongly risk aversion to liquidity and interest rate shocks.

3.4. Market trading standards

a. <u>Tick size</u>

Aggregate data shows that interest rates are set in one eights for most trades, although banks seem to use a finer sixteenth standard. However when analysing pricing behaviour on a yearly basis we find a changing pattern. In 1996 banks switched pricing interbank loans' from sixteenths to hundredths.

Figure 3.3 – Overnight loans pricing: tick measure



The bars represent the number of overnight trades as percentage of the total priced accordingly to each measure considered: hundredths and sixteenths. Notice the bars do add more than 100%, because there are some hundredths multiples of sixteenths. We performed the same analysis using trading value instead, and results remained unchanged. Further, we extended the analysis to other maturities, and exactly the same pattern was found for each and all of them.

Figure 3.3 emphasises the regime shift, showing the percentage of overnight loans that falls on each category tilted in 1996. The pricing shift reflects a reduction in the cost of trading, and might also result from banks adapting to an environment with lower interest rates, where smaller ticks are required as to keep the market highly liquid[19]. Further, odd pricing in our database is related to odd trade size, which might be related to particular hedging practices, such as the use of the interbank market do cover risks associated to assets for which a derivatives markets did not exist or was not sufficiently liquid, and the alternatives were simply too costly.

b. Trade size

One billion PTE trades are predominant, followed by .5 and 2 billion PTE.[20] Trade sizes are mostly in multiples of 0.5 billion PTE. However, transactions bellow 0.5 billion PTE are in 100 million multiples, as it can be seen in Table 3.11.[21]

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[19] Notice that a smaller tick, i.e., minimum price change, allows smaller spreads and decreases transactions costs, which in turn increase the number of arbitrage opportunities that otherwise would be ruled out simply because transaction costs would be too high.

[20] There are more than 33,000 trades settling overnight with face value of 1 billion PTE each, and 10,000 trades with deferred settlement with same face value.

[21] There are also some odd figures, but they are almost irrelevant. Size buckets account for roughly 70% of total unsecured interbank loans in 1998, while in the early 90s this figure closed 90%.

Table 3.11 – Interbank trade size buckets

Panel a. Percentage trades for which trade date and value date are equal.

		Trade size buckets, billion PTE										
		0.1	**0.2**	**0.3**	**0.4**	**0.5**	**1.0**	**1.5**	**2.0**	**3.0**	**4.0**	**5.0**
1989		7%	11%	11%	5%	**25%**	**16%**	4%	6%	2%	1%	1%
	88%	560	875	870	408	1.905	1.238	287	436	148	49	82
1990		6%	8%	9%	4%	**27%**	**22%**	4%	6%	2%	1%	1%
	91%	775	1.037	1.089	516	3.349	2.696	542	725	268	85	127
1991		4%	6%	7%	4%	**31%**	**25%**	4%	7%	2%	1%	1%
	92%	687	1.055	1.102	582	5.189	4.221	631	1.142	379	97	223
1992		4%	5%	6%	4%	**29%**	**27%**	4%	7%	3%	1%	2%
	92%	895	1.129	1.315	756	6.043	5.633	845	1.558	545	173	325
1993		3%	4%	4%	3%	**17%**	**32%**	4%	11%	5%	1%	3%
	87%	428	626	649	474	2.543	4.872	600	1.728	720	171	504
1994		3%	4%	4%	3%	11%	**28%**	5%	**14%**	6%	1%	5%
	84%	364	455	460	416	1.487	3.622	606	1.856	790	188	618
1995		4%	3%	4%	3%	12%	**27%**	6%	**13%**	6%	2%	4%
	83%	477	405	485	354	1.529	3.355	786	1.660	765	209	471
1996		3%	2%	3%	2%	11%	**22%**	7%	**13%**	7%	3%	5%
	78%	360	310	371	320	1.432	2.948	950	1.816	1.008	381	686
1997		2%	2%	2%	2%	8%	**20%**	6%	**14%**	8%	3%	6%
	73%	216	246	282	248	1.026	2.493	795	1.778	953	355	756
1998		1%	2%	1%	1%	5%	**16%**	6%	**14%**	8%	3%	8%
	65%	170	190	184	139	579	2.069	731	1.805	999	404	996
TOTAL		4%	5%	5%	3%	18%	**24%**	5%	**11%**	5%	2%	3%

Panel b. Percentage trades with value date deferred from trade date

		Trade size buckets, billion PTE										
		0.1	**0.2**	**0.3**	**0.4**	**0.5**	**1.0**	**1.5**	**2.0**	**3.0**	**4.0**	**5.0**
1993		2%	2%	2%	1%	15%	**37%**	4%	**16%**	7%	1%	5%
	92%	39	42	48	23	304	731	80	312	135	28	105
1994		2%	1%	2%	1%	12%	**43%**	4%	**16%**	7%	1%	6%
	93%	94	61	75	52	585	2.104	179	786	334	66	272
1995		2%	1%	2%	1%	9%	**37%**	4%	**17%**	8%	2%	7%
	91%	107	71	84	39	517	2.038	216	941	454	114	402
1996		2%	1%	1%	1%	6%	**24%**	6%	**18%**	10%	4%	8%
	81%	140	53	85	51	457	1.818	445	1.350	752	269	626
1997		2%	1%	1%	1%	8%	**21%**	7%	**16%**	9%	3%	9%
	77%	180	71	119	72	775	2.021	689	1.543	904	255	836
1998		1%	1%	1%	1%	7%	**16%**	6%	**16%**	10%	4%	11%
	74%	43	78	74	71	570	1.335	496	1.334	829	298	937
TOTAL		2%	1%	1%	1%	8%	**27%**	6%	**17%**	9%	3%	8%

Emphasis added to the two most relevant trade sizes. Shaded values are number of observations.

Two additional features regarding interbank market trading are relevant. Firstly, trade size has been increasing steadily over the sampling period and, secondly, interbank loans with deferred settlement are similar in size as compared to those for which value date and trade date are equal.

Clearly, trade size increases after 1994, as transition can be inferred from Table 3.11. Two billion loans became more relevant: 14% of the total number of transactions, against 6% in 1989. Transactions with face value 1 billion PTE show a declining trend both in relative and absolute terms. They dropped to about half since 1993. Comparison of panel a. and panel b in Table 3.11 shows that transactions are identically spaced irrespective of the value date. A steady increase in trade size is suggested by the decreasing number of trades in percentage of total on each of the panels of Table 3.11 above. We t-tested whether the two distributions have the same mean, assuming observations are drawn out of the same population. Results suggest that there may be a difference in these two populations. Therefore, there must be some different reasons why banks use one market segment or another.

4. Micro-mechanics of Interbank Money Markets

In this second part of the chapter we describe how do banks effectively act in the interbank money market its implications for liquidity management and monetary policy. We describe individual and bank group behaviour, as to show the institutional features of this market while attempting to find discernible patterns, such as preferential relationship lending and market making behaviour.

Methodologically, we split the sample in four categories of banks, ranked according to their asset size: *first*, the 'large' group comprising the 5 largest institutions; *second*, the next 5 under 'medium' sized banks; *third*, the 'small' group with those ranked between 11th and 20th; and *fourth*, the remaining banks not individually identified included in the 'Others' group.

4.1. Market participation rates

a. Overall interbank money market

Regarding its the main function, i.e. the provision of a mechanism for reserve management, banks' participation in the interbank money market is the most relevant statistic. Results are summarized in Table 3.12 and are in contrast with those reported by Furfine (1999), who finds larger banks buying of funds more often than smaller banks. [22] [23] We find the larger banks being more active in the interbank market as compared to the smaller ones. Global statistics show that each year the top 5 banks are lenders on 84.4% of days on average, while the 10 smaller banks in our database sell funds on 57.2% of days

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[22] We present the post 12th July 1993 results only, as they are the most relevant for the purposes of analysing the interbank money market structure. Prior to this date, results are heavily influenced by the monetary policy stance.

[23] It is worth to mention that our results refer to different loan maturities, covering interbank money market transactions that are absent in Furfine (1999) study. To cross check our results, we computed monthly average participation rates and essayed different time horizons to breakdown the data. Results remained however unchanged, except for the 1993 period when a slight change in behaviour was noticed. We found a less intense selling activity for large banks for the later period, which is consistent to our previous discussion and the stance of monetary policy.

only[24]. Yet they buy funds less frequently. Results change after 12th July 1993 and, though larger banks turn more active buying funds – participation rates shift from 40.2% to 71.1% of days – they remain sellers for most of the time – 89.7% of days.

The daily number of trades also decreases with bank's size, as does the transaction value per bank. Large banks show larger average trading values than smaller banks, suggesting that large banks do usually trade within group. Also, average loan size is larger when large banks are buying funds then when they are selling. This can be seen as supporting the hypothesis that small banks are usually buyers of funds, whom demand smaller amounts of funds as compared to large banks. When large banks need funding they are more likely to buy funds from large banks than from small banks. These results can be explained after considering banking structure in Portugal. Larger banks have a wide deposit base and are more able to fund their activities though an extensive branch network. Smaller banks lacking a wide deposit base finance their balance sheet with short-term liabilities through the interbank money market. Also, as they do not hold a well-diversified portfolio, the interbank market is used as an alternative insurance policy to holding large amount of excess reserves.

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[24] The participation figures reported are calculated yearly for each bank. Banks are then sorted by asset size. The portfolio is rearranged every year using disclosed balance sheet figures for each bank. Thus, composition of each category changes from year to year.

Table 3.12 – Banks' participation in the interbank market: 12/07/93 to 31/12/98

	Average Net Asset Value [a]	Yearly participation Rates		Average number of daily trades		Average bank trade size [a]	Average trading value daily [a]	
	billion PTE	Average	Median	per bank	within group	million PTE	per bank	Within group
BUY								
Top 5 banks	1 779	71.1%	77.9%	5.0	18.5	1 844.0	9 187.9	34 185.1
5-10	711	66.0%	73.2%	4.2	15.0	1 679.0	6 991.3	25 243.7
10-20	208	60.7%	70.1%	3.3	19.1	1 169.9	3 836.0	22 374.8
All the others	64				49.1	778.3		38 200.7
SELL								
Top 5	1 779	89.7%	94.4%	7.2	32.0	1 728.1	12 414.5	55 382.7
5-10	711	67.6%	73.5%	3.5	13.3	1 288.3	4 494.3	17 080.8
10-20	208	63.0%	64.0%	2.7	16.3	1 170.0	3 138.1	19 024.0
All the others	64				40.2	709.8		28 536.7

[a] – Values are reported in real terms, obtained after deflating nominal values using the CPI index and are reported relative to the 1989 price level, as mentioned in chapter 3.

Four groups were obtained after distributing all the banks according to the size of assets: 'Top 5' comprises the largest 5 banks in Portugal; '5–10' includes the next 5 largest banks; '10–20' are the remaining banks we are able to identify in our database; and "All the others" is a residual category where are all the remaining banks. Trade details of this latter category are coded and do not allow individual identification of the parties involved. The composition of each group was rebalanced yearly using asset size disclosed in banks' annual reports. We accounted for mergers and acquisitions in the banking industry, and new entrants. The number of banks underlying the calculations ranges between 37 and 53. The dataset comprises trade details for 20 identified banks –distributed by the first three groups – for the whole period after 1992. Nevertheless, in late 1998 two banks from the 5–10 group merged with a bank from the Top 5, and have been dropped from the sample afterwards. This is the only merger affecting our database since 1993. Also, 2 banks identified in our database did not exist before 1992. 'Yearly participation rates' were computed yearly for each bank dividing the number of days on which the bank traded – buying or selling funds – by the number of trading days. Median and average statistics relate to these values. 'Average number of daily trades' is the number of trades per day averaged for the whole period. 'Average bank trade' is the average transaction amount obtained dividing banks' traded amount by the number of trades on a given day, and averaging the figures obtained afterwards. 'Average trading value daily' is the value of daily trading for each bank or group averaged for the whole sampling period. Days when banks do no trade are excluded; i.e., they are not treated as meaning a zero transaction value. Reported statistics are significant at the 1% level.

The willingness of large banks to sell funds is also reflected on the daily average selling volume, which is 60% larger than buying. The reverse occurs for the small banks group, and though its elements are equally active on both market legs there is a remarkable difference the daily amount of funds bough on sold. The 'all the others' category is responsible for buying 30% of total volume turnover while selling 40% of it. They are selling counterparts in 60% of trades, and buyers in 40%, suggesting small banks are more prudent regarding reserve management, as they might hold larger amounts of excess reserves, which they are willing to sell to larger banks.

b. Overnight market participation rates

When we take a narrower perspective and focus on overnight loans only, evidence shows participation rates more than double over the 1989–1998 period. In 1998, banks were buying and selling funds on approximately 50% of days, whereas this figure was little above 20% in 1989[25]. However, when comparing results with the global market participation shown in Table 3.12, we find decreasing Banks' participation rates, notably before 1993[26]. Table 3.13 presents the figures for overnight loans in the interbank market after 12 July 1993.

Comparing overnight results with global market figures, banks ranked between the 6th and 10th position, inclusive, change from sellers into buyers of funds for most of the time, in a behaviour that is consistent with Furfine (1999). The small banks seem to be more active on selling overnight funds than for other maturities, as the average number of days buying funds is less than the corresponding days of selling, while the daily transaction volume does not differ

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[25] Although reported figures respect to 20 banks only, the dataset covers about 80% of total interbank money market turnover, making results highly representative of industry's behaviour.

[26] The low participation rates before July 1993 in the overnight segment is due to the excess liquidity in the banking system, and to the long term open market operations of The Banco de Portugal to drain excess reserves from the economy and bring down inflation and interest rates.

substantially. Sell trades concentrate close to the end of the reserve period, when banks know for certain how much excess liquidity they hold, while prior to that and being averse to unexpected liquidity and interest rate shocks they refrain selling from funds. The Top 5 banks persist as sellers of central bank funds for most time of the year, though the imbalance buying and selling days is reduced as compared to overall market figures. They buy and sell overnight funds on 63.2% and 71.3% of days on average, respectively.

Table 3.13 – Banks' participation in the overnight interbank market: 12/07/93 to 31/12/98

	Average Net Asset Value [a]	Yearly participation Rates		Average number of daily trades		Average trade size [a]	Average trading value daily [a]	
	billion PTE	Average	Median	per bank	within group	million PTE	per bank	Within group
BUY								
Top 5 banks	1 779	63.2%	67.6%	3.5	11.5	1 604.1	6 578.3	18 376.8
5-10	711	58.7%	65.1%	3.2	9.7	1 417.3	4 972.8	13 554.9
10-20	208	52.2%	59.2%	2.4	11.8	1 052.5	2 892.4	12 393.8
All the others	64				25.2	768.7		19 342.4
SELL								
Top 5		71.3%	71.9%	4.0	14.2	1 768.6	7 009.5	25 061.2
5-10		49.6%	45.9%	2.4	6.2	1 432.2	3 414.5	8 598.0
10-20		50.6%	49.0%	2.1	10.0	1 121.2	2 303.5	11 046.4
All the others					27.9	678.3		18 932.5

[a] – Values are reported in real terms, obtained after deflating nominal values using the CPI index, as mentioned in chapter 3. Check methodological notes in Table 3.12.

c. <u>Banks' preferences regarding loan maturity</u>

We have noticed before in section 3 that interest rates exhibit a predictable pattern along the reserve holding period cycle. We found that for the maturities up to 2-weeks, interest rates and trading volume spike on the first day of the maintenance period and plunge on the last day. This behaviour is apparently related to banks' risk aversion as they protect themselves from adverse liquidity and interest rate shocks. We want to know whether there is any different behaviour regarding banks' size. In doing so, we produced the daily interbank market balance sheet for each bank group, while disaggregating the data between overnight and the remaining loans. The basic idea is to capture banks' different behaviour, and describe what could be a potential different risk preference profile for each group. Results are presented in Table 3.14.

Table 3.14 – Interbank market daily balance sheet structure

	Daily trading flow		Number of banks		Number of loans		Number of counterparts	
	BUY	SELL	BUY	SELL	BUY	SELL	BUY	SELL
Top 5 banks	54.6%	52.2%	87%	86%	61%	50%	77%	76%
5-10	58.7%	51.2%	81%	63%	63%	44%	85%	84%
10-20	59.3%	67.8%	85%	81%	63%	65%	81%	89%
All the others	57.8%	66.6%	n.a.	n.a.	55%	70%	70%	86%

The 'Daily trading flow' is the average amount of trading accumulated during the day for all banks within each category. 'Number of banks' is the daily average number of banks operating in the market in each of its legs. 'Number of loans' is the average number of loans. 'Number of counterparts' is the number of different counterparts. Notice, the difference between the number of counterparts and loans occurs because banks can lend to or borrow more than once from the same institution. Values are presented as percentage of overnight loans over the total amount trades. The table reads as follows: Top 5 banks borrow 54.6% of its daily needs overnight, while lending for the same maturity is only 52.2% of total. That means that they lend relatively more for longer maturities as compared to borrowing. The other columns read similarly. Notice, that we report the loans only and we have no reason to assume borrowing (buy side) is equal to lending (sell side). On contrary, as we show on other tables, there is a tendency for banks being more heavily on one side of the balance sheet. For instance, large banks are predominantly selling funds, while the other are more often demanding funds.

The evidence supports the argument that the largest banks have a preference to borrow for overnight maturities when they are short of funds, and lend longer when they are in a surplus, whereas the small banks have a reverse behaviour. The average trade size per bank confirms the previous results, as large banks sell relatively less funds overnight than for longer maturities, whereas small sized banks are the most likely to buy the longer maturity loans. Indeed, the borrowing to lending ratio computed for large banks, considering the average amount traded, decreases from 94%, when considering overnight only, to 74% when taking the whole maturity spectrum. This increased lending is directed to smaller banks, for which the ratio change is reversed. We also report on Table 3.14 that overnight loans on the daily balance sheet are less representative on the buy side (57.8%) than on the sell side (66.6%). This, however, does not imply small banks are not net borrowers for all maturities. The only important result here is that small banks have different preferences when they are on either side of the market.

4.2. Market making and interest rate arbitrage

Usually banks are on the same leg of the market, either buying or selling, irrespective of loan maturity. Seldom we find banks doing both legs of the market, and also we do not find much evidence of banks buying and selling for the same maturity either. Table 3.15 shows that banks are simultaneously offering to buy and sell loans of same maturity on 25% of the days on average. Cocco et al. (2003) suggest this behaviour is related to relationship building in the interbank market. Accordingly, banks often buy funds they are offered by a usual lender, which they subsequently sell to other market participants. We could also hypothesize a market making behaviour for certain banks, as long as they are able to make profit on such behaviour. However the small magnitude of simultaneous borrowing and lending might just signal that banks use the interbank money market for reserve management purposes, and certain banks are on both sides for reasons related to the functioning of the payments system[27].

The results are not changed if we disaggregate data and report results by loan maturity, year, or both instead. Thought, the average number of days in which banks are simultaneously buying and selling varies according to loan maturities. Unsurprisingly, this figure is larger for shorter maturities than for larger, which we could relate to the flow of information arriving at the banks' trading desk, and the corresponding change its trading behaviour during the day, due to a sudden outflow of funds, and as long there is no persistent behaviour, we might assume there is no market making activity going on. However, as we move towards the end of the sampling period we observe for overnight loans, an increased tendency for some banks – mainly the largest ones – to increase participation on both market legs. Thought results are statistically not significant, we could interpret this as feeble evidence of certain larger banks starting to operate as market markers[28].

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[27] An intra-day overdraft at the central bank account suspends payments flows and requires the faulting bank to deposit enough funds to resume flows. As to an overdraft might be followed by a surplus, a bank might switch from borrowing into lending during the day. The inverse is also possible.

[28] This can be an important feature, mainly when we operate in an international context where small banks might not get direct access to loans from international counterparts due to insufficient credit record. A second tier market might develop such as large banks trade with each other at a larger scale and then market make central bank funds domestically. This is certainly the case when we think of an enlarged monetary union such as EU.

Table 3.15 – Percentage of days each bank buys and sells funds with the same maturity

Number of Observations	Mean	Median	Standard Deviation	Skewness	Kurtosis
191	0.2506	0.1935	.2318	.8839	2.8641

The variable shown is the percentage of days a given bank is at the same time buying and selling funds for at least one of the following maturity brackets: "overnight", "tom-next", "spot-next", "1 week", "2 weeks", "1 Month", "3 Months", "6 Months", "9 Months", "1 Year". It may happen, that on a given day a bank operates both trade legs for several maturities. The percentage of days was first computed yearly and thereafter averaged for the whole sampling period as to obtain the summary statistics presented in this table. Results are not changed if we use monthly percentages instead. The aggregate bank "OUT" has been excluded from summary statistics as not to bias results. We must stress that the aggregate "OUT" represents the rest of the banking system, covering banks not identified in our database. Not surprisingly, records show these banks buying and selling funds within the same maturity bracket daily.

When we change our perspective to analyse if banks exploit any arbitrage opportunities along the yield curve, i.e., for a given day they buy and sell funds of different maturities, the results change. Table 3.16 shows that banks choose amongst different maturities searching the best matching strategy to their needs for central bank reserve balances[29]. Significantly, on 32% of days banks simultaneously buy and sell central bank funds of different maturities. The median value is close to one quarter. Yet this issue deserves further attention.

Table 3.16 – Percentage of days each bank buys and sells funds with different maturities

Number of Observations	Mean	Median	Standard Deviation	Skewness	Kurtosis
191	0.3214	0.2400	0.2968	0. 6978	2.3688

A bank is considered to be buying and selling funds with different maturities if on a given day the amount of central bank funds bought and sold falls within different maturity brackets as explained before. The percentage of days was first computed yearly and thereafter averaged for the whole sampling period as to obtain the summary statistics presented in this table. Again, the aggregate bank "OUT" has been excluded from summary statistics as not to bias results.

29 To set up a yield curve uncovered arbitrage operation, a bank should go both long on short-term loans and short on long-term loans, or vice versa. Shall futures or forward contracts exist and the bank can hedge its position.

4.3. Sources of liquidity

Empirical literature suggests important credit rationing features in the interbank money market hindering its ability to offer complete insurance against liquidity shocks, and thus setting the central bank as a lender of last resort. Market depth and preferred trading are often analysed. We do not have data on the order book due to the fact that interbank markets are decentralized markets. However we might analyse trading counterparts and trading frequency for each group of banks, which offers a first approximation to credit rationing. We also investigate statistically significant differences between interest rates of different classes of banks.

There is another important issue regarding the sources of liquidity, which is related to the maturity of interbank loans. Indeed, banks can choose among alternatives sources of lending, and if liquidity shocks are persistent they might borrow for long term, instead of daily rolling over overnight loans. Alternatively, if they are risk averse, they might borrow for longer maturities and avoid interest rates shocks. We start our discussion explaining how banks choose amongst alternative loan applications and how this might be related to the minimum reserve requirements period

a. Loan maturity choice

We have shown before that banks are allowed to loan for different maturities, and that trading for the various maturities is not stable across days of the week. Overall, we find that for short maturities banks in general have a preference for trading at the beginning of the reserve holding period. However, we are interested in knowing whether this is a persistent behaviour across the industry, or if there are opposing views when we consider individual institutions.

Considering our grouping procedure, we essayed the average distribution of daily loans for across the reserve-holding period. Our results show that large banks are mainly active at the beginning of the reserve-holding period, while small banks become more active on the day the amount of required reserves becomes known with certainty. Also, they are more active at loans longer than overnight, while the small banks prefer trading at the shortest end of the maturity spectrum. Regarding overnight loans, it is interesting to notice that two days before the end of the period, small banks climb to a stable market share almost as equal to the 5 largest banks.

The results imply that large banks are wiling to absorb the over-night funds supplied by small banks, while reducing the amount of borrowing for other maturities. Possibly, when the next period starts, they are willing to resume lending long term to small banks. Small institutions limited ability to diversify away liquidity shocks internally, and a possible risk aversion might explain why they are often buying and selling overnight while attempting to obtain stable funds from other institutions at the same time.

Panel a. on Table 3.17 shows that small institutions are buying more long-term funds at the two extremes of the reserve-holding period. A different pattern is observed for large banks, willing to buy overnight excess funds on the day required reserves are known with certainty.[30]

When focusing on the sell side of the market, i.e., how do banks behave regarding lending, we find large banks withdrawing the market from the first to the last day of the reserve holding period across all maturities. Thus, decreasing the amount of funds they are willing to sell. On the other hand, small banks withdraw the market for longer maturities only, while keeping a fairly stable loan turnover on overnight loans irrespective of the day. However, and considering market turnover decreases along the reserve period, this might mean that small banks increase the market share when selling overnight funds. This might push interest rates down, and explain the interest rate behaviour found in overnight markets. Consequently, while the amount of overnight borrowing decreases – panel a. – lending increases in relative terms – panel b. We produced the same estimates using market shares in order to account for market fluctuations. Results are reported in Table 3.18. Overall, the relevant conclusions remain unaltered.

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[30] See chapter 3 for a discussion of the reserve requirements regime. In broad terms, the period to compute the amount of required reserves ends two days before the maintenance period. Therefore, banks cease to be concerned about uncertainty regarding minimum reserves, and might concentrate on managing liquidity shocks only.

Table 3.17 – Trading across the reserve maintenance period: 12/07/1993–31/12/1998.

Panel a. Borrowing decomposition by bank category

	Days of the reserve-holding-period						
	First day	+1	+2	−2	−1	Last day	p-value
Overnight Loans							
Top 5 banks	32.9	30.3	32.7	36.9 *	32.0	29.9	0.409
5–10	25.2	23.7	25.0	22.1	23.3	23.2	0.753
10–20	23.9	22.3	19.6 **	18.2 **	19.8 **	21.5 *	0.000
All the other	36.8	34.3	34.3	32.3 *	32.1 **	32.1 **	0.013
Loans of other maturities							
Top 5 banks	17.3	15.4	14.6	15.7	15.8	17.4	0.309
5–10	15.3	11.6 **	10.8 **	10.5 **	13.2 **	14.2 +	0.000
10–20	12.8	9.1	8.4	7.9	10.0	12.1	0.000
All the other	19.2	17.1 **	16.6 **	16.2 **	17.7 **	18.1	0.000
Ratio overnight to other							
Top 5 banks	1.90	1.97	2.24	2.35	2.03	1.72	
5–10	1.65	2.04	2.30	2.11	1.77	1.64	
10–20	1.86	2.45	2.33	2.31	1.99	1.78	
All the other	1.92	2.01	2.07	1.99	1.82	1.77	

Panel b. Lending decomposition by bank category

	Days of the reserve-holding-period						
	First day	+1	+2	−2	−1	Last day	p-value
Overnight Loans							
Top 5 banks	50.8	43.6 **	39.6 **	38.3 **	40.8 **	41.7	0.000
5–10	15.2	15.2	14.1	16.6	15.4	14.5	0.915
10–20	19.3	18.9	20.9	21.9	19.1	18.6	0.399
All the other	33.4	33.1	36.5	33.7	32.6	31.6	0.600
Loans of other maturities							
Top 5 banks	32.2	24.9 **	23.5 **	21.8 **	29.6	29.2	0.000
5–10	10.7	8.4 **	7.9 **	8.5 *	7.8 **	9.7	0.000
10–20	9.3	7.8 +	7.8	8.6	8.0	11.0 *	0.000
All the other	10.2	9.5	8.9	9.1	8.6 **	8.4 **	0.000
Ratio overnight to other							
Top 5 banks	1.58	1.75	1.69	1.76	1.38	1.43	
5–10	1.42	1.81	1.79	1.95	1.97	1.49	
10–20	2.07	2.42	2.69	2.54	2.38	1.69	
All the other	3.29	3.48	4.09	3.69	3.77	3.76	

Values of loans are as of billion PTE, except for the overnight to other ratio. The amount under each column represents the total amount lent or borrowed by each group per day. A t-test comparing coefficients on each day of the reserve-holding period against the first day is presented under the respective column. The one-tailed test checks whether the value of each day loan is significantly larger or smaller than the first day. Coefficients significantly different from zero at the one percent (five percent, ten percent) level are indicated by **(*,+). Results for the t-test were also done using the last day as benchmark, but conclusions remain unchanged. The p-value from an overall test of the restriction that there are no calendar effects and means are equal across all days is also produced. Results are posted in the last column.

Table 3.18 –Trading across the reserve maintenance period: 12/07/1993–31/12/1998.

Panel a. Borrowing market shares by bank category

	Days of the reserve-holding-period						
	First day	+1	+2	-2	-1	Last day	p-value
Overnight Loans							
Top 5 banks	0.26	0.26	0.26	0.29 *	0.27	0.25	0.381
5-10	0.20	0.20	0.21	0.20	0.21	0.21	0.904
10-20	0.22	0.23	0.20	0.19 +	0.21	0.22	0.161
All the other	0.33	0.32	0.33	0.33	0.31	0.32	0.799
Loans of other maturities							
Top 5 banks	0.30	0.32	0.29	0.32	0.30	0.31	0.436
5-10	0.24	0.22 *	0.21 +	0.23	0.23	0.25	0.186
10-20	0.23	0.22	0.23	0.20 +	0.22	0.26 *	0.013
All the other	0.36	0.38	0.40 +	0.37	0.37	0.38	0.590

Panel a. Lending market shares by bank category

	Days of the reserve-holding-period						
	First day	+1	+2	-2	-1	Last day	p-value
Overnight Loans							
Top 5 banks	0.43	0.40 +	0.38 *	0.36 **	0.38 **	0.39 *	0.021
5-10	0.12	0.13	0.11	0.13	0.13	0.13	0.673
10-20	0.17	0.18	0.19	0.21 **	0.19 *	0.18	0.071
All the other	0.29	0.30	0.32 *	0.32 +	0.31 +	0.30	0.250
Loans of other maturities							
Top 5 banks	0.54	0.51 +	0.49 *	0.47 **	0.54	0.55	0.000
5-10	0.18	0.19	0.19	0.21	0.16 **	0.19	0.015
10-20	0.17	0.17	0.17	0.18	0.17	0.19	0.529
All the other	0.22	0.22	0.22	0.23	0.21	0.20	0.560

Values are market shares. The amount under each column represents the total amount lent or borrowed by each group per day. A t-test comparing coefficients on each day of the reserve-holding period against the first day is presented under the respective column. The one-tailed test checks whether the value of each day loan is significantly larger or smaller than the first day. Coefficients significantly different from zero at the one percent (five percent, ten percent) level are indicated by **(*,+). Results for the t-test were also done using the last day as benchmark, but conclusions remain unchanged. The p-value from an overall test of the restriction that there are no calendar effects and means are equal across all days is also produced. Results are posted in the last column.

b. Number of counterparts

Overall, when a bank buys or sells funds in the interbank market it has on average 3.7 counterparts[31]. Considering only the relationships among the group of 20 banks, the number of counterparts decreases to 2.2[32]. A detailed analysis shows that, when buying funds, the largest 5 banks borrow from 2.4 counterparts out of the 20 identified in our database[33]. This figure is increased to 4.1 if we assume that it buys only once a day from small banks. The number of counterparts increases to 3.0 and 6.1, respectively, when the bank is lending. This is consistent with the fact that large banks are net lenders for most of the time, which is reasonable considering they are better diversified than small banks and able to withstand their liquidity shocks within their balance sheet. They are therefore likely to be lending to small banks, which face larger volatile liquidity shocks, in case of need. On the contrary, when small funds are in surplus, there are little reasons to believe that large banks are willing to borrow

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[31] Average across the 20 banks identified and assuming each trade in the group 'All the others' corresponds to a different counterpart. This assumption is reasonable as Table 3.19 shows that the number of daily trades with the same counterpart decreases with bank's size.

[32] The value is approximately constant all over the period. We did not find a statistically significant difference when considering the period after 12 July 1993 only.

[33] The statistic refers to the post 12 July 1993 period, and is the same for buying and selling. The average value is statistically significant at the 1% level and the values for the whole period 1989–1998 do not differ substantially. The reported value considers the 20 banks identified in our database only.

funds that, in principle, they are less likely to need. Thus, the lending happens often on a pre-determined direction from large to small banks.

Table 3.19 – Trades and counterparts in the interbank market: 12/07/93 to 31/12/98

	Number of counterparts		Number of trades with the same counterpart		Number of trades	
	Top 20[a]	All [b]	Top 20[a]	All [b]	Top 20[a]	All [b]
BUY						
Top 5 banks	2.43	4.20	1.37	1.19	3.34	4.98
5-10	2.06	3.55	1.35	1.17	2.78	4.16
10-20	2.01	2.86	1.25	1.14	2.52	3.28
SELL						
Top 5 banks	3.01	6.11	1.46	1.18	4.39	7.18
5-10	1.85	3.16	1.26	1.11	2.33	3.49
10-20	1.71	2.43	1.18	1.10	2.01	2.67

[a] – Restricting the analysis to the 20 banks identified in the database only. Trades that have a counterpart bank in the 'Top 20' group.

[b] – For banks not identified, i.e., those under the category 'All the others', each trade is considered equivalent to a different counterpart. In fact, it is highly unlikely that large banks trade with each small bank more than once a day.

The average number of counterparts and trades is calculated only for those days when banks choose to trade. The daily figures are averaged for the whole period for all banks in the corresponding group. A table is available for the period 1 January 1989 to 31 December 1998, however the values are similar to those presented in here. All the figures reported are significant at the 1% level.

We also find that the number of counterparts decreases with bank's size, which is not surprising. Also, as it can be seen in the buy and sell panels of Table 3.19, the other categories face a larger average number of sellers than buyers, as they do with the number of trades. The Top 5 banks sell relatively more to small banks than they buy. Out of the 7.18 daily trades to sell funds, 4.39 are with the largest 20 banks, while the corresponding figures when buying funds are 4.98 and 3.34 respectively. Table 3.21 details trading counterparts for overnight funds.

Table 3.20 – Trades and counterparts in the overnight market: 12/07/93 to 31/12/98

	Number of counterparts		Number of trades with the same counterpart		Number of trades	
	Top 20[a]	All [b]	Top 20[a]	All [b]	Top 20[a]	All [b]
BUY						
Top 5 banks	1.95	3.24	1.20	1.13	2.34	3.54
5-10	1.75	2.94	1.20	1.12	2.09	3.18
10-20	1.64	2.22	1.12	1.08	1.84	2.37
SELL						
Top 5	2.24	3.56	1.24	1.17	2.78	3.97
5-10	1.60	2.25	1.13	1.08	1.81	2.38
10-20	1.49	1.95	1.10	1.07	1.65	2.07

[a] – Restricting the analysis to the 20 banks identified in the database only. Trades that have a counterpart bank in the 'Top 20' group.

[b] – For banks not identified, i.e., those under the category 'All the others', each trade is considered equivalent to a different counterpart. In fact, it is highly unlikely that large banks trade with each small bank more than once a day.

The average number of counterparts and trades is calculated only for those days when banks choose to trade. The daily figures are averaged for the whole period for all banks in the corresponding group. The volatility of average figures is therefore due to time change and bank specific behaviour. A similar table is available for the period 1 January 1989 to 31 December 1998, however the values are very close to those presented in here.

All the figures reported are significant at the 1% level.

It is important to note that banks deal more than once a day with the same counterpart in those days when they go to the market. Large banks sell funds to the same bank 1.46 times a day, whereas this figure is 1.37 in case of buying funds[34]. Surprisingly, this multiple transaction feature is still present when we restrict the analysis to loans with same maturity only, though intensity is

[34] Figures relate to the group of 20 banks only. Hence, transactions with the 'All the others' group are excluded from computation. If we do not exclude this group and treat it as a single bank, results are exaggerated because it is highly unlikely that banks trade with a small bank alone more than once a day, except if for different maturities. On contrary, it is likely that banks choose to trade with more than a bank alone from this group. Considering each trade with 'All the others' as equivalent to a different counterpart, results are somewhat changed as presented in Table 3.19.

reduced. For example taking overnight loans only, the top 5 banks buy and sell funds to the same counterpart 1.2 times per day on average. Nonetheless, most often banks prefer a single transaction with each counterpart – 73.41% and 72.82% of days, for buying and selling funds respectively. Only on 15.83% of those days banks choose to trade they do it twice with the same counterpart, for the same maturity and direction.

Regarding counterpart choice for trading, panel a. in Table 3.21 shows the average number of daily trades and counterparts per bank group when the bank chooses to trade – either buying or selling – with at least one bank from corresponding group. Banks do not trade always with all groups. There are several occasions when banks chose a particular group. This becomes clear in panel b. where we show the average number of trades and counterparts per bank when a bank chooses to buy or sell overnight funds in the interbank market. There should be reasons for banks choosing a restricted number of counterparts to trade with, such as the availability of liquidity but also the price of funds and the credit risk of the counterpart. It is possible that banks may ration credit against each other either in the form of price or quantity.

The counterpart choice is not clear-cut. When choosing to trade and apart from the residual 'all the others' group, large banks prefer small banks both to lend and to borrow funds. The result derives from high participation rates for large banks when selling funds. When we adjust for this distinction, and compare periods of buying and selling funds, large banks are relatively more likely to trade with a large bank, than with any other category – the average number of loans taken from large banks and from the 10-20 group is 0.71 and 0.76, respectively, whereas the figures for days of lending are 0.64 e 0.91. Because average loan is larger, we conclude large banks prefer exposures to the same bank group.

Table 3.21 – Trading counterparts in the overnight market: 12/07/93 to 31/12/98

Panel a. When banks chose to trade with each group

	Average number of daily counterparts per bank				Average number of daily transactions per bank			
	Top 5 banks	5-10	10-20	All the others	Top 5 banks	5-10	10-20	All the others
BUY								
Top 5 banks	1.23	1.20	1.39	2.36	1.65	1.39	1.54	2.36
5-10	1.22	1.15	1.30	2.26	1.57	1.33	1.44	2.26
10-20	1.22	1.15	1.25	1.66	1.41	1.25	1.37	1.66
SELL								
Top 5	1.28	1.36	1.56	2.64	1.72	1.76	1.80	2.64
5-10	1.19	1.13	1.22	1.71	1.38	1.31	1.34	1.71
10-20	1.11	1.16	1.19	1.48	1.23	1.29	1.30	1.48

The figures are bank averages within each category across the period considered, and are computed for those days when banks choose to trade with a bank from the corresponding category. Therefore, there are no observations with zero values as long as we require the bank to trade with at least one bank of the corresponding category. The table reads as follows: when a Top 5 bank buys funds from banks in the '10-20' group it chooses to close deals with 1.39 banks on average. The average daily number of deals is 1.54, meaning that the bank may choose to trade more than once with the same bank and for identical overnight maturity.
Values are significant at the 1% level.

Panel b. When banks chose to trade irrespective of the counterparts

	Average number of daily counterparts per bank				Average number of daily transactions per bank			
	Top 5 banks	5-10	10-20	All the others	Top 5 banks	5-10	10-20	All the others
BUY								
Top 5 banks	0.53	0.25	0.68	1.78	0.71	0.29	0.76	1.78
5-10	0.53	0.27	0.47	1.68	0.68	0.31	0.52	1.68
10-20	0.56	0.21	0.42	1.04	0.65	0.65	0.65	1.04
SELL								
Top 5	0.48	0.44	0.79	1.84	0.64	0.57	0.91	1.84
5-10	0.32	0.32	0.41	1.20	0.37	0.37	0.45	1.20
10-20	0.46	0.29	0.44	0.76	0.51	0.32	0.48	0.76

The figures are bank averages within each category across the period considered, and are computed for those days when banks choose to buy or sell funds. The table reads as follows: when a Top 5 bank buys funds the daily number of counterparts is distributed as follows: .53 in the 'Top5', .25 in the '5-10', .68 in the '10-20', and 1.78 in the 'All the others' categories. On average, in those days buying funds a bank from the 'Top 5' buys funds from 3.24 banks, distributed unevenly across the counterpart categories.
Values are significant at the 1% level.

Small banks do not evidence a preference for a counterpart when buying funds. They are equally likely to borrow from any group, and the same applies to the days when they are lending funds. This might happen because being less diversified are subject to more volatile liquidity shocks, which they sought to cancel out in the interbank money market. Indeed, interbank market shares are disproportionate to banks' size.

We produced estimates for overnight loans only, and reported results in Table 3.22. The 5 largest banks buy funds from small banks 49% of days, while they do so from banks within the same group only on 28% of days. The second most important partners are in the '10–20' group both buying and selling funds to large banks. On 32% and 36% of days, 'Top 5' banks buy from and sell funds to banks in the '10–20' group. Despite the high frequency of trading with small banks, large banks transactions occur mainly with banks of the same size. When buying funds, large banks buy 2 370 million of PTE daily from their peers, representing about 36% of total daily average transaction[35]. When not enough funds are available within banks of similar size, large banks seem to prefer the smallest banks to trade with, probably because the closest categories are more likely to be buying funds when large banks need them just because they are more often short of funds than any other bank in the system.

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[35] The average transaction considers also those days when the bank does not buy from large banks but is buying funds from banks of any other group. I.e., those days count as zero in computing the daily average turnover.

Table 3.22 – Frequency of overnight loans by bank category: 12/07/1993 to 31/12/1998

	Percentage of days trading with each group					Average trading value per bank daily				
	Overall	Top 5 banks	5-10	10-20	All the others	Overall	Top 5 banks	5-10	10-20	All the others
BUY										
Top 5 banks	0.65	0.28	0.13	0.32	0.49	6578.3	2370.9	516.1	2167.9	1523.2
5-10	0.60	0.26	0.14	0.21	0.44	4972.8	1650.0	576.6	1075.5	1670.6
10-20	0.50	0.23	0.09	0.17	0.31	2892.4	1065.2	273.0	956.5	597.6
SELL										
Top 5	0.71	0.27	0.23	0.36	0.50	7009.5	2151.3	1385.4	1491.2	1981.6
5-10	0.50	0.13	0.14	0.17	0.35	3414.5	665.9	688.3	543.3	1517.0
10-20	0.48	0.20	0.12	0.18	0.24	2303.5	834.8	385.7	570.4	512.4

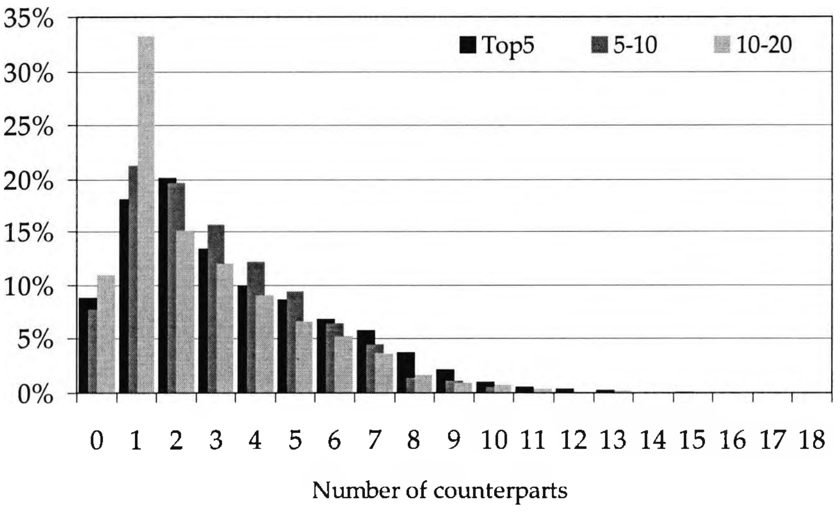
Values are as of million PTE for trading value, and deflated using the CPI index and procedures mentioned elsewhere.

The percentage of days is modeled as a binomial variable taking values 1 and 0, according to which trade does or does not occur. The sample mean indicates the percentage of days trading, or the probability a given bank will trade daily within each category. The 'Overall' column represents the percentage number of days banks buy or sell funds. The remaining 'Top 5 banks', '5-10', '10-20', and 'All the others' represent the percentage of days for trading under each category. The figures do not add up to the value posted under column 'Overall' as banks can buy and sell to different banks' groups on the very some day.

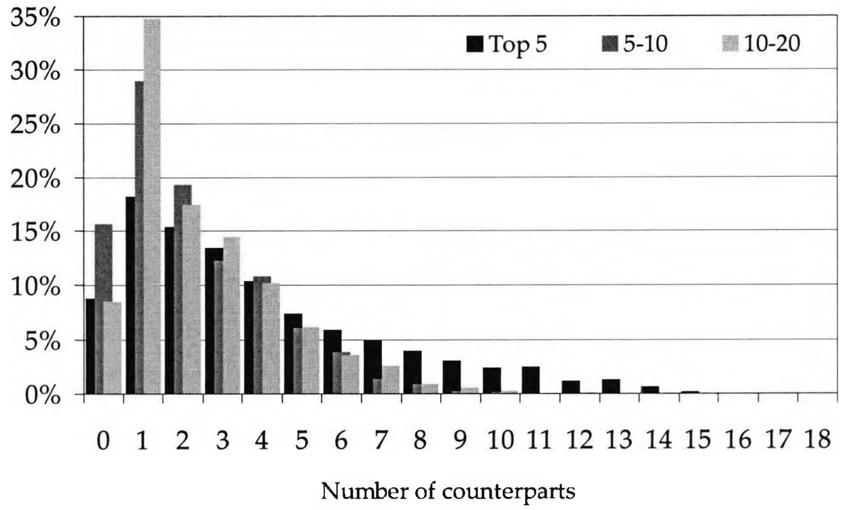
The average daily trading value per bank represents the average transactions per bank broke down by counterpart. The same four groups identified before have been taken as counterparts, and averages were computed only for those days when banks choose to trade, either buying or selling funds. Therefore, the top part of table represents the average trading value per bank daily, when the bank is buying funds, while the bottom represents the same when the bank is selling funds. In both situations it does not matter the counterpart group as long as the bank trades on that day. We make a caveat that reported averages contain both time and individual specific effects as we are averaging across time and banks. Supply and demand of central bank funds for large banks are statistically different from each other, suggesting that large banks are slightly in excess of funds daily, while the remaining banks tend to be short. The shortage is practically inexistent for 'All the others' banks. On average and resting on overall market figures small banks are balanced buying and selling funds; i.e., they drift between days of buying and days of selling central bank funds, around a zero value mean.

Figure 3.4 – Number of counterparts per bank in the overnight market

Panel a. Banks buying funds



Panel b. Banks selling funds



The number of counterparts is computed for the 20 top banks only. Lack of identification of small banks suggests that we may underestimate the true number of counterparts.

c. Persistency of counterpart choice

So far our results show that banks' choices fall on a restricted number of trading partners, and the average number of counterparts banks choose to trade daily is fairly stable across the four groups considered. However, this small figure might reflect a wide diversity of trading partners or, on contrary, the same trading counterparts persistently from day to day.

In order to solve the puzzle and analyse how banks choose their counterparts and evaluate whether there is persistency or relationship banking amongst market participants, we compute the different number of counterparts for each bank for alternative time horizons. If banks buying or selling funds use the same counterparts recurrently, we expect the figure to stabilize insensitive to the time horizon length. Results are presented Table 3.23.

Table 3.23 – Number of counterparts over time

Panel a. Weekly: 12/07/1993 – 31/12/1998

	Number of observations	Mean		Percentiles					
				p-10	p-25	Median	p-75	p-90	Max
BUY									
TOP5	1283	3.4	2.6	1	1	3	5	7	15
5-10	1290	3.0	2.1	1	1	3	4	6	10
10-20	2155	2.6	2.3	0	1	2	4	6	13
SELL									
TOP5	1382	3.9	3.3	1	1	3	6	9	15
5-10	1251	2.2	1.9	0	1	2	3	5	10
10-20	2321	2.4	2.0	1	1	2	3	5	12

Panel b. Monthly: 12/07/1993 – 31/12/1998

	Number of observations	Mean		Percentiles					
				p-10	p-25	Median	p-75	p-90	Max
BUY									
TOP5	322	7.3	4.3	2	3	8	11	13	17
5-10	318	7.1	3.4	2	5	7	10	11	15
10-20	588	5.5	4.1	1	2	4	9	11	17
SELL									
TOP5	329	8.2	4.4	2	4	8	11	14	18
5-10	325	5.4	3.1	1	3	5	8	10	14
10-20	606	5.6	3.4	1	3	6	8	10	16

The number of counterparts is obtained after computing the number of different counterparts per bank for each week/ month in panel a. and panel b., respectively. For each group the figures obtained were hence averaged across time and for all the banks pertaining to it. The number of observations for the buy group is slightly different from the sell group. The difference is due to the fact that banks are not always buyers and sellers of funds. During certain weeks/ months, banks are either only buyers or only sellers.

The median number of different counterparts per week, considering trading amongst the largest 20 banks only when they are buying funds, is 3 for the 10 largest banks and 2 for the other categories. Expanding the dataset to encompass the remaining banks in the system, the median number of different counterparts under some restrictive assumptions increases to 5 and 3, respectively[36]. The number selling counterparts to each group of banks buying funds increases due to higher frequency of trading with small banks as explained before. We find a similar pattern from the perspective of banks selling funds, though the small difference in means is statistically insignificant[37].

When we expand the time horizon, the number of counterparts increases both for buying and selling banks. When we reach a period as long as one year, each bank seems to transact with almost every other bank in the interbank market. This may happen for reasons related to periods of fund shortage, when certain banks are willing to pay a penalty rate as to obtain funds.

In order to analyse whether banks have preferred partners we must extend the analysis to frequency of trading and include volume trading per preferred counterparts. We can find evidence of preferred trading partners if the trading amount shows much less volatility than the number of counterparts, i.e., if

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36 Following previous arguments, trades with small banks in the 'all the others' group are considered as equivalent to different counterparts. An adjustment was made as to the number of week counterparts to be drawn from the day with maximum number of trades within the week. On the other extreme, we essayed the number of different banks as being equivalent to the number of trades during the week truncated at the maximum with the number of banks within the 'All the others category". Results become blurred, but the small number of counterparts feature still persists in the data. Under this assumption, the frequency decreases below 5% beyond 10 different counterparts, and vanishes when we get a number as large as of 20. For an average number of banks of 47 for the post 12 July 1993 period, this illustrates the point

37 The null hypothesis of equal means for banks buying and selling funds is rejected at a 1% level of significance using a t-test. Confidence intervals based on a Poisson distribution leads to the same conclusion, as the average values are outside the intervals of one another.

trading volume is concentrated with a small number of banks. Top 5 banks sell funds to the same counterpart in 12.45 transactions a month when they are selling funds. There is less frequency when we consider the buying of funds, where the same counterpart is used only 7.17 of times.

d. Interest rate discrimination

Is there any visible pattern in interest rates when pricing loans for different categories of banks? In particular, do small banks pay higher interest rates when borrowing, and receive lower rates when lending. If this is the case, we expect large banks to benefit from better conditions to access the interbank money market, and small banks to be rationed out.[38] Small banks are likely to be more risk adverse regarding reserve management and accumulate excess reserves, which they seek to sell out only when the reserve maintenance period expires, and they are quite sure those excess funds are not needed. Under these circumstances, small banks should experience larger than usual trading close to the end of the reserve holding period, when they know for certainty the minimum reserve requirements. Also, if price discrimination occurs and small banks stop borrowing when the period closes, then interest rates towards the end of the reserve holding period might also reflect different market participation, with larger banks' loans dominating the scene.

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[38] A price rationing effect is present, which can aggravate quantity credit rationing that is likely to be present.

We analyse interest rates spreads for each ban category in Table 3.24. We concentrate on the shorter maturities because these are the most used to compensate for unexpected liquidity shocks and, therefore, are the most relevant in assessing interbank money market ability to cooperatively insure bank specific liquidity shocks in the banking system.

Table 3.24 – Interest rates spreads: 13/07/93 to 31/12/1998

Panel a. Borrowing decomposition by bank category

	Days of the reserve-holding-period						
	First day	+1	+2	-2	-1	Last day	p-value
Overnight Loans							
Top 5 banks	-0.217	-0.168	-0.298 +	-0.274	-0.194	-0.288 *	0.003
5-10	-0.082	-0.103	-0.068	-0.091	-0.118	-0.034 +	0.001
10-20	0.079	0.069	0.007 +	0.123	0.096	0.020 *	0.000
All the other	0.118	0.090	0.163	0.182 *	0.115	0.152 +	0.002

Panel a. Lending decomposition by bank category

	Days of the reserve-holding-period						
	First day	+1	+2	-2	-1	Last day	p-value
Overnight Loans							
Top 5 banks	0.141	0.154	0.227 *	0.220 *	0.204 *	0.117	0.000
5-10	0.124	0.109	0.028	0.177	0.087	-0.064 **	0.000
10-20	-0.025	0.013	0.021	-0.086	-0.051	-0.053	0.000
All the other	-0.148	-0.160	-0.146	-0.147	-0.140	-0.077 **	0.000

Values are standardized deviations from the mean. Results are reported for overnight loans only and for regimes 3 and 4. A t-test comparing coefficients on each day of the reserve-holding period against the first day is presented under the respective column. The one-tailed test checks whether the value of each day loan is significantly larger or smaller than the first day. Coefficients significantly different from zero at the one percent (five percent, ten percent) level are indicated by **(*,+). Results for the t-test were also done using the last day as benchmark, but conclusions remain unchanged. The p-value from an overall test of the restriction that there are no calendar effects and means are equal across all days is also produced. Results are posted in the last column.

It should be noted that the last day deviation from daily mean is consistently significant. If large banks wait for the last day of the reserve maintenance period they borrow at the lowest interest rate, while small banks pay the highest interest rate two days before the period closes. This is the day when the amount of required reserves is known exactly. A similar pattern is found for other maturities. Large banks seem to ration credit to small banks charging above average interest rates when lending, while being able to borrow at below average interest rates. The evidence also supports the argument that large banks are market makers in the interbank money market. Results suggest that large banks make a profit from the bid-ask interest rate spread.[39]

5. Conclusion

We find that though overnight loans settling on day of trading are dominant, but banks also use up to one-week loans for purposes of reserve and liquidity management. Banks usually attempt to top minimum reserve requirements at the very beginning of the reserve holding period. Total volume of overnight and one-week loans is systematically larger on the first day of the reserve holding period, and tom-next and spot-next loans spike towards the end of the period, as banks secure interest rates and liquidity funds for the next reserve holding period, because due to the quasi-contemporary reserve regime they partially know their liquidity needs in advance. This seasonal pattern is not observed for maturities above one week, i.e., for maturities above the reserve holding period length.

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[39] A comparison of bid-ask interest rate spread by bank category on a daily basis is nevertheless required.

The ability to distribute funding across different maturities might produce a smoothing effect on overnight rates, however at a cost of propagating the liquidity shock in the system, as banks might borrow or lend for longer than wanted if an arbitrage opportunity exists, or if they have to lend in case they borrowed too much at the beginning of the period. We find for the shortest maturity that interest rates for outright and value date loans are different. Overnight loans have systematically lower interest rates than tom/next and spot/next trades. The effect is robust to reserve holding period effects, although the same cannot be said about the longer rates.

Very short term rates exhibit day of the reserve-maintenance-period effects suggesting banks do not wait till the end of the reserve holding period to build up their minimum reserve requirements. Our results are in some respect comparable to Balduzzi (1997), who found interest rates higher on the first day, but contrary to empirical evidence for the Federal funds market where a U-shaped interest rate behaviour along the reserve maintenance period is reported. Our results show interest rates decreasing every day and plunging on the very last day. Banks do hoard funds very early in the maintenance period, pressuring interest rates up across all maturities. Also, due to a quasi-contemporary regime system, they borrow value date funds before last period, thus anticipating next period liquidity needs. This explains why the overnight market is more active around the day required reserves become known to all banks. Prior to that they prefer to borrow and lend for a period length of up to one week. Eventually banks turn into lenders when period end approaches and they realize they have excess reserves, thus pressuring interest rates down. An abnormal amount of trading is found two days before the last day of the reserve-holding period, i.e., the date when banks know exactly the amount of reserves they must hold.

Participation rates show large banks are more active in interbank money markets than small banks, both in terms of number of trades and volume. The same conclusion applies even when we restrict our analysis to overnight trades only. Yet, while the top 5 large banks are on average selling funds daily, the remaining are buyers for most of the time. Also, small banks are responsible for a larger share of overnight lending when approaching the end of the reserve-holding period, while large banks are more active at the beginning of the period.

When we consider interbank loans of different maturities we find that when in surplus, large banks are more likely to lend long term to medium sized and small banks, while buying overnight when they are short. This might reflect small banks' aversion to liquidity shocks, preferring to secure funds at the beginning of the maintenance period in order to avoid unexpected shocks to interest rates. This strategy is likely to cause accumulation of excess reserves, which banks attempt to sell overnight close to the end of the reserve holding period, when the required reserves are disclosed and become known two days before the expiration day.

We also find, at least more recently, that large banks might be acting as market makers for varying maturities, assuming trading positions and arbitraging away imbalances in the interbank market yield curve. This is likely to happen at an international level where small banks do not have track record to borrow from any large institution. Our evidence on this respect is weak because our data set ends just before the introduction of Euro and the pan-European interbank money market. Yet, this is an issue deserving further attention, as a two-tier interbank money market is very much likely to develop as large banks operate as market makers domestically at their country of origin.

Finally, banks show a preference for trading within the same group. We do not explore bilateral and reputation lending, as this is out of the scope of this chapter. Nevertheless, as a first approximation we find banks restrict trading to a reduced number of partners. However, when taking a long time horizon, we do not find evidence that those partners do not change. On contrary, if we extend the time horizon, banks trade with almost everyone in the market. No bank seems to be excluded from borrowing or lending in the market. However, we find evidence that credit rationing might occur, either via quantity, restricting the amount available to each bank, or via interest rate discrimination.

Chapter 4

Interbank Markets: Liquidity Insurance and Potential Systemic Risks

1. Introduction

In this chapter I present a dynamic model of banks' behaviour in interbank markets. Economic literature defines interbank markets as private arrangements to absorb transitory liquidity shocks and, therefore, offer a cooperative liquidity insurance contract to financial institutions. I examine the ability of interbank markets to allocate liquidity among banks, and analyze the potential systemic risks stemming from bilateral contracting for different maturities among banks. Conclusions emphasize the real channels of risk contagion in banking industry. Under certain circumstances interbank markets may fail to provide the desired liquidity insurance. Central bank standing facilities – such as ready deposit and lending on demand – might resolve the problem while at the same time reducing interest rates volatility. We find that rational expectation explains the interbank term structure, as interest rates are defined as weighted averages of future liquidity shocks in such a way that central bank provision of liquidity might offset unmatched liquidity shocks and reduce overall market volatility. Conversely, excessive central bank intervention might amplify volatility and bilateral interbank market exposures. The rest of the chapter is organized as follows. Section 2 motivates the problem. In section 3 we revise the most relevant theoretical and empirical contributions to interbank market modeling and its links with central bank operational monetary policy. Section 4 develops a model of interbank market lending, where banks can contract loans of different maturities. Section 5 uses a rational expectations framework to derive optimal interbank investment policies for banks facing institution specific and industry wide liquidity shocks. Interbank market equilibrium is analyzed in section 6. The interbank market yield curve and interbank bilateral exposures are determined from the interplay of banks' policies choice. Section 7 concludes.

2. Motivation and Background

Banks are involved in daily transactions in the interbank market resulting from liquidity shocks. From the individual perspective, there are some sources of liquidity that can be predicted in advance with fairly good accuracy – take for example transactions in stock and foreign exchange markets or maturing securities – but others constitute a stochastic shock. Thus, due to the nature of its deposit contracts, they must hold enough funds to meet stochastic liquidity withdrawals on demand. But, reserves are costly and banks must engage in reserve management borrowing and lending to other banks in the interbank money market envisaging costs reduction. Thus, the interbank market provides liquidity insurance to banks while creating at the same time a network of relationships that might be a source of financial fragility.

It is well known that financial intermediaries are vulnerable to systemic risks, and propagate shocks to the rest of the economy both through the payments system and bilateral exposures in the interbank market. Many financial crises are originated outside the financial system, and the interbank markets operate as shock propagators. Davis (1995) shows that financial fragility in businesses and families leads to financial system fragility and produces broad economic effects and externalities, mainly by creating instability in the payments system. Calomiris (1995) argues that shocks originating unambiguously at the heart of the financial system are rare and, also, the distinction between shocks and propagators is unclear. Financial propagators can be as important as financial shocks in contributing to macroeconomic instability. Kaufman (1994) and Benston and Kaufman (1995) show evidence that exogenous shocks to the financial system decreasing the amount of reserves, which are not replaced by central bank actions, might ignite banking problems, which in turn worsen economic conditions widely.

The propagation of shocks might be related to poor risk management. There are two lines of defense against financial fragility and systemic risks: first, internal control of risks at the firm level and, second, prevention of contagion from one bank to another. The former, supports regulatory actions aiming at improving the soundness of financial institutions individually, such as the requirement to use internal risk management models and bank monitoring, the imposition of capital adequacy requirements, and general restrictions on banking activities. The latter, involves all sorts of action undertook by regulators to prevent contagion, i.e., to offset shocks to the financial system that are likely to undermine overall economic stability. The two lines of defense are unambiguously linked as economic literature shows. An action sponsored by the government or the central bank closely depends on the effectiveness of the regulatory measures at the individual bank level.

Calomiris (1995), commenting on the commercial paper crisis of June 1970 in the United States (the Penn Central Crisis), stressed that the prompt intervention of the Fed, encouraging banks to borrow at the discount window to finance loans to issuers, prevented the crisis to widespread. The Penn Central crisis is just an example of instability in the financial markets, which can develop into systemic risks. On the same line of reasoning, Calomiris and Khan (1991) say the discount window may be necessary to prevent occasional, costly, forced liquidation of solvent banks. The lender of last resort, or liquidity provision by a central bank, is important in a fractional reserve banking system. This is not to say that an interbank funds market cannot effectively distribute reserves, but markets for liquidity occasionally gridlock, as it is well documented in literature on credit rationing. Bhattacharya and Gale (1987) show that banks place excessive confidence in interbank markets to absorb transitory liquidity shocks and, therefore under invest in the liquid assets relative to the walrasian unconstrained equilibrium first best.

In practice the balance between action and inaction is very delicate. Economic theory postulates that the central bank should act only when the problem is a pure liquidity problem, with no liquidity being pumped in when banks face insolvency rather than liquidity shortages. But the distinction between liquidity and solvency becomes one and very hard in times of financial distress[1]. Also problems grounded on liquidity shortage originally can faster develop into a credit risk assessment problem. And default on interbank market investments may stem from inadequate credit risk assessment of the counterparty.

We want to model how banks offset expected and unexpected liquidity shocks in the interbank money market, and to which extent the resulting bilateral exposures are a real threat to financial system stability. We argue that systemic risks and liquidity problems are often associated and are a major concern of financial intermediaries, governments and monetary and financial authorities. We focus on the second defensive line only, and show that individual bank failures can develop into contagion and propagate through the financial system and, from there, to the real economy. Regulators might tackle the problem by aiming at the propagation mechanism and creating resilience in

[1] See Goodhart (1995).

the financial system[2]. In analyzing banking interaction, we aim at finding out how interbank money market exposures relate to banks' liquidity shocks and reserve management choices, and how it may threaten financial stability. Banks liquidity management is central to the analysis that follows.

We contribute to existing research in several ways. For the first time we present a model of bank interaction in the interbank market where banks can to a certain extent forecast liquidity shocks in advance and choose to trade with each other at a range of maturities.

Second, the availability of loans of different maturities allows banks to have a strategic behaviour in anticipation of future liquidity shocks. We link banks' early hoarding to idiosyncratic – i.e., uncorrelated with the remaining banks in the system – and industry wide – i.e., having an impact on the aggregate market liquidity – liquidity shocks.

Third, we model banks as heterogeneous agents and explore its implications upon the interbank market ability to offer full insurance against idiosyncratic and aggregate liquidity shocks. We derive results from banks' risk aversion and credit rationing behaviour in presence of central bank standing facilities when the central bank open market operations do not target banks specificity.

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[2] This is one among many bank regulation issues that remains unresolved. See Bhattacharya et Al. (1998: 746)

Fourth, we link the interbank term structure of interest rates to the monetary policy and banks' expectations of future liquidity shocks. Within a rational expectations framework we show that current interest rates can be linked to the term structure of liquidity shocks, banks' characteristics and the degree of central bank commitment to interest rate stability.

3. Models of Banking

Reserve management models view the banking firm as having a liquidity mismatch, i.e., banks hold reserves mainly to meet depositors' demand for cash, which is assumed to be random. First models consider that reserves, as formed with cash and securities, are the only alternatives for banks to meet their liquidity needs. The reserve management problem for a single bank was originally addressed by Poole (1968), Frost (1971), Baltensperger (1974) and Baltensperger and Milde (1976). The basic static model assumes a single bank investing in two assets: non-interest bearing reserves – X – and interest-earning assets – A – in the form of credit loans. The bank funds its assets with deposits – D – and equity capital. The liquidity problem arises because deposits and loan repayments are random. Defining Z as the net withdrawals with density function $f(Z)$, and assuming zero equity, the bank objective function becomes:

$$\tilde{\pi} = r_A(D-X) - \int_X^Z c(\tilde{Z}-X) f(Z)dZ \qquad [1]$$

Solving equation [1] they find the optimal amount of reserves for the risk neutral bank, which balances the costs of foregoing investment return due to excess reserves, with the expected net costs if the bank is shall of central bank funds and has to borrow from the central bank at a penalty rate, or has to convert the portfolio of outstanding loans into cash.

Baltensperger and Milde (1976) extend the basic model assuming the bank has the choice between loans, marketable securities and reserves. To a certain extent, the amount of excess reserves decreases with the costs of selling the securities portfolio. Ho and Saunders (1985) develop a micro model of the Federal funds market, linking the determinants of the Federal funds rate to banks' reserve management decisions and to monetary policy uncertainty. Using a general utility function allowing for banks' risk aversion, they model banks as maximising the expected utility of terminal profit from participating in the Federal funds market. The Fed funds market is regard as an alternative source of liquidity to banks, other than holding excess reserves or borrowing from the central bank at a higher cost. They postulate that banks can contract loans in the Fed funds market based on their expectations about future liquidity shocks. The liquidity shock is known only later, when the Fed funds market is closed and banks have no alternative source of funding except the discount window facility, which they can access at a penalty rate. This set up and the timing of events – i.e., first, the bank can contract in the interbank market and, second, the liquidity shock is realized – is particularly useful to analyse individual bank exposure in the Fed funds market and the implications of banks expectations upon interest rate determination. However, the model misses

In their model, Ho and Saunders (1985) specify that the cost of holding an excess reserve position – $\tilde{r}$ – depends on the monetary policy rate – $\tilde{k}$ – plus a risk premium which is linear on the total amount of excess reserves in the banking system after the market for Federal funds clears – $\tilde{X}$. The reserve adjustment opportunity curve is assumed to slope downwards – i.e., the expected returns from holding excess reserves are less than the expected costs of borrowing from the discount window to meet a reserve deficiency. In equilibrium, the risk neutral bank demand function for Fed funds is given by:

$$\tilde{r} = \tilde{k} - 2eE\left(\tilde{Z}\right) - 2eM \qquad [2]$$

where e is the slope of the reserve adjustment opportunity curve in respect to the bank's excess reserve end of the day position, $E\left(\tilde{Z}\right)$ is the expected liquidity shock, and M stands for the amount of interbank borrowing. Thus we have that the amount of interbank borrowing is a negative function of the interbank interest rate, and depends positively on the liquidity shock. If we aggregate across all banks, imposing interbank market clearing, we find that the prevailing interbank rate depends on the price elasticity of each bank's Fed funds demand function, and the size distribution of all banks participating in the market. The larger the bank, the greater the influence it has on the market clearing rate, which is in turn determined by the expected liquidity shocks and the target rate, or the yield on short term instruments. Assuming that all participants have homogeneous expectations regarding the future course of short term interest rates the interbank market rate can be written as:

$$\tilde{r} = A\tilde{k} - \sum_i E(\tilde{Z}_i) \qquad [3]$$

Hence, Fed funds rates are linked to monetary policy, via the short term rate $\tilde{k}$, and to banks' characteristics, i.e. the liquidity shocks – $\tilde{Z}_i$ – and the diversity of banks' size – included in A. Equation [3] is useful to analyze the sources of interbank market volatility. Individual bank equilibrium conditions [2] allow us to explore the dynamics of interbank loans for each individual bank, and for the market as a whole. But the authors do not explore this topic and focus on the volatility of interest rates instead.

Chen and Mazumdar (1992) focus on the optimal reserve management policy for a given bank using a stochastic dynamic framework. They assume that banks' demand for liquidity in the interbank market fluctuates following a Brownian motion, and it is subject to external shocks and reserve requirements constraints. Their model links bank's reserve management with the Fed funds rate. Similarly to Ho and Saunders (1985) they derive implications for the transmission of the monetary policy and the term structure of interest rates, and claim that small banks are net sellers of Fed funds, whereas large banks are net buyers. Clouse and Dow Jr. (1999) argue that most models of Fed funds markets are unable to explain extreme fluctuations in the Fed funds rate, and they support that a fixed cost is able to explain some unusual behaviour in the Fed funds rate volatility. Giorgio (1999) explains that optimal reserves are linked with financial innovation. Since reserves are a tax on banks, financial innovation can make reserves less effective by creating new investments that are close substitutes of the assets subject to reserve coefficients. We can add, that liquidity enhancing financial innovation increase the interest rate elasticity of demand for Fed funds, and makes more difficult to assess liquidity risks in the financial system.

The aforementioned models ignore that banks' reserve management is also constrained by compulsory reserve requirements, which are due at regular intervals. Hamilton (1996) brought the effects of the reserve maintenance period into discussion. He argued that money market funds should be perfect substitutes in all days of the reserve requirement period. Compulsory reserve requirements should not imply that interest rates deviate from the martingale property within the reserve maintenance period. His hypothesis being validated would render valid prior reserve management models[3]. However, he observed that interest rates in levels and volatility spike towards the end of the reserve maintenance period, implying that reserves on different days cannot be taken as perfect substitutes. He concludes that institutions matter, and interbank market loans are mainly justified by transaction costs and liquidity services. It is exactly the liquidity service, or liquidity insurance, that prevents banks from arbitraging away interest rate differences across days of the week and explains

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[3] Previous models are valid in banking systems subject to contemporaneous reserve requirements, i.e., where banks current account balances are checked daily, contrary to the averaging procedure adopted in the US and the European Union.

time varying interbank rate volatility[4]. The model allows us to derive implications for monetary policy, but it offers little insight into the reserve management problem, and the intensity and persistency of interbank trading, in particular.

Quiróz and Mendizabal (2001) and Kempa (2005) combine the central bank monetary operational policy with interbank market investments to analyse the behaviour of the overnight money market rate. Their models are in the spirit of Poole's (1968) reserve management model, but it is extended to incorporate central bank financing of liquidity shocks via standing facilities and open market operations. There is an obligatory averaging reserve requirement, and banks are allowed to trade overnight loans in the interbank market before liquidity shocks are realized. Financial institutions choose the amount of funds deposited at the central bank as to maximize profits derived from short term reserve management. In Kempa (2005) banks maximize the revenue from making interbank loans minus the costs when using standing facilities[5].

$$V_t = \max E_t\left(\Pi_t\right) = E_t\left(r_t M_t - c_t\right) \qquad [4]$$

where $r_t M_t$ denotes the profit from interbank lending, and $E_t\left(c_t\right)$ is the expected cost. For a single bank the expected cost is determined by the size of

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[4] A bank may refrain from investing due to a severe liquidity shortage, even if interest rates are very high in the current period relative to the next.

[5] Kempa (2005) extends Quiróz and Mendizabal (2001) model into a more general framework.

the expected liquidity shock versus the amount of available central bank funds. The bank must use the borrowing facilities – r_l – when the shock exceeds the current account balance. Otherwise, it is paid the deposit facility rate on positive balances. No reserve requirements equilibrium implies that the interbank interest rate – r_t – is determined by the marginal deposit facility rate – r_d – plus an additional cost which is function of the expected shortage central bank reserves at the end of the day.

$$r_t = r_d + (r_l - r_d)F\left(-X_t - \Theta_t - \bar{Z}_t\right) \qquad [5]$$

where X_t is banks' current account balance at the central bank; Θ_t is the total amount of open market operations; and $f\left(\bar{Z}_{1t}\right)$ denotes the density of the liquidity shock to the banking system, that the author decomposes in idiosyncratic shocks and shocks having an aggregate impact on the market. Under compulsory reserve requirements the problem has not closed form solution, but the equilibrium can approximately be described by equation [5]. Institutional features of the reserve maintenance period imply time varying volatility on the money market rate, and he derives optimal operational monetary policy rules.

On a different theoretical perspective Bryant (1980), Donaldson (1992), Bhattacharya and Fulghieri (1994), Rochet and Tirole (1996), Allen and Gale (1997, 2000), Freixas et al. (2000) explain interbank market investments using static models, where asymmetric information and adverse selection are the key ingredients of the game. Time preference is absent in these models, and the fact that banks may build up persistent inter-temporal relationships in the interbank markets is an unexplored issue. Donaldson (1992) develops a model focusing on bank runs and the role of interbank markets to provide liquidity after an external liquidity shock. He argues that if reserve providers do not exercise captive power in the interbank market the asset prices will not decrease and thus bank runs and contagion are prevented from occurring. Thus, he finds a rationale for central bank intervention in the economy as either a lender of last resort, or as preventing reserve suppliers to exercise any captive power they may have on the interbank market. Eventually, suspension of convertibility is also a rule that banks can exercise to overcome liquidity constraints.

Rochet and Tirole (1996) address explicitly the contagion issue, and justify the existence of interbank markets and inter-bank linkages as necessary to ensure bank continuation in case of negative liquidity shocks. The model has three periods as to accommodate timing of the usual events: the bank makes a decision on its investments in period one. In the second period, the bank suffers a liquidity shock, and borrows in the interbank market to increases the amount of liquidity. Finally, in the third period information is disclosed and the outcome is evaluated. In this model the banking problem arises because depositors do not know their true type ex-ante and might want to early liquidate bank deposits. Intermediaries are risk neutral and offer consumers the facility to early withdraw their money at no cost. If banks are overexposed to the long-term illiquid asset, there might be panic and a bank run develops. Interbank markets in this set-up serve the purpose of preventing banks from fire-selling its loan portfolio and offer individuals liquidity insurance. However, these models do not seem able to fully capture the existing interdependencies among banks in real world interbank markets and the expectations about future liquidity shocks.

Conversely, dynamic models offer a richer perspective of the reserve management problem. Dynamic models allow us to explore the dynamics of interbank market loans and interest rates, discuss systemic threatens to the financial system, and understand interbank rates responses to operational monetary policy. Most problems are nonlinear, and as such they do not have close form solutions. An alternative is to obtain a linear approximation of the model, and derive marginal conditions around equilibrium. Other authors discover the dynamics of the model using simulation. Kempa (2005) follows this route for the European interbank money market. Degryse and Nguyen (2005) examine interbank exposures in the Belgian banking system to assess contagion risk. Analogously, Bartolini et al (2001, 2002) develop a model for the Fed funds market in order to replicate stylized facts, in particular, a striking pattern that depository institutions tend to hold more reserves during the last few days of each reserve maintenance period.

Dynamic modeling of the interbank market is a difficult task due to its complexities and diversity of bank behaviour during the day. Existing, macroeconomic models explain the interbank market from an aggregate perspective, but they abstract from the structure of the market and institutions involved[6]. Micro models, with exception of the static game theoretic approaches, ignore bilateral exposures and the systemic risks issue. Only recently, dynamic models have been incorporating the possibility banks have to raise funds from interbank money markets or asset securitization into the analysis, but they fail to address the reserve management problem at the aggregate level, its interaction with optimal monetary policy and its implications for interbank exposure and persistence, the exception being the recent paper of Kempa (2005).

In this chapter we make simplifying assumptions in order to achieve the desired outcome – i.e., to analyze the impact of bank-specific and industry-specific liquidity shocks on overall interbank investments and to banks' risk exposures. In particular, we do not focus on the reserve maintenance calendar effects, because standing facilities limit the impact of reserve requirements on our final solutions, and on the other, the model can be easily extended to incorporate this and other institutional constraints. Rather, we aim at understanding the reasons why banks hold excess reserves, on one hand, and whether we can find persistency on this behaviour, on the other. We want to discover the relationship between liquidity shocks and the dynamics of interbank market exposures. The dynamic micro model of reserve management we present next is useful to explain interbank market trading, and its

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[6] See Spindt and Hoffmeister (1988), Balduzzi et al. (1997), and Bindseil (2001).

implications upon the level of excess reserves and interest rate determination. More importantly, the model allows us to study how interbank loans respond to idiosyncratic and aggregate liquidity shocks, and under which circumstances recurrent borrowing might develop into persistent interbank exposures.

The model we develop next might be seen as an extension of Ho and Saunders (1985) and addressing similar issues as Kempa (2005). But, given that we are mainly concerned with the systemic threats that interbank markets raise to the financial system, our set up allows for an explicit treatment of persistency in interest rates and interbank loans. The study of liquidity management dynamics and of interdependency in interbank markets is introduced in order to better understand how shocks travel through the banking system and develop into systemic risks if no action is undertaken by the central bank. The action of the central bank – either as lender of last resort or as provider of liquidity – is essential when interbank markets fail to redistribute funds, and its implications deserve to be analyzed. The central bank might mitigate asymmetric information and resolve credit rationing problems that are common on interbank contracting. Systemic threats to financial stability, due to interbank linkages might be appropriately analyzed using this setup.

4. The Model

4.1. Introduction

We build up an intermediation model where banks choose deposits to finance the loan portfolio. Deposits are subject to exogenous reserve requirements, such as in Shaffer (1999). However, for the sake of simplicity we assume for the moment that the reserve to deposit ratio is set to zero. The bank is not able to control changes in other assets to achieve a particular balance sheet configuration at the end of the day. Changing banking assets other than reserves takes more than one day, due to a lag response in the deposit base. Thus, in the very short run banks are unable to change both composition and size of deposits and loans, which are assumed to behave stochastically. Transitory and unexpected liquidity shocks have to be managed either through the discount window or through contracting in the interbank market. The problem faced by the bank manager is to choose an optimal interbank market investment strategy given the daily stochastic liquidity flows.

Following Ho and Saunders (1985), we model the micro-decisions of market participants, focusing on the decisions taken by banks to borrow or lend in the inter-bank market, and relate these to the short-term liquidity management problem. Implicitly, the model emphasizes the liquidity transformation function performed by depository institutions. Additional functions are well documented in economic literature, and include among many others risk management, provision of a payments system and delegated monitoring[7].

Banks face a maturity and liquidity mismatch between assets and liabilities, which is understood as being a potential source of financial fragility and, ultimately systemic risk. Banks borrow mainly short term and lend long term. Because its liabilities are redeemed on demand, banks must hold enough cash reserves to face unexpected withdrawals, and make the necessary arrangements to obtain liquidity in case of shortage. Due to asymmetric information, most banks' assets are illiquid, which makes it very difficult to obtain reserves through selling assets in case the bank faces an unexpected liquidity withdrawal. Banks might use a wide range of financial instruments to hedge maturity risk, e.g., swaps and securitization. But, liquidity risk cannot be fully hedged in advance, and the interbank markets serve the purpose of allocating liquidity in the banking system minimizing expected losses and increasing financial system resilience.

The banking problem is solved in two stages. After having decided on the optimum amount of reserves to hold in the long run, banks engage in periodic liquidity trading in order to minimize the costs of excess or shortage of funds. We state that the amount of borrowing and lending in the inter-bank markets is

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[7] The seminal paper of Merton (1994) presents a functional approach to financial intermediation, where these issues are discussed in detail.

mainly driven by the banks' liquidity needs. We assume that the amount of funds and its maturity a given bank supplies or demands in the interbank market is a function of expected liquidity shocks and the opportunity costs of holding excess cash reserves, or of incurring into a liquidity shortage[8].

Banks are able, under certain conditions, to arbitrage interest rates differences across maturities, but they are unable to influence the liquidity shock by manipulating interest rates on deposits and loans. Also, we allow the liquidity shock to vary from institution to institution.

For tractability we assume that banks can invest (borrow) only in two assets whose maturities are respectively 1 day (overnight) and 2 days[9]. Though it is natural to think of the model as a two-day reserve management, we are really interested in the 'informational time' rather than 'calendar time'. The two periods aim at capturing the idea that banks arbitrage across maturities and are able to adjust their reserve positions according to expected future liquidity shocks. Having two assets with different maturities allows banks to trade claims

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[8] The bank sets up the reserve level before the uncertainty is resolved. I normalise the reserve level to zero, although it could be defined alternatively as a proportion of the past average value of deposits (in fact, this is the reserve requirement ratio).

[9] Alternatively, one can regard one and two period investments as standing for short and long term. Conclusions are not changed. However, the liquidity shocks can have a different interpretation, as in the long term we have loans maturing and the shocks become more predictable. Also, the shocks will be more sensitive to credit risk exposures, as in the long future liquidity shortages are closely related to default on loans.

on expected cash flows, therefore introducing dynamics into the system. In fact, when making interbank market investments banks bring into consideration their expectations about future liquidity shocks. At the same time interaction and mutual exposure will emerge out of banks lending and borrowing actions, as each bank can be simultaneously a lender and a borrower of funds. This feature allows us to exploit systemic risk and contagion in the financial system and, particularly, in the interbank market. We abstract from explicit consideration of credit risk, except to the case where credit rationing may occur in the interbank market.

The model places emphasis on the precautionary motive demand for reserves. Banks' demand of funds is driven both by the need to meet reserve requirements and to build up excess reserves as a buffer to avoid overdrafts and the associated penalties when changes in reserves are stochastic. Thus, the problem to the bank is to choose the amount of excess reserves that minimizes the penalty and opportunity costs, or that maximizes net benefits of excess reserves. The dual problem is to choose the optimal policy mix for investing in the interbank market.

4.2. Notation

We use the following notation throughout the chapter:

$M_{i,m,t}$ – m-period interbank borrowing or lending for bank i at time t

$\tilde{X}_{i,t}$ – excess (insufficient) reserves for bank i at time t

k_t – risk-free interest rate

$\tilde{r}_{1,t}$ – one-period interbank interest rate prevailing at time t

$\tilde{r}_{2,t}$ – two-period interbank interest rate prevailing at time t

$\tilde{d}_{i,t}$ – return (cost) from holding excess (insufficient) reserves at time t

$\tilde{Z}_{i,t}$ – liquidity shock related to shifts in the demand for loans and/or deposits and to the payments system

η_i – conjectured response of the one-period interest rates to interbank investments made by bank i

ξ_i – conjectured response of the two-period interest rate to interbank investments made by bank i

$\tilde{\Pi}_i$ – profits of bank i

i – the i-th bank in the system ($i = 1,2,..,N$)

m – is the time maturity of interbank investments ($m = 1,2$)

4.3. The model

The business day is decomposed in two sub-periods – from time t until t_0, and from t_0 until $t+1$. The bank opens for a fraction of the day, the business hours – running from t until t_0 – during which it faces a stochastic liquidity shock. For the remaining of the day – from t_0 until $t+1$, when next day starts – the bank is closed for business, and settlement takes place. During business hours the bank manager has complete knowledge over the reserve flows to the bank, and can adjust the interbank market portfolio appropriately, making new loans to maximize the return on excess reserves, and borrowing from other banks to minimize the costs of liquidity shortages.

However, there is always a fraction of the daily flow of funds that remains stochastic, because the information systems at the bank do not convey to the trading desk all the relevant information regarding liquidity demand on a timely basis[10], and some shocks reach the bank only after hours, when the interbank market trading day is over. Therefore, banks do not know their end of day reserves exactly.

For the sake of simplicity, we assume in the model that the interbank market closes just before the bank manager realizes the liquidity state. Therefore, all interbank investments are based upon bank manager's beliefs about the liquidity shock in this period and periods ahead. In practice this is equivalent to say that new information concerning liquidity needs is not known until the next day, when the central bank produces the final overnight settlement reports[11].

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[10] As an illustration, when the information regarding the liquidity demand by clients reaches the trading desk it is too late. The bank manager lacks information about the reserves withdrawn by depositors when the interbank market is still open. This widens the basis for cash flow uncertainty and might introduce higher volatility on the level of reserves.

[11] We must make a caveat here. The assumption that the new information is not known until early next day does not impact conclusions. In fact we could assume the bank manager can gain access to an information system that allows him or her to know the flow of funds after the interbank market closes. But, considering the information is available only after hours is of no

This set up allows one to introduce the discount window facility.[12] The discount window is regarded as a "residual lender, both de **facto and de jure**".[13]. If at the end of the day banks have an overdraft position they must either borrow at the discount window or pay a penalty. We assume as in Close and Dow Jr. (1999) that borrowing from the discount window and paying a penalty due to cash shortage have the same cost structure. Hence, the alternative to banks is either borrow in the interbank market to fund the expected deficient reserve position, or choose to go to the discount window, i.e., allow the reserves to go below the required level.

The uncertainty banks face for the remaining of the day – between the time interbank market closes and the time settlement procedures are initiated – provides an explanation for holding excess reserves. At this point it is important to distinguish between discount window facility and open market operations undertaken by the central bank. Open market operations are assumed to take place within interbank market opening hours, allowing banks to adjust their interbank investment portfolio as information is conveyed to the market.

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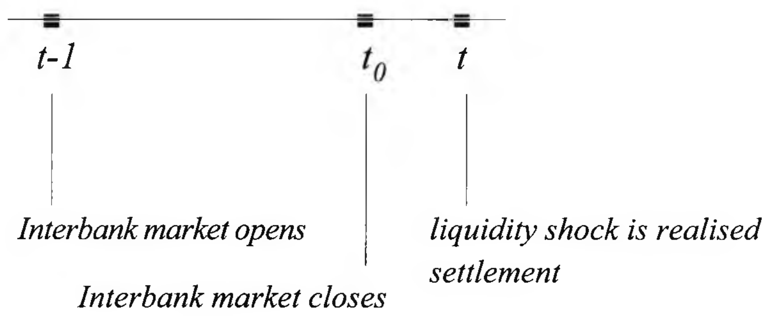
relevance to determine interbank market investments on that day. Only next day can the bank manager account for the unforeseen information and undertake the necessary actions.

[12] Notice that if the interbank market closes after the liquidity shock is realized the bank will never use the central bank for credit, unless the interbank market is unable to provide liquidity at a competitive cost. No need for central bank borrowing arises in this set up, except when liquidity shocks are industry-specific and the market fails to provide the necessary liquidity.

[13] See Shaffer (1999: 1836). Emphasis added

Graphically, the problem is depicted in Figure 4.1 following:

Figure 4.1 – The timing of events



On the assumption that interbank market trading reflects bank's specific liquidity shocks, a risk-neutral bank maximizes the following objective function on current and future expected profits:[14]

$$\max_{\{M_{i,1,t},M_{i,2,t}\}} E_0\tilde{\Pi}_i = \max\sum_{t=1}^{\infty}\delta^t E_0\tilde{\Pi}_{i,t} \qquad [6]$$

where $\tilde{\Pi}_{i,t} = \tilde{X}_{i,t}\tilde{d}_{i,t} + M_{i,1,t}\tilde{r}_{1,t} + M_{i,2,t}\tilde{r}_{2,t} + M_{i,2,t-1}\tilde{r}_{2,t-1}$.

Notice that we assume for the sake of simplicity, that contrary to common money market practice interbank loans are sold at face value. The assumption seems not to alter the conclusions and leaves calculus much simplified. Also,

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[14] We could assume that the bank manager maximizes expected utility on profits. Considering an utility function on profits alone, allows one to introduce risk aversion in bank's manager behaviour. However, the conclusions would not change significantly. The bank's risk aversion would result in a term structure where interest rate premiums would depend on the degree of risk aversion. Alternatively, we could model the bank behaviour as in O'Hara (1983), where managers are assumed to maximize a private utility function where bank's profits play a predominant role.

returns accruing to two-period investments are distributed evenly over the two periods. Alternatively, we could assume that each day outstanding interbank investments are evaluated and the difference between last period and current period values is taken as the current period return.[15]

Expression [6] is subject to the following constraints:

a. <u>The excess reserve budget constraint</u>

$$\tilde{X}_{i,t} = \tilde{Z}_{ai,t} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1} \qquad [7]$$

At the end of the day, the bank faces an amount of excess reserves, $\tilde{X}_{i,t}$, that is either positive or negative, depending on the actual behaviour of $\tilde{Z}_{ai,t}$[16]. Notice that $\tilde{X}_{i,t}$ inherits the stochastic properties of the liquidity shock, and it

15 Formally, the profit function could be written as:

$$\tilde{\Pi}_{i,t} = \tilde{X}_{i,t}\tilde{d}_{i,t} + M_{i,1,t}\tilde{r}_{1,t} + \left[\frac{M_{i,2,t}\left(1+2\tilde{r}_{2,t}\right)}{1+\tilde{r}_{1,t+1}} - M_{i,2,t}\right] + \left[M_{i,2,t-1}\left(1+2\tilde{r}_{2,t-1}\right) - \frac{M_{i,2,t-1}\left(1+2\tilde{r}_{2,t-1}\right)}{1+\tilde{r}_{1,t+1}}\right]$$

which is, approximately, equivalent to

$$\tilde{\Pi}_{i,t} = \tilde{X}_{i,t}\tilde{d}_{i,t} + M_{i,1,t}\tilde{r}_{1,t} + \left[M_{i,2,t}\left(2\tilde{r}_{2,t} - \tilde{r}_{1,t+1}\right)\right] + \left[M_{i,2,t-1}\tilde{r}_{1,t}\right]$$

16 See Appendix A1.

is also influenced by the decisions undertaken on how much to invest or borrow in the interbank market on that particular day.[17]

The excess reserve constraint can be reconciled with the bank's balance sheet identity. Assets held by the bank are the loan portfolio $L_{i,t} \geq 0$, the securities portfolio $S_{i,t} \geq 0$, the still alive inter-bank investments $M_{i,m,t-m}$, where $m = 1,2$ stands for interbank investments maturity, and the excess reserves $X_{i,t}$. Assets are funded with deposits $D_{i,t} \geq 0$, and equity capital $K_{i,t} \geq 0$. Formally,

[17] Because we do not model explicitly for alternative investment policies, other than inter-bank market investments, past liquidity shocks, $Z_{i,t-s}$, enter the excess reserve equation and determine the current level of reserves. Therefore, if past liquidity shocks are systematically positive, the amount of excess reserves will be unbounded upwards, *ceteris paribus*. Conversely, persistent negative shocks will push the bank into a severe shortage of central bank funds. However, on one hand it is reasonable to assume that liquidity shocks have zero mean, or they fluctuate around a deterministic trend. On the other hand, one can argue that the liquidity shock itself – $Z_{i,t-s}$ – captures the decisions undertaken by the bank to align reserves with the long term desired level. Thus, in case the bank is experiencing a sustainable inflow of liquidity it can, for example, increase the loan portfolio, which offers superior returns when compared to inter-bank investments. This issue is not crucial to the problem we discuss here, and it seems not to change very much the nature of the results. Except that interbank investments will be larger in case liquidity shocks do not revert to the zero mean. Moreover, the stochastic nature of $Z_{i,t}$, and $X_{i,t}$, is not violated. We think of $Z_{i,t}$ as having two components: a deterministic part, $L_{i,t}$, indexed to bank's assets or past liquidity shocks, for example; and a pure liquidity shock, $w_{i,t}$, which conveys no information about bank's investment policy.

at the end of the day, after the inter-bank market closes and all transactions are settled, the balance sheet constraint is:[18]

$$\tilde{L}_{i,t} + \tilde{S}_{i,t} + M_{i,1,t} + M_{i,2,t} + M_{i,2,t-1} + \tilde{X}_{i,t} = \tilde{D}_{i,t} + \tilde{K}_{i,t} \qquad [8]$$

Substitute for the excess reserves in day t, as given by equation [7], in the balance sheet identity and solve for the liquidity shock $Z_{ai,t}$:

$$\tilde{Z}_{ai,t} = \tilde{D}_{i,t} - \left(\tilde{L}_{i,t} + \tilde{S}_{i,t}\right) + \tilde{K}_{i,t} - \bar{Z}_{i,t-s} \qquad [9]$$

The current liquidity shock depends on deposits, loans, securities, and equity generating processes. Assuming that equity capital remains stable in the short term, then it is solely driven by fluctuations in deposits that are not compensated by identical changes in long-term investments.[19]

Equation [9] emphasises the transformation function performed by financial intermediaries, stressing the liquidity mismatch between assets and liabilities, and its implications for liquidity management.[20]

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18 We assume reserve requirements on deposits are set equal to zero. In practice, however, positive reserve requirements mean that the fluctuation in excess reserves and liquidity shocks is less pronounced than formula [4] suggests.

19 In practice the Basle capital adequacy ratio and the compulsory reserve requirements on deposits place a restriction on the dynamics of loans and deposits.

20 See Appendix A1.

b. Reserve adjustment opportunity cost

$$\tilde{d}_{i,t} = k_t - \beta_{i,0}\tilde{X}_{i,t} - \beta_{i,1}\sum_{n=1}^{N}\tilde{X}_{n,t} \qquad [10]$$

The reserve adjustment opportunity curve is similar to Ho and Saunders (1985)[21], where the effective opportunity cost of each unit of excess reserves is known ex-post, only after the interbank investment decisions are made. Ho and Saunders (1985) specify the return (cost) of holding an excess (deficient) reserve position based on the reserve adjustment opportunity curve (RAC), which is assumed to slope downwards, i.e., "the expected returns from holding excess reserves are less than the expected costs of borrowing from the discount window to meet a reserve deficiency. Such a slope will result if market demand and supply curves for short-term securities are imperfectly elastic, due, e.g., to preferred habitat considerations. The cost of discount window borrowing is viewed as 'penal' after allowing for both the explicit and implicit costs of such borrowing."[22]

The difference in here is that the penal rate is assumed to depend not only on the specific liquidity shock of a given bank, but additionally it depends on

[21] For simplicity, we assume symmetric reserve adjustment costs in excess or shortfall of reserves. Unlike Ho and Saunders (1985) we assume also that the opportunity cost of each unit of excess reserves for bank i is also a function of other banks' excess reserves.

[22] Ho and Saunders (1985:979).

the industry-specific liquidity shock. The intuition is that the opportunity cost of being short of reserves increases when the market as a whole is short of funds. Banks with large positive central bank balances face a higher reward function.

The coefficients $\beta_{i,0}, \beta_{i,1} > 0$ capture the fact that excess reserves will be penalized. Thus, when $\tilde{X}_{i,t} < 0$, the bank has to pay a penal rate on the funds borrowed from the central bank through the discount window that is in excess to the risk-free interest rate k_t.[23]

Conversely, if $\tilde{X}_{i,t} > 0$ the bank has excess reserves at the central bank, which earn no interest and the interest forgone on those investments can be captured by a negative return on investments. We expect that informal limits on the discount window are captured by the slope of the reserve adjustment opportunity cost – i.e., $\beta_{i,0}$ and $\beta_{i,1}$.

The reserve adjustment opportunity curve is equivalent to:[24]

$$\tilde{d}_{i,t} = k_t - \beta_{i,0}\tilde{Z}_{ai,t} - \beta_{i,1}\tilde{Z}_{an,t} + \beta_{i,0}\left[M_{i,1,t} + (1+L)M_{i,2,t}\right] \qquad [11]$$

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[23] We think of the interest rate as the return on risk free securities, such as treasury bills or any other interest bearing central bank bills. Alternatively, this rate could be thought as the rate at which the central bank is willing to buy or sell overnight funds during inter-bank market opening hours. Although, to be exact there should be a positive spread between bid and offer, I assume, for the sake of simplicity, the rate is equal to the bid-ask mid-point value.

[24] See Appendix A2

The linear specification of the reserve opportunity adjustment curve deserves some comments. First, the relationship is valid only on the neighborhood of equilibrium. It is likely that when banks move away from equilibrium the curve tilts and shifts, reflecting the non-linear behavior imposed by non-monetary factors, such as bilateral credit rationing, informal limits on the use of the discount window and the implicit costs of central bank overdrafts.

Second, the functional form of $\tilde{d}_{i,t}$ may determine negative excess reserves if the opportunity cost is lower than the interbank interest rates. The bank may, then, find it optimal to overdraft its account at the central bank in order to invest in the interbank market. Notice, however, that borrowing at the central bank does not go up indefinitely, as costs increase with the overdraft amount, thus balance eliminating any arbitrage profits.

Third, $\beta_{i,0}$ and $\beta_{i,1}$ aim at capturing banks' different behaviour. The opportunity cost each bank perceives depends on its funding structure and may, therefore, be reflected on the coefficients size. Also, coefficients might account for banks size. Indeed, interbank markets literature suggests that small and large banks face different opportunity costs regarding the access to the discount window, and smaller banks are less penalized than large banks. Also, the European Central Bank requires banks to post collateral in order to gain access to the daily marginal lending facilities.

Fourth, the size of beta coefficients is linked to financial innovation, as the degree of tradability of banks' assets is able to create sources of liquidity alternative to interbank markets. If a large proportion of banks' assets is securitized, the quest for liquidity becomes less problematic, as the cross elasticity among different asset categories is high. A positive liquidity shock might then have a smaller impact on the expected opportunity cost relative to an incipient financial market where bank's assets are barely securitized, as banks might sell securitized assets rather than borrowing uncollateralized funds from other banks.[25]

c. Individual demand/ supply of interbank funds

$$\tilde{r}_{i,1,t} = \tilde{r}_{1,t} + \frac{\eta_i}{2} M_{i,1,t} \qquad [12]$$

$$\tilde{r}_{i,2,t} = \tilde{r}_{2,t} + \frac{\xi_i}{2} M_{i,2,t} \qquad [13]$$

where $\eta_i, \xi_i < 0$.

This constraint allows interbank market interest rates to be sensitive to the amounts each individual bank decides to invest or borrow in the interbank market. Each bank faces a downward slopping linear demand function for the funds it supplies in the interbank market. Each bank observes the market interest rates at time t and believes its actions can marginally affect the interest rate. The interest rate it earns from investing in the money market

[25] This perception, however, raises another important issue. The central bank might be endowed with a market maker of last resort status, when banks unable to sell securities use central bank funds to sustain financial market crashes.

decreases proportionately to the amount of funds supplied. Identically, the interest rate the bank has to pay also increases when the bank demands more borrowing in the market.[26]

This expression accounts for transaction costs, allowing the bid and ask interest rates to fluctuate around mid-point $\tilde{r}_{1,t}$ and $\tilde{r}_{2,t}$. When the bank is offering funds in the interbank market – $M_{i,m,t} > 0, m = 1,2$ – the return will fall below the interest it has to pay when borrowing funds, i.e., $M_{i,m,t} < 0, m = 1,2$. The greater the pressure exercised in the interbank market, the more the bank will be penalized. The ability to influence interest rates might be assumed to be proportional to the bank's interbank market share, depend on market conditions and the relative strength of interbank funds demand and supply.[27]

Banks' perceive their actions as being competitive in the sense that they take current interest rates as given. Increasing market supply of funds, due to positive liquidity shocks, shifts the demand function to the left and lowers

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[26] To better understand this specification, assume a mechanism such as there exists a market dealer coordinating the market and running the order book. Banks place orders according to different interest rates. The dealer discloses the relevant information such as the last interest rate and the orders in the book. At each moment a bank demanding funds knows the interest rate charged, which is likely to increase with the amount of funds borrowed. Borrowing costs increase both with market depth, liquidity and the desired loan size. The coefficients η_i and ξ_i will decrease with perceived market's liquidity and depth.

[27] One can additionally think of a risk premium each bank is required to pay above the market interest rate. The risk premium will depend on level of risk of the borrowing bank perceived by the rest of the industry.

interest rates. Conversely, the function will shift rightwards when there is a market liquidity shortage and interest rates are high.

Later we will show that market interest rate depends on the reserve adjustment opportunity curve for each individual bank. This allows one to endogenize banks behavior in an interbank market equilibrium framework and drop this restrictive assumption. Interest rates are then determined by the actions of all banks simultaneously. We will return to this issue in section 3.2.

d. Market Equilibrium

$$\sum_{n=1}^{N} M_{n,m,t} = 0 \qquad m = 1,2 \tag{14}$$

where N is the total number of banks, and $m = 1,2$ is the maturity of interbank investments that we restrict to two maturities only.

Equation [14] says that supply and demand of funds must equal in order to achieve equilibrium. Implicitly, we assume that the central bank does not buy or sell overnight funds in this market. Central bank open market operations are perceived to be liquidity shocks to the system. In this sense, interbank interest rates are now tied up with the interest rate offered by the central bank in open market transactions.

5. Optimal interbank borrowing and lending

5.1. Optimal investment policy for a single bank

The optimal investment policy for a single bank can be obtained solving the inter-temporal profit equation [15] subject to the excess reserve budget constraint [16], the reserve adjustment opportunity curve [17], and the perceived demand/ supply of interbank market funds [18] and [19]:

$$\max_{\{M_{i,1,t},M_{i,2,t}\}} E_0\tilde{\Pi}_i = \max \sum_{t=1}^{\infty} \delta^t E_0 \tilde{\Pi}_{i,t} \qquad [15]$$

subject to

$$\tilde{X}_{i,t} = \tilde{Z}_{ai,t} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1} \qquad [16]$$

$$\tilde{d}_{i,t} = k_t - \beta_{i,0}\tilde{X}_{i,t} - \beta_{i,1}\sum_{n=1}^{N}\tilde{X}_{n,t} \qquad [17]$$

$$\tilde{r}_{i,1,t} = \tilde{r}_{1,t} + \frac{\eta_i}{2}M_{i,1,t} \qquad [18]$$

$$\tilde{r}_{i,2,t} = \tilde{r}_{2,t} + \frac{\xi_i}{2}M_{i,2,t} \qquad [19]$$

where $0 < \delta < 1, \beta_{i,0}, \beta_{i,1} > 0, \eta_{i,t}, \xi_{i,t} < 0$.

The first step is to obtain the rational expectations solution for the inter-temporal profit function is to differentiate [15] in order to the inter-bank market investments $M_{i,1,t}$ and $M_{i,2,t}$, thus obtaining the optimal sequences $\{M_{i,1,t}\}_0^{\infty}$ and $\{M_{i,2,t}\}_0^{\infty}$ that maximize the profit function. The Euler equations candidates to answer the problem are then solved for $M_{i,1,t}$ and $M_{i,2,t}$ to produce the following optimal investment sequences:[28]

$$\begin{aligned}
M_{i,2,t} = {} & \lambda_{i,1} M_{i,2,t-1} - b_{i,k}\tilde{k}_t - b_{i,r1}\tilde{r}_{1,t} + b_{i,r2}\tilde{r}_{2,t} \\
& + b_{i,zai} E_{t_0} \tilde{Z}_{ai,t} + b_{i,zan} E_{t_0} \tilde{Z}_{an,t} + \\
& + b_{i,r2} \sum_{j=1}^{\infty} \lambda_{i;2}^{-j} E_{t_0} \tilde{r}_{2,t+j} + \\
& + \sum_{j=1}^{\infty} \pi_{i,t+j} E_{t_0} \left(-\frac{1}{2\beta_{i,0}} \tilde{k}_{t+j} + \frac{1}{\eta_i} \tilde{r}_{1,t+j} + \tilde{Z}_{ai,t+j} + \frac{\beta_{i,1}}{2\beta_{i,0}} \tilde{Z}_{an,t+j} \right)
\end{aligned} \qquad [20]$$

$$\begin{aligned}
M_{i,1,t} = {} & \frac{a_i}{\eta_i}\left(1 + \lambda_{i,1}\right) M_{i,2,t-1} - c_{i,k} k_t + c_{i,r1}\tilde{r}_{1,t} - c_{i,r2}\tilde{r}_{2,t} + \\
& + c_{i,zai} E_{t_0} \tilde{Z}_{ai,t} + c_{i,zan} E_{t_0} \tilde{Z}_{an,t} \\
& + c_{i,r2} \sum_{j=1}^{\infty} \lambda_{i,2}^{-j} E_{t_0} \tilde{r}_{2,t+j} + \\
& + \frac{a_i}{\eta_i} \sum_{j=1}^{\infty} \pi_{i,t+j} E_{t_0} \left(-\frac{1}{2\beta_{i,0}} \tilde{k}_{t+j} + \frac{1}{\eta_i} \tilde{r}_{1,t+j} + \tilde{Z}_{ai,t+j} + \frac{2\beta_{i,1}}{2\beta_{i,0}} \tilde{Z}_{an,t+j} \right)
\end{aligned} \qquad [21]$$

All b_i's and c_i's are finite and positive.

5.2. Discussion of results

All the variables have the expected signs. Positive liquidity shocks will lead banks to invest in the interbank market as long as the expected returns exceed the costs, opportunity costs inclusive. The higher the interest rate, ceteris paribus, the more the bank will invest in the interbank market. Incidentally, the bank may find it optimal to have negative excess reserves in case the interbank

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[28] See Appendix A3.

interest rates are high and the penalty imposed by the central bank is not so severe that becomes binding.

The current period expected liquidity shock determines positively both the one-period and two-period investments. The allocation of the shock between the two market segments – one-period and two-period – is dependent on the bank's perceived liquidity in each market, the transaction costs, and the opportunity costs of excess reserves in each period. If the bank has reasons to believe that using the two-period market entails lower costs, then the decisions will be biased towards investing long the current period and, eventually, borrow next period to support the investment strategy. However, because the overnight market is more liquid as compared to longer maturities, banks will prefer to invest for the very short-term and roll over investments, *ceteris paribus.* Also, the bank may find it optimal so spread the investment between short and long-term, particularly when one market segment is very illiquid – as measured both by a high interest rate and large interest rate sensitivity. This conclusion stands as long as the bank is assumed to remain risk neutral and interest rates have rational expectations equilibrium.[29]

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[29] Rational expectations equilibrium for interest rates means that making a two-period investment yields exactly the same return as investing one period followed by the roll over of the investment in the second period. This issue is discussed latter.

Next, we simulate the model under various scenarios. Parameters and variables values were determined for the steady-state solution, assuming initial interbank market trading and excess reserves start both at zero values:

1. Daily interest rates: $k_t = r_{1,t} = r_{2,t} = 0.0002$

2. Reserve adjustment opportunity curve coefficients: $\beta_{i,0} = \beta_{i,1} = 0.0001$

3. Interest rate change to market trading: $\eta_i = \xi_i = -0.00005$

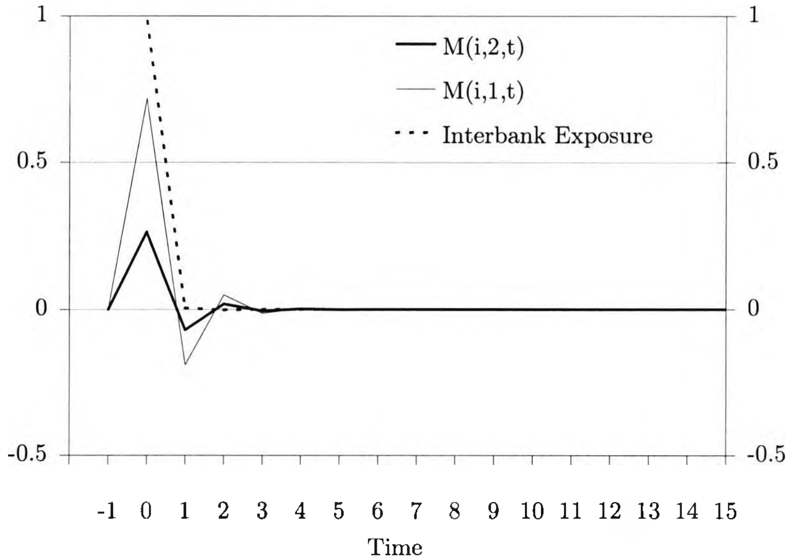
When shocks are zero, banks do not engage in interbank market trade, unless the market is not at equilibrium and it is optimal to borrow and hold excess reserves, or go short of reserves and invest in higher interbank market yields. Further, such opportunities, when existing, are transitory as market response restores interest rates equilibrium. Speculation is possible when banks expectation regarding next period interest rates is different from market average. Identically to the aforementioned case, speculative gains will vanish at the speed expected interest rates converge to the point of no trade. We discuss the case of bank specific shocks and its implications for reserve management first. Aggregate liquidity shocks and interdependence is discussed in the next section.

a. <u>A liquidity shock lasting for one period</u>: $\tilde{Z}_{ai,t} = 1, \tilde{Z}_{ai,t+j} = 0, j = 1,2,...$

When facing a positive liquidity shock, investments will be split between the two maturities. The reason is that, given rational expectations, banks will try to minimize the costs or maximize the profits of the investment strategy.

Therefore, because interest rates are responsive to changes in the amount invested, banks will invest in both maturities 'one' and 'two' until equalizing return of the two alternatives is equal.

Figure 4.2 – Interbank market loans dynamics: $\tilde{Z}_{ai,t} = 1, \tilde{Z}_{ai,t+j} = 0, j = 1, 2, ...$

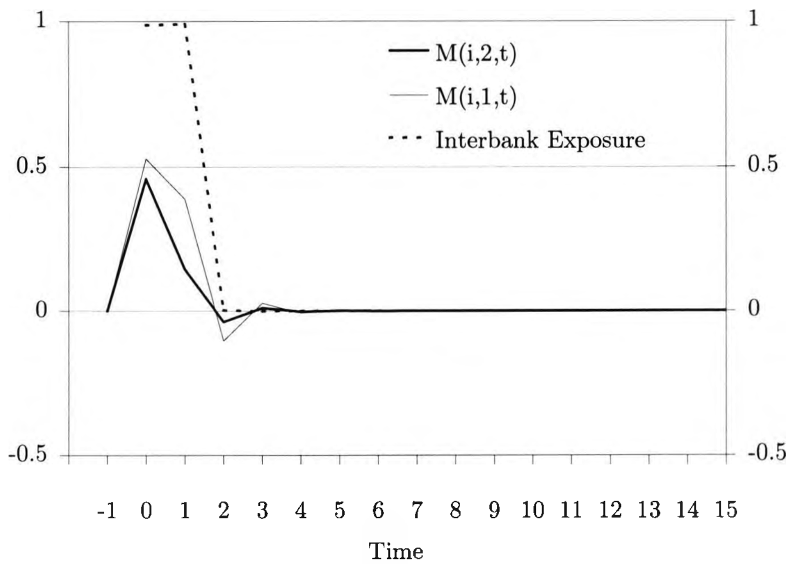


The amount invested in each market depends on the size of the relative coefficient o market sensitivity, i.e. of $o = \eta_i / \xi_i$. If the long maturity segment is less liquid relative to the overnight alternative $(o < 1)$, as it is often the case, the bank will concentrate investments in short maturity investments. The contrary occurs, when markets are perceived to be in very short supply of overnight funds. Figure 4.2 depicts the case when $o = 1$. Nevertheless, despite identical sensitivities between short and long-term loans, banks prefer investments that match the liquidity shock expected time length.

b. <u>A liquidity shock lasting for two periods</u>: $Z_{ai,t} = Z_{ai,t+1} = 1, Z_{ai,t+j} = 0, j = 2,3,...$

When the shock lasts two periods the bank will show a greater preference for two-period investments, as compared to the one-period liquidity shock discussed above. Figure 4.3 shows the dynamics of one and two-period interbank market investments dynamics for this case.

Figure 4.3 – Interbank market loans dynamics: $Z_{ai,t} = Z_{ai,t+1} = 1, Z_{ai,t+j} = 0, j = 2,3,...$

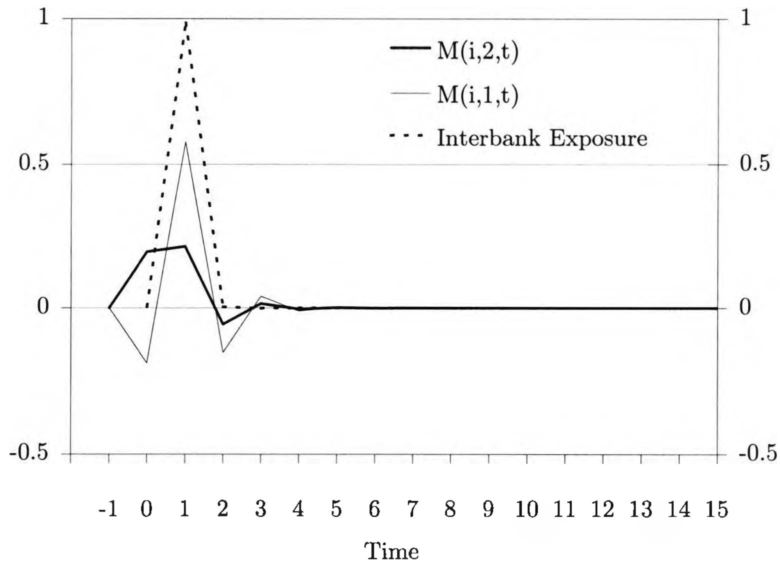


Short-term investments share about half of the total portfolio value. This follows from the fact that both market segments face the same interest rate sensitivity, i.e., $o = 1$.

c. <u>Anticipated liquidity shocks:</u> $Z_{ai,t} = 0, Z_{ai,t+1} = 1, Z_{ai,t+j} = 0, j = 2,3,...$

When shocks are anticipated the bank will start borrowing and lending the period before the actual liquidity shock takes place. In practice one would expect the bank to wait to borrow until the period when the liquidity shock happens. But, on contrary, the model predicts that banks will hoard funds early in the period when they expect a negative liquidity shock ahead.

Figure 4.4 – Interbank market loans dynamics: $Z_{ai,t} = 0, Z_{ai,t+1} = 1, Z_{ai,t+j} = 0, j = 2,3,...$



The rationale for this behaviour can be found on the reserve adjustment opportunity cost. Interest rates are assumed to fluctuate when the bank engages in interbank market trading and is conditioned by aggregate market liquidity shocks – i.e., other banks trading activity. When a shock is expected ahead, the bank knows that on the date of borrowing interest rates will go up, and it will attempt to split the effect between the two periods, first borrowing a proportion of required funds on period one for the long term, while investing the proceeds into short term loans. Next, it receives the proceeds from the short-term loan maturing this period and borrows an additional amount to compensate for the liquidity shock. The ability to split the effort between different maturities depends on interbank market depth and banks' trading impact upon market interest rates. When the short-term market is highly liquid the proportion of funds borrowed for the long term is small. It should, finally, be emphasized that this banking behaviour extends liquidity shocks into the future and heightens exposures in the interbank market for longer periods.[30]

d. Autocorrelated liquidity shocks: $Z_{ai,t} = 1$, $Z_{ai,t+j} = \rho^j Z_{ai,t}$, $j = 1,2,3,\ldots$

Finally, I take the case when shocks are serially correlated. I assume that the law of motion for $Z_{ai,t}$ is $Z_{ai,t+j} = \rho^j Z_{ai,t}$, $j = 1,2,3,\ldots$.[31] The expressions below define the interbank market investment strategy when interest rates are taken as given and there are no industry specific liquidity shocks ($Z_{an,t} = 0$).[32]

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[30] Should we consider reserve maintenance effects and the perfect substitutability of reserves between days of the reserve period and early borrowing would be reinforced. In fact, banks will borrow when interest rates are expected to be the lowest, avoiding periods of liquidity shortage. Under more general circumstances, i.e., reserve period effects apart, a bank will borrow for the long-term while lending for the short-term in an attempt to secure funds early in the period and avoid the negative impact upon interest rates on the day the liquidity shock occurs effectively.

[31] Alternative motions for the accumulated liquidity shocks can be assumed such as second or higher order serial correlation. First-order serial correlation however is adequate to capture zero mean reverting liquidity shocks.

[32] The equations are simplified expressions for:

$$M_{i,2,t} = \lambda_{i,1} M_{i,2,t-1} - \left[b_{i,k} - \frac{1}{2\beta_{i,0}} \lambda_{i,1} \left(\lambda_{i,2}^{-1} + \delta \right) \frac{1}{1-\lambda_{i,2}^{-1}} \right] k_t - \left[b_{i,r_1} + \frac{1}{\eta_i} \lambda_{i,1} \left(\lambda_{i,2}^{-1} + \delta \right) \frac{1}{1-\lambda_{i,2}^{-1}} \right] r_{1,t} + b_{i,r_2} \frac{1}{1-\lambda_{i,2}^{-i}} r_{2,t} + \left[b_{i,zai} - \lambda_{i,1} \lambda_{i,2} \left(\lambda_{i,2}^{-1} + \delta \right) \frac{\rho}{\lambda_{i,2}} \frac{1}{1-\left(\rho/\lambda_{i,2}\right)} \right] E_{t_0} \tilde{Z}_{ai,t}$$

$$M_{i,2,t} = -\Psi_{i,M_{i,2},t} M_{i,2,t-1} + \Psi_{i,Z_{ai},t} E_{t_0} \tilde{Z}_{ai,t} - \\ -\Psi_{i,k,t} k_t - \Psi_{i,r_1,t} \tilde{r}_{1,t} + \Psi_{i,r_2,t} \tilde{r}_{2,t} \tag{22}$$

$$M_{i,1,t} = -\Phi_{i,M_{i,2},t} M_{i,2,t-1} + \Phi_{i,Z_{ai},t} E_{t_0} \tilde{Z}_{ai,t} - \\ -\Phi_{i,k,t} k_t + \Phi_{i,r_1,t} \tilde{r}_{1,t} - \Phi_{i,r_2,t} \tilde{r}_{2,t} \tag{23}$$

Graphically, the optimization problem has the solution shown in Figure 4.5.

e. Purely competitive bank

An important case to discuss is when the interbank market is competitive and there are no transaction costs. This is equivalent to setting $\eta_i = \xi_i = 0$. Banks act as price takers and are assumed to borrow and lend at the market prevailing market interest rate. In practice this is equivalent to say that the bank is small relative to the market, and behaves as if the market is permanently able to absorb any positive or negative liquidity shocks without any price fluctuations.

Under these circumstances, we have a joint solution for $M_{i,1,t}$ and $M_{i,2,t}$. Under rational expectations, neutral banks will be indifferent between short and long term investments as long as the two alternatives yield the same expected

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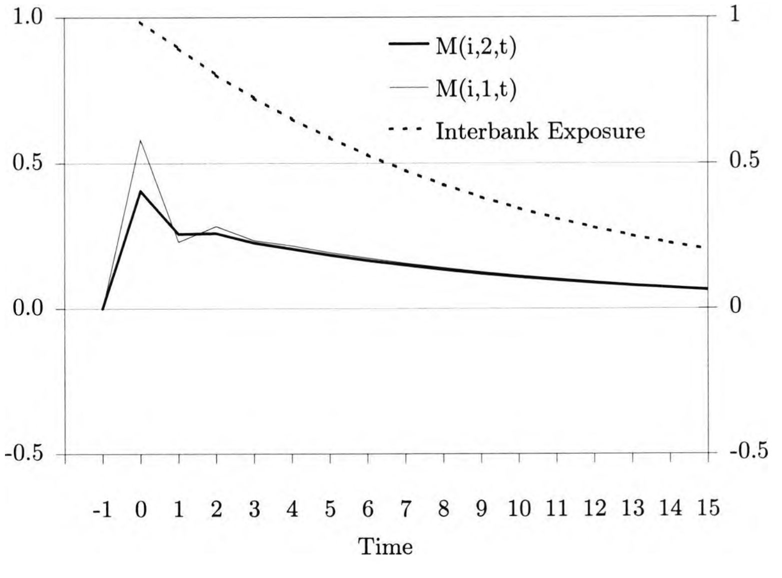
$$M_{i,^1,t} = \frac{a_i}{\eta_i}\left(1+\lambda_{i,1}\right) M_{i,2,t-1} - \left[c_{i,k} - \frac{a_i}{\eta_i} \frac{1}{2\beta_{i,0}} \lambda_{i,1} \left(\lambda_{i,2}^{-1} + \delta\right) \frac{1}{1-\lambda_{i,2}^{-1}} \right] k_t + \left[c_{i,r_1} - \frac{a_i}{\eta_i} \frac{1}{\eta_i} \lambda_{i,1} \left(\lambda_{i,2}^{-1} + \delta\right) \frac{1}{1-\lambda_{i,2}^{-1}} \right] r_{1,t} + \\ + \left(\lambda_{i,2}^{-1} \frac{1}{1-\lambda_{i,2}^{-1}} - 1 \right) c_{i,r_2} r_{2,t} + \left[c_{i,zai} + \frac{a_i}{\eta_i} \lambda_{i,1} \lambda_{i,2} \left(\lambda_{i,2}^{-1} + \delta\right) \frac{\rho}{\lambda_{i,2}} \frac{1}{1-\left(\rho/\lambda_{i,2}\right)} \right] E_{t_0} \tilde{Z}_{ai,t}$$

return. This can be seen in the analytical expression that is a solution to the problem, which links one and two-period interest rates:[33]

$$E_{t_0}\tilde{r}_{1,t+1} = \delta\tilde{r}_{1,t} + \frac{(1+\delta)}{\delta}\tilde{r}_{2,t} \qquad [24]$$

Figure 4.5 – Interbank market loans dynamics: $Z_{ai,t} = 1, Z_{ai,t+j} = \rho^j Z_{ai,t}, j = 1,2,3,...$



Next period overnight rate is expected to equal the difference between the current two-period and the overnight interest rates. The bank can still determine the optimal investment policy for the interbank market, but due to the assumed risk-neutrality, there is no allocation rule that leads the choice between one and two-period investments. The decision is mostly arbitrary.

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33 See Appendix A4 for an analytical derivation.

Intuition helps in explaining this result. Assume the bank has an excess of liquidity that will last for two periods. If the interest rates are such that making a two-period investment, or making two consecutive one-period investments yields the same expected return, the bank will be indifferent between these alternatives. On the other hand, being a price taker, if two period investment's return is different from that of one period investment that is rolled over, the bank will make a gain from arbitrage opportunities.[34]

Naturally, the result follows from bank's assumed risk neutrality. As far as the expected return on both alternatives different, the bank will borrow from one market segment to invest on the other and make a positive profit. Nevertheless, introducing risk aversion into the problem, in the sense that investors have a preference for sure returns, does not change the results very much. Banks will now seek a reward for incurring the additional risk, and the relationship between the two-period and one-period interest rates will be additionally intermediated by the bank's risk aversion, which commands an interest rate risk premium for longer maturities.[35]

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[34] To be rigorous, the bank is not arbitraging the yield curve, as the followed strategy is uncovered and leaves open the risk of a potential loss.

[35] The coefficients on each demand function can be interpreted as banks' risk aversion. When being different, banks have different incentives to enter uncovered arbitrage trading.

6. Interdependence and contagion potential: the case of two banks

When using the inter-bank market to lend short-term funds, each bank builds up an exposure to the counterparty. If, for any reason, the borrowing counterparty fails to pay back the lending bank it presents a threat of systemic risk that may spread through real channels, in addition to the expected market business contraction due to information channels[36]

I assume, for the sake of simplicity there are only two banks – bank A and bank B – and solve for the inter-bank market equilibrium. The procedure is in three steps. First, I use the interbank demand functions of bank B to determine the sensitivity of interest rates $r_{1,t}$ and $r_{2,t}$ to changes in interbank investments $M_{i,1,t}$ and $M_{i,2,t}$ with $i = A, B$. Second, I make use of the interbank market equilibrium constraints, $M_{A,1,t} + M_{B,1,t} = M_{A,2,t} + M_{B,2,t} = 0$ and derive expressions for $r_{1,t}$ and $r_{2,t}$ as weighed averages of expected liquidity shocks and inter-bank investments at time t and t+1.[37] [38] Interest rates are determined by the interaction of the actions of both banks. Each bank faces a demand and supply

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[36] Information channels are mainly related to asymmetric information. Information channels come into play when, due to asymmetric information, interbank lending is rationed because financial institutions perceive each other as being risky. This mutual rationing may gridlock the interbank market, as it ceases to perform the liquidity provision function, though financial institutions might be solvent. Such a market failure may require central bank assistance.

[37] This is the same as: $M_{A,1,t} = -M_{B,1,t}, M_{A,2,t} = -M_{B,2,t}$

[38] See Appendix A3

curves for one and two period investments. Third, I substitute for the interest rates and the interest rate sensitivity coefficients in the system of Euler equations for bank A and obtain the optimal interbank market investments sequences $\{M_{i,1,t}\}_0^\infty$ and $\{M_{i,2,t}\}_0^\infty$.

6.1. Demand and supply of funds in the interbank market

When there are only two banks in the market, the demand function of one bank is the supply function of the other, and vice versa. Bank A is able to determine how interest rates change just by observing the willingness of bank B to buy or sell funds in each market segment as interest rates change. Thus, the interest rates sensitivity coefficients η_A and ξ_A are necessarily linked to the reserve adjustment opportunity curve of the other bank. This statement makes it possible to determine η_A and ξ_A from the $\beta_{B,0}$ coefficient on bank's B reserve adjustment opportunity cost function [5][39]

The coefficients η_A and ξ_A can be determined from the optimal investment sequences $\{M_{B,1,t}\}_0^\infty$ and $\{M_{B,2,t}\}_0^\infty$ for bank B.[40] In a rational expectations

[39] Note that the marginal change in interest rates due to changes in interbank investments does not depend on $\beta_{i,1}$, because liquidity shocks can only produce parallel shifts in the reserve adjustment opportunity curve, without tilting it. Yet, the level of interest rates depends on the liquidity shocks themselves. Positive liquidity shocks will push interest rates downward and vice-versa.

[40] The solution for bank B has equivalent Euler equations [15] and [16].

equilibrium it can be shown that for given interest rates changes, interbank investment responses depend almost exclusively on $\beta_{B,0}$. Furthermore, the extent of the response depends on the size of $\beta_{B,0}$. The higher $\beta_{B,0}$, the larger the change in the interest rate bank B is willing to pay for additional borrowing. This reflects bank's high sensitivity to the opportunity cost of holding excess reserves. The intuition is that when bank B perceives the central bank discipline to be very tight, it is willing to pay high interest rates to avoid closing the day with an expected negative cash position.

One can approximate the analytical result analyzing the way bank B makes decisions concerning the excess reserve management problem.[41] At equilibrium, bank B chooses the amount of excess reserves $X_{B,t}$ and the investment policy $M_{B,1,t}$ and $M_{B,2,t}$ such as the expected marginal opportunity cost of holding excess reserves, given by the reserve adjustment opportunity cost, equals the marginal return in each market segment.[42]

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[41] Though the solution proposed in the following lines is not exactly equivalent to the analytical solution proposed in the lines above it presents a very good approximation. A shortcoming of this approach is, however, that it does not fully account for the possible substitution effect between $\{M_{i,1,t}\}_0^\infty$ and $\{M_{i,2,t}\}_0^\infty$ when interest rates change.

[42] In a purely competitive setup, where bank's actions do not have any impact on interest rates, the equilibrium is achieved when excess reserves marginal opportunity cost equals interest rates in each market segment. In case interest rates are responsive to loan size, the marginal revenue and interest rates in each market segment are not necessarily equal. Alternatively, it is expressed as a weighted averaged of one and two-period interest rates. Nevertheless, the non-arbitrage rational expectations equilibrium condition must be met at every moment in time, or

For bank A, the expected marginal opportunity cost of holding excess reserves is approximately equal to $-\beta_{A,0}\Delta X_{A,t}$. When the excess reserves increase by 1, the marginal opportunity cost decreases $\beta_{A,0}$. Notice now that the change in excess reserves might depend either on $M_{A,1,t}$ or $M_{A,2,t}$. Whether the change in excess reserves is attributable to $M_{A,1,t}$ or $M_{A,2,t}$, one- and two-period interest rates must at a $\beta_{A,0}$ rate, in such a way to keep equilibrium. Considering only two banks and that bank A lends to bank B, and vice versa, the relationship between interest rates and interbank market investments for bank B is linked to bank A opportunity cost, and can be written as follows.

$$\frac{\partial \tilde{r}_{1,t}}{\partial M_{B,1,t}} = \frac{\eta_A}{2} = -\beta_{B,0} \tag{25}$$

$$\frac{\partial \tilde{r}_{2,t}}{\partial M_{B,2,t}} = \frac{\xi_A}{2} = -\beta_{B,0} \tag{26}$$

The similarity between the two maturities is derived from risk neutrality conditions and from the fact that both investments $M_{i,1,t}$ and $M_{i,2,t}$ have the same weighted contribution to the opportunity cost function. Results follow from the assumption that when bank A chooses to increase one-period investments it keeps two-period investments constant, and vice-versa. Though

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the bank will arbitrage away any profits borrowing and lending for different maturities. Naturally, this condition follows from the postulated rational expectations and risk neutrality of banks, i.e., it is not exactly equivalent to riskless arbitrage. We have already showed that $\beta_{B,1}$ does not have a direct impact on the interest rates changes when the interbank market investments change, because each bank assumes that the impact of $\beta_{B,1}$ on interest rates depends on the aggregate liquidity shock to the banking system and not to the interbank market investment decision itself.

the analytical solution is more complete and accounts for the relationship between the two maturities, it can be shown to depend mainly on $\beta_{B,0}$ and, therefore, not changing the form of the final solution to the problem.

6.2. Interbank market 'yield curve'

Having determined how interest rates respond interbank market investments, highlighting the inter-relationship between bank A and bank B, we can now proceed to analyze how interest rates are determined in the interbank market. Imposing the market equilibrium constraint and solving for the interest rates we get the interbank market yield curve.[43]

Interest rates are weighted averages of expected aggregate liquidity shocks in periods t and t+1 and bank's liquidity preference relative to the counterpart as measured by $\beta_{d,0} = \beta_{A,0} - \beta_{B,0}$.[44]

$$\tilde{r}_{1,t} = k_t + \beta_{d,0}\left(M_{A,1,t} + M_{A,2,t} + M_{A,2,t-1}\right) - \left(\beta_{d,1}E_{t_0}\tilde{Z}_{aA,t} + \beta_{d,2}E_{t,0}\tilde{Z}_{aB,t}\right) \qquad [27]$$

$$\begin{aligned}\tilde{r}_{2,t} = {} & \frac{1}{1+\delta}\tilde{r}_{1,t} + \frac{\delta}{1+\delta}k_{t+1} + \frac{\delta}{1+\delta}\beta_{d,0}\left(M_{A,2,t} + E_{t_0}M_{A,1,t+1} + E_{t_0}M_{A,2,t+1}\right) - \\ & -\frac{\delta}{1+\delta}\left(\beta_{d,1}E_{t_0}\tilde{Z}_{aA,t+1} + \beta_{d,2}E_{t_0}\tilde{Z}_{aB,t+1}\right)\end{aligned} \qquad [28]$$

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[43] The yield curve is obtained directly from the Euler equations.

[44] The equations are obtained after substituting for:

$$\beta_{d,0} = \beta_{A,0} - \beta_{B,0}$$
$$\beta_{d,1} = \beta_{A,0} + 1/2\,\beta_{A,1} + 1/2\,\beta_{B,1}$$
$$\beta_{d,2} = \beta_{B,0} + 1/2\,\beta_{A,1} + 1/2\,\beta_{B,1}$$

The interest rates equations [27] and [28] are the rational expectations solutions to demand and supply functions in the interbank market. The interbank return on inter-bank investments is equal to the risk free interest rate – k – plus a liquidity premium, that depends on the aggregate liquidity shock. If the aggregate liquidity shock is positive, interest rates will decrease in response to the excess liquidity.[45] Conversely, if banks as a whole face insufficient cash reserves, they will drive interest rates up when competing for short-term funds. In fact, this is what happens in inter-bank markets when most of the banks are on the same market side. Particularly, during highly volatile periods, most banks are buying funds and triggering a sharp increase in money market interest rates unless the central bank steps in selling funds to restore equilibrium and reintroduce market confidence.

The model is able to explain the high variability of interest rates while the excess reserves are expected to be fairly stable over time. The data generating processes for $\tilde{Z}_{aA,t}$ and $\tilde{Z}_{aB,t}$ can be used to explain why interbank market interest rates are independent of transaction costs from participating in the market. The perceived penalty imposed by the central bank on non-performing banks is central to explain the time pattern in interest rates.

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[45] One should want to impose that interest rate on inter-bank investments never goes below zero. Such a constraint, being binding, could explain why banks may end the day up with excess reserves, just because they cannot find good investment alternatives.

Interest rates respond to banks' perceptions of each others reserve adjustment opportunity curve parameters $\beta_{A,0}$ and $\beta_{B,0}$. If bank A is more conservative then it might be willing to drive interest rates up in order to obtain the necessary interbank market funds and avoid the costly overdraft penalties.

When considering multi-period interest rates – i.e., $\tilde{r}_{2,t}$ – the liquidity premium is related not only to current liquidity shocks, but also to future expected liquidity shocks. This can explain, under certain circumstances, the wide gap between rates of close maturities. When expected liquidity shocks are highly volatile across time, interest rates inherit a similar volatility pattern.

Equations [27] and [28] are at the root of the yield curve for interbank investments and may help to determine the rationally expected sequence one-period interest rates. Note that the two-period return on a inter-bank loan is $2\tilde{r}_{2,t}$ and for the rational expectations equilibrium to verify we must have:[46]

$$2\tilde{r}_{2,t} = \tilde{r}_{1,t} + E_{t_0}\tilde{r}_{1,t+1} \qquad [29]$$

and the expected overnight interest rate next period is:

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[46] To be consistent with the rest of the exposition, we assume that interest earned in period t is not reinvested for the next period. Only the principal earns interest. This is why we assume the two-period investment return as being equal to twice the two-period interest rate.

$$E_{t_0}\tilde{r}_{1,t+1} = \tilde{r}_{1,t} + \frac{2\delta}{1+\delta}\left(k_{t+1} - k_t\right) + \frac{2\delta}{1+\delta}\beta_{d,0}\left(M_{A,t+1} - M_{A,t}\right) + \\ + \frac{2\delta}{1+\delta}\beta_{d,1}\left(E_{t_0}\tilde{Z}_{aA,t} - E_{t_0}\tilde{Z}_{aA,t+1}\right) + \\ + \frac{2\delta}{1+\delta}\beta_{d,2}\left(E_{t_0}\tilde{Z}_{aB,t} - E_{t_0}\tilde{Z}_{aB,t+1}\right) \quad [30]$$

where $M_{A,t} = M_{A,1,t} + M_{A,2,t} + M_{A,2,t-1}$ and $M_{A,t+1} = M_{A,2,t} + E_{t_0}M_{A,1,t+1} + E_{t_0}M_{A,2,t+1}$.

Equivalently, the expected one-period interest rate for investments at time t+1 is the current one-period interest rate plus a liquidity premium related to the relative size of the liquidity shocks ahead. When we expected small liquidity shocks in the future interest rates fall below the current level. On contrary, if the market is expected to remain short, the liquidity premium will increase proportionately. Note that it may happen that no matter an expected shortage of liquidity next period, expected interest rates fall below current interest rates in case the liquidity shock is sufficiently high.[47] It is also interesting to note that current and future two-period investments have an impact on $E_{t_0}\tilde{r}_{1,t+1}$.

6.3. Optimal investment policy and interdependencies

To obtain the optimal sequences $\left\{M_{A,1,t}\right\}_0^\infty$ and $\left\{M_{B,1,t}\right\}_0^\infty$, we substitute for the interest rates in the Euler equations and simplify[48]

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[47] This is the case when $E_{t_0}\tilde{Z}_{an,t} - E_{t_0}\tilde{Z}_{an,t+1} < 0$. It suffices that $E_{t_0}\tilde{Z}_{an,t} < E_{t_0}\tilde{Z}_{an,t+1} < 0$

[48] See Appendix A5.

$$M_{A,2,t} = \lambda_{A,1} M_{A,2,t-1} + \varpi_{A,t} E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t} - \beta_{aB,1}\tilde{Z}_{aB,t}\right) + \\ + \frac{1}{2\beta_0}\sum_{j=1}^{\infty}\pi_{A,t+j} E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t+j} - \beta_{aB,1}\tilde{Z}_{aB,t+j}\right) \quad [31]$$

$$M_{A,1,t} = \frac{\alpha_A}{\eta_A}\left(1+\lambda_{A,1}\right) M_{A,2,t-1} + \varpi_{A,1,t} E_{t_0}\left[\beta_{aA,1}\tilde{Z}_{aA,t} - \beta_{aB,1}\tilde{Z}_{ab,t}\right] + \\ + \frac{\alpha_A}{\eta_A}\frac{1}{2\beta_0}\sum_{j=1}^{\infty}\pi_{A,t+j} E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t+j} - \beta_{aB,1}\tilde{Z}_{aB,t+j}\right) \quad [32]$$

where $\varpi_{A,2,t} = -\frac{1}{2\beta_0}\lambda_{A,1} > 0$ and $\varpi_{A,1,t} = -\frac{\alpha_A}{\eta_A}\frac{1}{2\beta_0}\left(1+\lambda_{A,1}\right) > 0$.

Note that due to the assumption that there are only two banking firms, the optimal investment policies for bank A and B are exactly symmetrical. When they have different expectations about each other liquidity shocks, the interbank market may fail to redistribute liquidity and gridlock. When expected liquidity shocks to the banking system sum up to zero the yield curve is horizontal at the risk-free interest rate, reflecting absence of any arbitrage gains on the assumption that banks are risk neutral.

6.4. Discussion of results

Next, we simulate interbank market behaviour under a set of different scenarios. The scenarios discussed below are bounded by the two limiting cases of symmetric liquidity shocks on one extreme, and of asymmetric liquidity shocks on the opposite side. The impact and persistence of liquidity shocks upon investment decisions and interest rates is calibrated using the following parameters: $k_t = 0.0002$, $\beta_{A,0} = 0.001$, $\beta_{B,0} = 0.002$, $\beta_{A,1} = \beta_{B,1} = 0.0001$. Interest rates are endogenous to the model and derived from interbank market equilibrium conditions.

a. <u>Weighted identical shocks</u>: $E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t+j} - \beta_{aB,1}\tilde{Z}_{aB,t+j}\right) = 0,\ j = 0,1,2,\ldots.$

When weighted liquidity shocks are asymmetric, no interbank market trading takes place. This illustrates the case when both banks are willing to borrow or to lend. Define the cut-off rate as the interest rate above (below) which the bank is willing to start lending (borrowing). In case both shocks are positive, each bank sees the cut-off rate reduced to a level compatible to its equilibrium of no trade.

Figure 4.6 – Cut-off rate for banks A and B

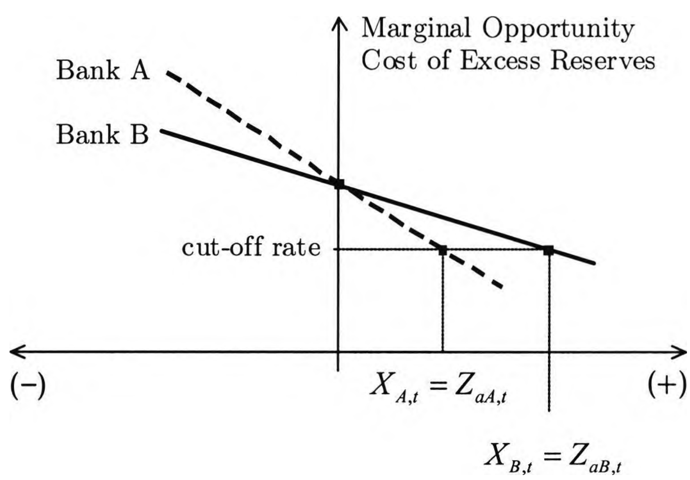

Figure 4.6 illustrates the cut-off rate concept for this specific case. At the cut-off rate level both banks want to hold excess reserves equal to their liquidity shocks. Hence, no trade takes place. Notice that if the marginal cost of borrowing drops below the cut-off rate, both banks are willing to borrow, and

for marginal returns above the cut-off rate both banks are willing to supply funds in the interbank market. Yet, none of these outcomes is feasible given the market equilibrium condition.

Figure 4.7 – Interest rate dynamics: $E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t}-\beta_{aB,1}\tilde{Z}_{aB,t}\right)=0$ and

$$E_{t_0}\tilde{Z}_{aA,t+j}=E_{t_0}\tilde{Z}_{aB,t+j}=0 \; j=1,2,...$$

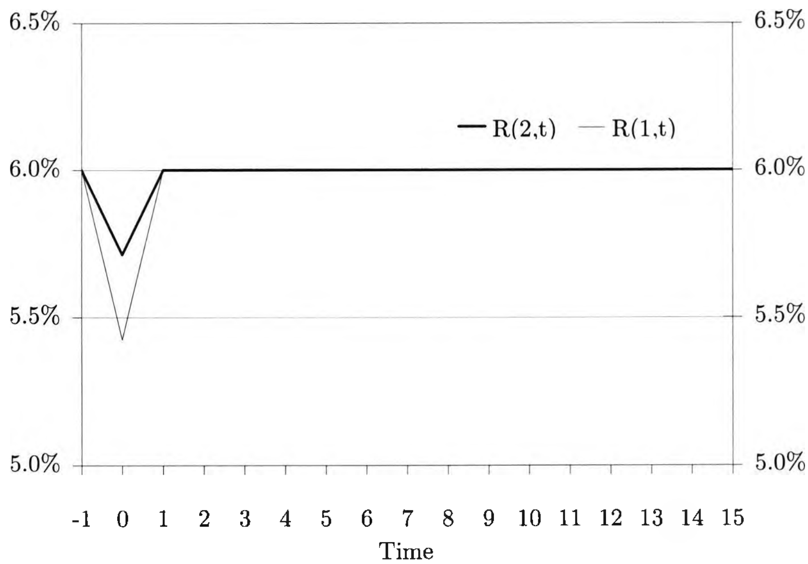

Figure 4.7 shows how interest rates change when both banks face positive liquidity shocks and the weighted difference of these shocks is zero. Given the choice of parameters, we simulate a liquidity shock to bank A double the size of that to bank B. No interbank market trade takes place, because following the shock both banks are willing to lend at the market interest rates. Also, they are willing to accept lower interest rates to maximize expected return. Eventually, their joint action will bring interest rates down to a level below which they do not anymore find it optimal to lend. Truly, interest rates predicted by the model are not observed in the market, as no agreement is reached as to support

trading. The suggested values stand only as a yardstick, beyond which banks are willing to start lending and borrowing. In fact, they represent the perceived opportunity costs of funds for one and two-period maturities. Not surprisingly, and mainly due to the specification of the reserve adjustment opportunity curve, the interest rates are sensitive to the size of the liquidity shocks $Z_{aA,t}$ and $Z_{aB,t}$.

Assuming the cut-off rates reflect the yield curve, it is interesting to note that if liquidity shocks are both negative the yield curve tilts to the left, with short-term interest rates increasing above long term rates, and both increasing above the interest rate k_t. On contrary, when liquidity shocks are positive, the yield curve shifts downwards and tilts to the right.

b. <u>Identical liquidity shocks</u>: $E_{t_0}\tilde{Z}_{aA,t} = E_{t_0}\tilde{Z}_{aB,t} \neq 0$, $E_{t_0}\tilde{Z}_{aA,t} = E_{t_0}\tilde{Z}_{aB,t} = 0,\ j = 1,2,...$

Although banks expect identical liquidity shocks there may still be trading, depending on the relative size of $\beta_{aA,1}$ and $\beta_{aB,1}$. Figure 4.8 below illustrates the case when both banks face a positive liquidity shock equal to 1. Because bank A has a more stringent reserve adjustment opportunity cost function, it is willing to borrow from bank B and increase its excess reserves when the interest rates decrease. Eventually, the two banks find an equilibrium interest rate that is preferred to both. Bank A will borrow from bank B.[49]

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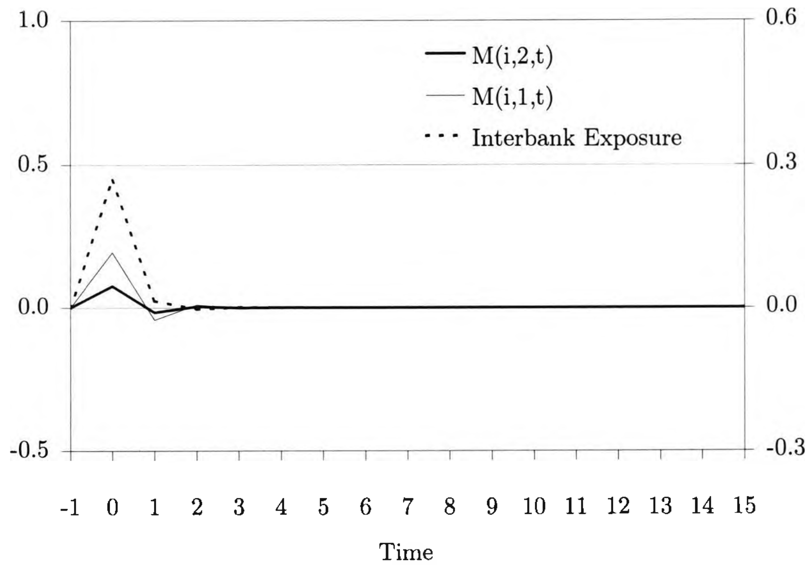
[49] The opposite result is achieved if B faces a more stringent reserve adjustment opportunity cost function than bank A. Nevertheless, interest rates would show exactly the same behaviour.

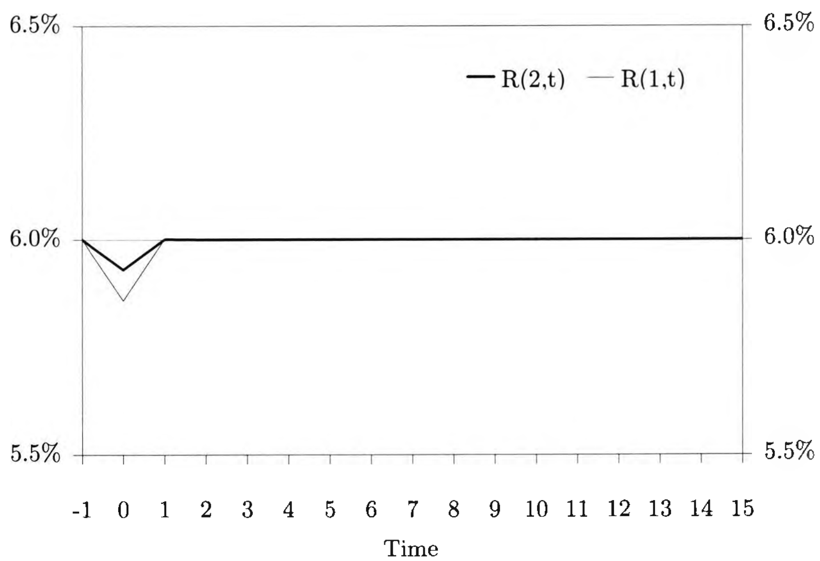
Figure 4.8 – Interbank dynamics: $E_{t_0}\tilde{Z}_{aA,t} = E_{t_0}\tilde{Z}_{aB,t} \neq 0$ and

$$E_{t_0}\tilde{Z}_{aA,t} = E_{t_0}\tilde{Z}_{aB,t} = 0,\ j = 1,2,...$$

Panel a. Interbank market loans



Panel b. Interbank market yield curve



Interest rates will decrease as the yield curve shifts downwards and tilts to the right. The change depends on the relative size of $\beta_{aA,1}$ and $\beta_{aB,1}$: i.e., the smaller the difference between these two parameters the lower the interest rate volatility. Changes in $r_{1,t}$ exceed those of $r_{2,t}$ because the transitory liquidity shock disappears next period. Thus, the excessive liquidity pressure is concentrated on one-period loans, making the overnight interest rate more volatile relative to longer maturities.

We could hypothesise that banks preferences for excess reserves is linked to the reserve holding period length. It is possible that a risk adverse bank demands more excess reserves because it prefers to secure funds early at the beginning of the reserve holding period. Under those circumstances the reserve adjustment opportunity costs would change over the maintenance period. However, this would be inconsistent with the expected martingale property of interest rates.

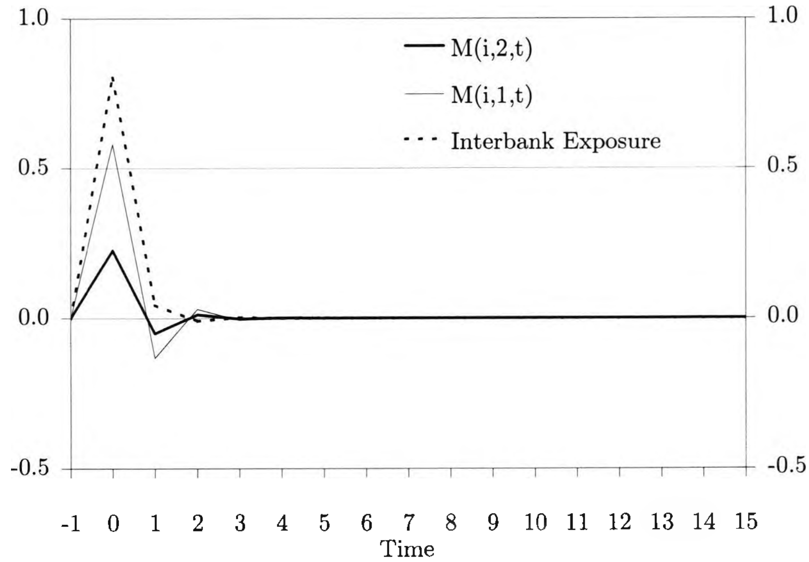
c. Perfectly symmetrical shocks:

This is the case when the interbank market can perform to full extent the role of provider of liquidity insurance. Interest rates are kept fairly stable when liquidity shocks have opposite signs, as it can be seen in Figure 4.9. Notice that the optimal interbank action (borrowing or lending) for each bank is not exactly symmetrical to the shock because the opportunity cost functions are different. The solution converges to symmetry as the difference between the opportunity cost functions for bank A and B becomes negligible. The limiting case of identical banks is discussed next.

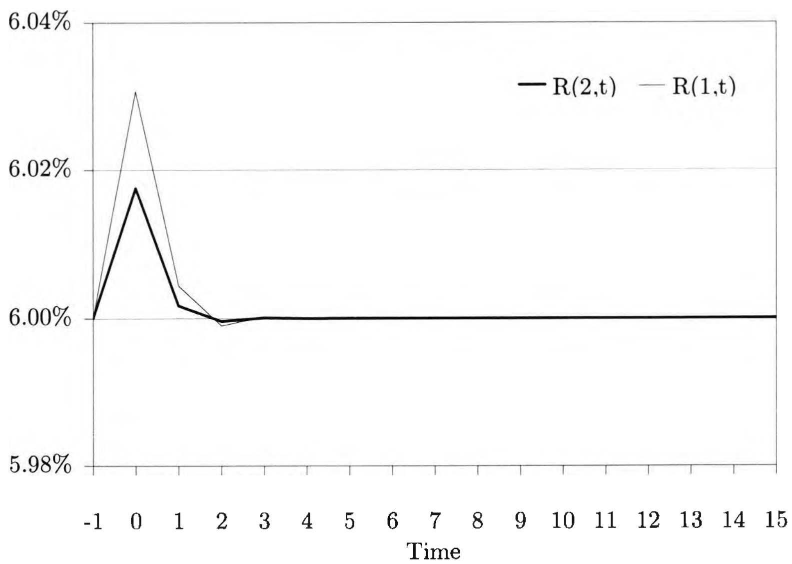
Figure 4.9 – Interbank dynamics: $E_{t_0}\tilde{Z}_{aA,t} = -E_{t_0}\tilde{Z}_{aB,t} = 1$ and

$$E_{t_0}\tilde{Z}_{aA,t} = E_{t_0}\tilde{Z}_{aB,t} = 0,\ j = 1, 2, \ldots$$

Panel a. Interbank market loans



Panel b. Interbank market yield curve



6.5. A special case: two identical banks

A special case arises when the two banks are identical in all respects. Trading volume and interest rate volatility have some special characteristics and in case both banks are hit by identical liquidity shocks – i.e., there is a industry wide liquidity shock – the interbank market might gridlock and thought banks are solvent we need the central bank to step in as a lender of last resort, and both banks are borrowing using the marginal lending facilities. In the more general case when liquidity shocks are bank specific, trading takes place and the use of the discount window or marginal lending facilities is mitigated. Interest rates are equal to the weighted average of expected aggregate liquidity shocks.

$$\tilde{r}_{1,t} = k_t - (\beta_0 + \beta_1) E_{t_0}\left(\tilde{Z}_{aA,t} + \tilde{Z}_{aB,t}\right) \quad [33]$$

$$\tilde{r}_{2,t} = \frac{1}{1+\delta}\tilde{r}_{1,t} + \frac{\delta}{1+\delta}\left[E_{t_0}k_{t+1} - (\beta_0 + \beta_1) E_{t_0}\left(\tilde{Z}_{aA,t+1} + \tilde{Z}_{aB,t+1}\right)\right] \quad [34]$$

Two period interest rates conforms the expectations hypothesis. When banks are risk neutral, the next period expected interest rate already includes a liquidity risk premium. In fact, next period the interest rate will deviate from the central bank target by an amount equal to the aggregate liquidity shock.

$$\tilde{r}_{2,t} = w\tilde{r}_{1,t} + (1-w) E_{t_0}\tilde{r}_{1,t+1} \quad [35]$$

where the weight $w = 1/(1+\delta)$ depends on the subjective discount function.

The optimal investment sequencies are:

$$M_{A,2,t} = \lambda_{A,1} M_{A,2,t-1} - \frac{1}{2}\lambda_{A,1} E_{t_0}\left(\tilde{Z}_{aA,t} - \tilde{Z}_{aB,t}\right) + \frac{1}{2}\sum_{j=1}^{\infty}\pi_{A,t+j} E_{t_0}\left(\tilde{Z}_{aA,t+j} - \tilde{Z}_{aB,t+j}\right) \quad [36]$$

$$M_{A,1,t} = \frac{\alpha_A}{\eta_A}\left(1+\lambda_{A,1}\right) M_{A,2,t-1} - \frac{\alpha_A}{\eta_A}\frac{1}{2}\left(1+\lambda_{A,1}\right) E_{t_0}\left[\tilde{Z}_{aA,t} - \tilde{Z}_{aB,t}\right] + \frac{\alpha_A}{\eta_A}\frac{1}{2}\sum_{j=1}^{\infty}\pi_{A,t+j} E_{t_0}\left(\tilde{Z}_{aA,t+j} - \tilde{Z}_{aB,t+j}\right) \quad [37]$$

Contrary to the case when banks have different reserve adjustment opportunity cost functions, the market fails to provide a solution when both banks face identical liquidity shocks. Though shadow interest rates change reflecting bank's market positions, no trade will take place because banks have exactly the same preferences. In case banks A and B face an identical positive liquidity shock interest rates will be driven down to the cut off rate.

More problematic is the case when both banks are short of liquidity. Interest rates will be driven up to the point where banks will choose to borrow from the central bank. Interest rates might increase unboundedly, and still no bank is willing to sell funds to the other. This means that the market is overall short of funds and the central bank intervention lending funds at the marginal lending facility curbs interest rate increase. Alternatively, in small open economies, banks can borrow in the foreign interbank market, paying higher interest rates up to the point where the cost of getting funds from other banks equals the costs of funding from the central bank.[50]

6.6. Extensions: interdependence in case of several banks

The model can be extended to encompass several banks. The most interesting case is when banks are different and subject to different idiosyncratic and common industry liquidity shocks. Assuming the above formulation, we regard bank B in our model as standing for the remaining of bank industry. Therefore, bank A faces a liquidity shock that can be offset for the liquidity shock on the remaining banking industry. Alternatively, we could assume at each moment the industry is divided between banks willing to borrow funds – bank A – and banks with excess reserves and that work as potential lenders – bank B. For borrowing banks, the ability of the interbank market to clear negative liquidity shocks depends on how the rest have enough liquidity to lend. In case banks with surplus do not have enough funds to match the needs of those in deficit, interest rates will be driven up and interbank trading is reduced. On contrary, if there is too much excess liquidity on the lending side, interest rates will be forced downwards, while interbank trading might increase.

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[50] Presumably, funding in the foreign interbank market is more expensive mainly due to the costs of hedging exchange rate risk and the spread from reduced reputation of the borrowing bank. Nevertheless, if banks perceive the opportunity cost of borrowing from the central bank too high, they might prefer to borrow from abroad, while the discount window rate stays below the effective interest rate paid on foreign loans.

Nevertheless, the overall impact upon interbank market trading and the level of bilateral exposure depends greatly on how borrowing and lending banks are sensitive to the excess reserves opportunity cost.[51]

7. Conclusion

We developed a dynamic model of interbank trading, where banks can borrow and lend for different maturities. Banks are subject to specific and common liquidity shocks, and must hold positive reserve balances at the central bank daily. When banks fail to have enough cleared funds they must borrow from the discount window or marginal lending facilities, for which they pay a penalty rate and collateralize with assets from their own portfolio.

We analysed the interbank market ability to provide liquidity insurance under different scenarios and the implications of interbank trading for the size of bilateral exposures and potential systemic threats to the banking system. This paper contains also some implications for monetary policy, while showing that the interbank term structure of interest rates depend on banks' expected

[51] Notice that the larger the number of banks willing to lend funds, the less sensitive the interbank interest rate is to demand of funds from borrowing banks. Therefore, in fact, each bank faces a time-varying market interest rate response to its demand of funds. Though, each bank has a stable excess reserve opportunity cost function, the greater the number of banks on a given side of the interbank market the less the weighted average interest rate response.

liquidity shocks, and when liquidity shocks are distributed unevenly across banks the likelihood of increased interest rate volatility increases.

In general, we find that banks chose loans of varying maturities as to match the expected pattern of liquidity shocks and, smooth interest rates when maximising the inter-temporal profits from reserve management activity. Choosing interbank loans of different maturities creates persistence in the interbank market, and it is possible that transitory negative liquidity shocks are financed with long-maturity interbank loans. Hence, banks' interbank exposure does not disappear with the liquidity shock when it reverts to zero.

The model suggests that persistence increases with the range of maturities available from which the bank can choose and, also, it depends on the degree of liquidity available at each market segment, as measured by interest rate sensitivity. Highly liquid markets, such as the overnight market, are more likely to be chosen for borrowing and lending. As a corollary, a highly liquid overnight market, ready to absorb any liquidity shock with small interest rate fluctuation, is likely to mitigate persistence, and therefore reduces potential systemic threats. A rationale is found in support of central bank standing facilities. Lending and borrowing overnight from the central bank may help to alleviate persistence in the interbank market and, therefore, reduce bank-by-bank interbank market exposure.

It has been shown that under certain circumstances the interbank market may gridlock and fail to provide the intended liquidity insurance. As expected, the market is highly fragile when banks face positively correlated liquidity shocks. In this case, the central bank must clear the market, either through the discount window or by allowing banks to have negative excess reserves at the end of the accounting reserve period. If the shocks are persistent and banks are not able to realise enough liquidity by selling the loans and securities portfolio, the central bank acts as a lender of last resort to prevent the system to halt.

When liquidity shocks are bank specific the interbank market is usually able to allocate liquidity amongst market participants. Banks with excess reserves are natural lenders to banks with shortage of funds until each one achieves equilibrium, but this is not always the case. It may happen that a bank with a positive liquidity shock ends the day borrowing funds from other banks if interest rates are sufficiently low.

Our model does not account for credit rationing. And in case of bank specific liquidity shocks, we assume that banks with excess funds lend with no limits to all the others at the equilibrium interest rate. However, and despite the idiosyncrasy of liquidity shocks, banks' individual preferences for excess liquidity might gridlock the interbank market. If the bank has a preference for excess reserves to face en-of-the day unexpected liquidity shocks arising from the payments system, the bank in shortage of funds is forced to borrow from the discount window though the system as a whole has enough aggregate funds, while interest rates of different maturities are pushed upwards. This result can be interpreted as a price credit rationing effect.

The market certainly gridlocks when shocks are industry wide and all banks face a negative liquidity shock, or when all expect a negative liquidity shock. This is also the case in small open economies when exchange rate stability is pursued by the central bank. In that case, banks might face liquidity shortage and be unable to meet reserve requirements at the central bank. Lending to banks short of funds is therefore needed to keep the system running. Should the central bank refrain from lending or prevent borrowing from abroad and banks solvency would be put in jeopardy, as fire selling assets would imply huge losses to banks in distress.

The model can be extended to accommodate several banks, having different liquidity preferences. We would also like to ask what are the implications of averaging reserve requirements over a maintenance period, and its implications upon interest rates and the amount of borrowing and lending. Credit rationing and regular central bank provision of liquidity might be brought into the analysis. In particular it would be interesting to explore how central bank main refinancing operations might not have the desired impact, as big banks getting the main share of funds do not effectively distribute the funds to other banks through the interbank market due to credit rationing considerations. This two-tier system, is particularly suited for the Eurosystem, where small banks might experience difficulties in accessing the first tier liquidity market and have to borrow from large centre banks whom, in turn, have accumulated enough liquidity – either borrowing from other large banks or from the central bank – and are willing to lend to small banks.

8. Appendix

Appendix A1 – Banks daily excess reserves

The amount of reserves held by bank i in day t, after the inter-bank market closes and all trades are settled is equal to

$$\tilde{X}_{i,t} = \left(X_{i,t-1} - M_{i,1,t} - M_{i,2,t} + \tilde{Z}_{i,t}\right) + \left(M_{i,1,t-1} + M_{i,2,t-2}\right) \qquad \text{[A.1]}$$

where, $\tilde{Z}_{i,t}$ is the realized liquidity shock. We assume interest rate paid on interbank deposits is negligible and for practical reasons can be included in the random liquidity shock $\tilde{Z}_{i,t}$.[52]

The reserve position at the end of the day has two terms. The first term in brackets, on the right hand side of equation [A.1] is out of the control of the bank at time t and relates the surplus (deficit) in the reserve account in the previous day, and the daily inflow (outflow) of money resulting from past inter-bank investments maturing this period, and from a liquidity shock, which we assume random as a function of other balance sheet items, as we explain below. The second term on the right hand side of equation [A.1] represents the interbank investment policy for period $t-1$.

To simplify equation [A.1] substitute backwards and solve for $\tilde{X}_{i,t}$:

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[52] The optimisation procedure is unchanged and left more tractable.

$$\tilde{X}_{i,t} = \sum_{i=0}^{t} \tilde{Z}_{i,t-s} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1} \qquad [A.2]$$

Assuming that $\sum_{s=0,t} \tilde{Z}_{i,t-s}$ can be expressed as a function of past and current period liquidity shocks, where the latter is random at time t, $\sum_{s=0,t} \tilde{Z}_{i,t-s} = \sum_{s=1,t} Z_{i,t-s} + \tilde{Z}_{i,t}$. However, for the sake of tractability we express the daily excess reserve positions at time t as $\tilde{Z}_{ai,t} = \sum_{s=0,t} \tilde{Z}_{i,t-s}$.

$$\tilde{X}_{i,t} = \tilde{Z}_{ai,t} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1} \qquad [A.3]$$

Appendix A2

Substitute the excess reserve constraint [A.3] into the reserve adjustment opportunity curve.

$$\begin{aligned} \tilde{d}_{i,t} = k_t - \beta_{i,0}\left[\tilde{Z}_{ai,t} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1}\right] - \\ -\beta_{i,1}\sum_{j=1}^{N}\left[\tilde{Z}_{aj,t} - M_{j,1,t} - M_{j,2,t} - M_{j,2,t-1}\right] \end{aligned} \qquad [A.4]$$

By construction $\sum_{j=1,n} M_{j,1,t} = \sum_{j=2,n} M_{j,2,t} = 0$ and defining $\tilde{Z}_{an,t} = \sum_{j=1,n} \tilde{Z}_{aj,t}$, we obtain:

$$d_{i,t} = k_t - \beta_{i,0}\left[\tilde{Z}_{ai,t} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1}\right] - \beta_{i,1}\tilde{Z}_{an,t} \qquad [A.5]$$

Appendix A.3

The profits accruing to bank i at time t are defined as:

$$\tilde{\Pi}_{i,t} = \tilde{X}_{i,t}\tilde{d}_{i,t} + M_{i,1,t}\tilde{r}_{i,1,t} + M_{i,2,t}\tilde{r}_{i,2,t} + M_{i,2,t-1}\tilde{r}_{i,2,t-1} \qquad [A.6]$$

Substitute the following constraints into the profit function,

$$\tilde{X}_{i,t} = \tilde{Z}_{ai,t} - M_{i,1,t} - M_{i,2,t} - M_{i,2,t-1} \qquad [A.7]$$

$$\tilde{d}_{i,t} = k_t - \beta_{i,0}\tilde{X}_{i,t} - \beta_{i,1}\sum_{j=1}^{n}\tilde{X}_{j,t} \qquad [A.8]$$

$$\tilde{r}_{i,1,t} = \tilde{r}_{1,t} + \frac{\eta_{i,t}}{2}M_{i,1,t} \qquad [A.9]$$

$$\tilde{r}_{i,2,t} = \tilde{r}_{2,t} + \frac{\xi_{i,t}}{2}M_{i,2,t} \qquad [A.10]$$

and then substitute the expression obtained in the inter-temporal objective function.

The problem is to choose a sequence $\{M_{i,m,t}, t \geq 0\}$ to maximize the profit function, subject to past values of $\{M_{i,m,t}, t < 0\}$. Within a rational expectations framework the Euler equations are the candidates to a solution. Thus, differentiating the inter-temporal profit function $\tilde{\Pi}_i$ with respect to $M_{i,m,t}$, for $t = 0,1,2,...$ and $m = 1,2$. Equate to zero and take expectations based on current information.[53]

$$\frac{\partial\tilde{\Pi}_i}{\partial M_{i,1,t}} = \frac{\partial\sum_{t=1}^{\infty}\delta^{-1}\tilde{\Pi}_{i,t}}{\partial M_{i,1,t}} = 0 \qquad [A.11]$$

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[53] Note that the system of Euler equations is similar to

$$\frac{\partial\tilde{\Pi}_i}{\partial M_{i,1,t}} = \frac{\partial\tilde{X}_{i,t}}{\partial M_{i,1,t}}\tilde{d}_{i,t} + \frac{\partial\tilde{d}_{i,t}}{\partial M_{i,1,t}}\tilde{X}_{i,t} + \tilde{r}_{1,t} + \eta_{i,t}M_{i,1,t} = 0, \text{ and}$$

$$\frac{\partial\tilde{\Pi}_i}{\partial M_{i,2,t}} = \frac{\partial\tilde{X}_{i,t}}{\partial M_{i,2,t}}\tilde{d}_{i,t} + \frac{\partial\tilde{d}_{i,t}}{\partial M_{i,2,t}}\tilde{X}_{i,t} + \tilde{r}_{2,t} + \xi_{i,t}M_{i,2,t} + \delta^{-1}\left[\frac{\partial\tilde{X}_{i,t+1}}{\partial M_{i,2,t}}\tilde{d}_{i,t+1} + \frac{\partial\tilde{d}_{i,t+1}}{\partial M_{i,2,t}}\tilde{X}_{i,t+1} + \tilde{r}_{2,t} + \xi_{i,t}M_{i,2,t}\right] = 0$$

$$M_{i,1,t} = -\frac{1}{2\beta_{i,0} - \eta_i} k_t + \frac{1}{2\beta_{i,0} - \eta_i} \tilde{r}_{1,t} - $$
$$ - \frac{2\beta_{i,0}}{2\beta_{i,0} - \eta_i} M_{i,2,t} - \frac{2\beta_{i,0}}{2\beta_{i,0} - \eta_i} M_{i,2,t-1} + \qquad [A.12]$$
$$ + \frac{2\beta_{i,0}}{2\beta_{i,0} - \eta_i} E_{t_0} \tilde{Z}_{ai,t} + \frac{\beta_{i,1}}{2\beta_{i,0} - \eta_i} E_{t_0} \tilde{Z}_{an,t}$$

and

$$\frac{\partial \tilde{\Pi}_i}{\partial M_{i,2,t}} = \frac{\partial \sum_{t=1}^{\infty} \delta^{-1} \tilde{\Pi}_{i,t}}{\partial M_{i,2,t}} = 0 \qquad [A.13]$$

$$2\beta_{i,0} M_{i,2,t-1} + (1+\delta)\left(2\beta_{i,0} - \xi_i\right) M_{i,2,t} + \delta 2\beta_{i,0} E_{t_0} M_{i,2,t+1} =$$
$$-k_t - \delta E_{t_0} k_{t+1} + (1+\delta)\tilde{r}_{2,t} +$$
$$+2\beta_{i,0} E_{t_0} \tilde{Z}_{ai,t} + \delta 2\beta_{i,0} E_{t_0} \tilde{Z}_{ai,t+1} + \qquad [A.14]$$
$$+\beta_{i,1} E_{t_0} \tilde{Z}_{an,t} + \delta \beta_{i,1} E_{t_0} \tilde{Z}_{an,t+1} -$$
$$-2\beta_{i,0} M_{i,1,t} - \delta 2\beta_{i,0} E_{t_0} M_{i,1,t+1}$$

The first-order conditions show that decisions about $M_{i,1,t}$ and $M_{i,2,t}$ are interrelated. The equilibrium is a pair of sequences for $M_{i,1,t}$ and $M_{i,2,t}$, that must satisfy the boundary conditions. An analytical solution to the program can be found by solving the system recursively by substituting the first Euler equation into the second.

First, lead the first maximization condition [A.12] once and take expectations, conditional on the information available at time t_0.[54]

[54] I make use of the "law of iterated expectations": $E_{t_0}\left(E_{t_0+1} M_{i,2,t+1}\right) = E_{t_0} M_{i,2,t+1}$

$$E_{t_0} M_{i,1,t+1} = -\frac{1}{2\beta_{i,0} - \eta_i} k_{t+1} + \frac{1}{2\beta_{i,0} - \eta_i} E_{t_0} \tilde{r}_{1,t+1} - \\ -\frac{2\beta_{i,0}}{2\beta_{i,0} - \eta_i} E_{t_0} M_{i,2,t+1} - \frac{2\beta_{i,0}}{2\beta_{i,0} - \eta_i} M_{i,2,t} + \\ + \frac{2\beta_{i,0}}{2\beta_{i,0} - \eta_i} E_{t_0} \tilde{Z}_{ai,t+1} + \frac{\beta_{i,1}}{2\beta_{i,0} - \eta_i} E_{t_0} \tilde{Z}_{an,t+1} \qquad [A.15]$$

Second, we substitute the expressions for $M_{i,1,t}$ and $E_{t_0} M_{i,1,t+1}$ in equation [A.14], and re-arrange

$$\delta E_{t_0} M_{i,2,t+1} + \left[1 - \frac{\xi_i}{\alpha_i}\right](1+\delta) M_{i,2,t} + M_{i,2,t-1} = \\ -\frac{1}{2\beta_{i,0}} k_t + \frac{1+\delta}{\alpha_i} \tilde{r}_{2,t} + \frac{1}{\eta_i} \tilde{r}_{1,t} - \delta \frac{1}{2\beta_{i,0}} E_{t_0} k_{t+1} + \delta \frac{1}{\eta_i} E_{t_0} \tilde{r}_{1,t+1} + \\ + E_{t_0} \tilde{Z}_{ai,t} + \frac{\beta_{i,1}}{2\beta_{i,0}} E_{t_0} \tilde{Z}_{an,t} + \delta E_{t_0} \tilde{Z}_{ai,t+1} + \delta \frac{\beta_{i,1}}{2\beta_{i,0}} E_{t_0} \tilde{Z}_{an,t+1} \qquad [A.16]$$

where $\alpha_i = -\frac{2\beta_{i,0}\eta_i}{2\beta_{i,0} - \eta_i} > 0$.

For the sake of simplicity we define:

$$E_{t_0} \Lambda_t = -\frac{1}{2\beta_{i,0}} k_t + \frac{1+\delta}{\alpha_i} \tilde{r}_{2,t} + \frac{1}{\eta_i} \tilde{r}_{1,t} + E_{t_0} \tilde{Z}_{ai,t} + \frac{\beta_{i,1}}{2\beta_{i,0}} E_{t_0} \tilde{Z}_{an,t} \qquad [A.17]$$

and

$$E_{t_0} \Gamma_{t+1} = -\delta \frac{1}{2\beta_{i,0}} E_{t_0} k_{t+1} + \delta \frac{1}{\eta_i} E_{t_0} \tilde{r}_{1,t+1} + \delta E_{t_0} \tilde{Z}_{ai,t+1} + \delta \frac{\beta_{i,1}}{2\beta_{i,0}} E_{t_0} \tilde{Z}_{an,t+1} \qquad [A.18]$$

Replacing in equation [A.16] above, and simplifying:

$$\delta E_{t_0} M_{i,2,t+1} + \left[1 - \frac{\xi_i}{\alpha_i}\right](1+\delta) M_{i,2,t} + M_{i,2,t-1} = E_{t_0}\left(\Lambda_t + \Gamma_{t+1}\right) \qquad [A.19]$$

The problem meets transversality conditions. We assume the exogenous stochastic processes faced by bank i are of order less than $\sqrt{\delta^{-1}}$, and search for a stochastic process $\{M_{i,2,t+j}\}_{j=0}^{\infty}$ that satisfies the Euler equations and transversality condition.

We follow Sargent and Wallace [1975) to find a rational expectations solution to this model.[55] Re-write equation [A.19] using the operator B,

$$\left[\delta^{-1}B^{-2}+\left[1-\frac{\xi_i}{\alpha_i}\right](1+\delta)B^{-1}+1\right]E_{t_0}M_{i,2,t-1}=E_{t_0}\left(\Lambda_t+\Gamma_{t+1}\right) \qquad [A.20]$$

and factorise in order to find the two roots to the equation that are a solution to the problem.

$$\left[\delta^{-1}\left(\lambda_1-B^{-1}\right)\left(\lambda_2-B^{-1}\right)\right]E_{t_0}M_{i,2,t-1}=E_{t_0}\left(\Lambda_t+\Gamma_{t+1}\right) \qquad [A.21]$$

The roots can be obtained through term-by-term identification:

$$\delta\lambda_1\lambda_2=1 \qquad [A.22]$$

$$\delta\left(\lambda_1+\lambda_2\right)=-\left(1-\frac{\xi_i}{\alpha_i}\right)(1+\delta) \qquad [A.23]$$

Solving for λ_1 and λ_2,

---

55 The disadvantage of this procedure is that it is possible to obtain a solution but not recognize it as one of many solutions. The others are obscured in the functional forms that are ruled out a priori. See Taylor (1977, 1381).

$$\lambda_1, \lambda_2 = \frac{-\left[(1+\delta)\left(1-\frac{\xi_i}{\alpha_i}\right)\right] \pm \sqrt{\left[(1+\delta)\left(1-\frac{\xi_i}{\alpha_i}\right)\right]^2 - 4\delta}}{2\delta} \qquad [A.24]$$

It is not hard to show that $|\lambda_1| < 1$ and $|\lambda_2| > 1$. In fact, $-1 < \lambda_1 < 0$ and $\lambda_2 < -1$. Thus, we have a convergent sequence of $\{M_{i,1,t}\}_{t=0}^{\infty}$ as a solution to the problem.[56]

$$\left(\lambda_1 - B^{-1}\right) E_{t_0} M_{i,2,t-1} = \frac{1}{\delta} \frac{1}{\lambda_2 - B^{-1}} E_{t_0}\left(\Lambda_t + \Gamma_{t+1}\right) + o\lambda_2^t \qquad [A.25]$$

where o is a constant which must be set to zero to satisfy the transversality condition, the expression above becomes,

$$\left(\lambda_1 - B^{-1}\right) E_{t_0} M_{i,2,t-1} = \frac{1}{\lambda_2 \delta} \frac{1}{1 - \frac{1}{\lambda_2} B^{-1}} E_{t_0}\left(\Lambda_t + \Gamma_{t+1}\right) \qquad [A.26]$$

Notice that, by definition $1/\lambda_2 = \lambda_1 \delta$. Using this result in equation [A.26], and simplifying

$$M_{i,2,t} = \lambda_1 M_{i,2,t-1} - \lambda_1 \frac{1}{1 - \lambda_1 \delta B^{-1}} E_{t_0}\left(\Lambda_t + \Gamma_{t+1}\right) \qquad [A.27]$$

$$M_{i,2,t} = \lambda_1 M_{i,2,t-1} - \sum_{j=0}^{\infty} \lambda_1 \delta B^{-1} E_{t_0}\left(\Lambda_t + \Gamma_{t+1}\right) \qquad [A.28]$$

$$M_{i,2,t} = \lambda_1 M_{i,2,t-1} - \lambda_1 \sum_{j=0}^{\infty} \lambda_2^{-j} E_{t_0}\left(\Lambda_{t+j} + \Gamma_{t+j+1}\right) \qquad [A.29]$$

---

56 This follows because:

$-(1+\delta)\left(1-\xi_i/\alpha_i\right) < 0$ and $\left[(1+\delta)\left(1-\xi_i/\alpha_i\right)\right] > \sqrt{\left[(1+\delta)\left(1-\xi_i/\alpha_i\right)\right]^2 - 4\delta}$.

Substituting now for the expressions of Λ_{t+j} and Γ_{t+j+1}, the expression obtained links current two-period interbank investments with current and expected interest rates and the expected liquidity shocks to the bank itself and to the banking system as a whole.

$$\begin{aligned} M_{i,2,t} &= \lambda_{i,1} M_{i,2,t-1} - \frac{\lambda_{i,1}(1+\delta)}{\alpha_i} \sum_{j=0}^{\infty} \lambda_{i,2}^{-j} E_{t_0} \tilde{r}_{2,t+j} + \\ &+ \sum_{j=0}^{\infty} \pi_{i,t+j} E_{t_0} \left(-\frac{1}{2\beta_{i,0}} \tilde{k}_{t+j} + \frac{1}{\eta_i} \tilde{r}_{1,t+j} + \tilde{Z}_{ai,t+j} + \frac{\beta_{i,1}}{2\beta_{i,0}} \tilde{Z}_{an,t+j} \right) \end{aligned} \quad [A.30]$$

where $\pi_{i,t} = -\lambda_{i,1}$, $\pi_{i,t+1} = -\lambda_{i,1}\left(\lambda_{i,2}^{-1} + \delta\right)$, $\pi_{i,t+j} = -\lambda_{i,1}\left(\lambda_{i,2}^{-1} + \delta\right)\lambda_{i,2}^{-j+1}$, for $j = 2,3,\ldots$[57]

or, with more detail and emphasizing current period variables

$$\begin{aligned} M_{i,2,t} &= \lambda_{i,1} M_{i,2,t-1} + \frac{\lambda_{i,1}}{2\beta_{i,0}} \tilde{k}_t - \frac{\lambda_{i,1}}{\eta_i} \tilde{r}_{1,t} - \frac{\lambda_{i,1}(1+\delta)}{\alpha_i} \tilde{r}_{2,t} - \\ &- \lambda_{i,1} E_{t_0} \tilde{Z}_{ai,t} - \frac{\lambda_{i,1}\beta_{i,1}}{2\beta_{i,0}} E_{t_0} \tilde{Z}_{an,t} - \\ &- \frac{\lambda_{i,1}(1+\delta)}{\alpha_i} \sum_{j=1}^{\infty} \lambda_{i,2}^{-j} E_{t_0} \tilde{r}_{2,t+j} + \\ &+ \sum_{j=1}^{\infty} \pi_{i,t+j} E_{t_0} \left(-\frac{1}{2\beta_{i,0}} \tilde{k}_{t+j} + \frac{1}{\eta_i} \tilde{r}_{1,t+j} + \tilde{Z}_{ai,t+j} + \frac{\beta_{i,1}}{2\beta_{i,0}} \tilde{Z}_{an,t+j} \right) \end{aligned} \quad [A.31]$$

---

[57] Note:

$$\pi_{i,t+2} = -\lambda_{i,1}\left(\lambda_{i,2}^{-1}\delta + \lambda_{i,2}^{-2}\right) = -\lambda_{i,1}\lambda_{i,2}^{-1}\left(\delta + \lambda_{i,2}^{-1}\right)$$

$$\pi_{i,t+3} = -\lambda_{i,1}\lambda_{i,2}^{-2}\left(\delta + \lambda_{i,2}^{-1}\right)$$

...

$$\pi_{i,t+j} = -\lambda_{i,1}\lambda_{i,2}^{-j+1}\left(\delta + \lambda_{i,2}^{-1}\right)$$

Now, we can find an expression for $M_{i,1,t}$ substituting [A.31] in [A.12]

$$\begin{aligned} M_{i,1,t} = & \frac{\alpha_i}{\eta_i}\left(1+\lambda_{i,1}\right) M_{i,2,t-1} - \frac{1+\lambda_{i,1}}{2\beta_{i,0}-\eta_i} k_t - \\ & - \frac{\alpha_i}{\eta_i}\left(\frac{\lambda_{i,1}}{\eta_i}+\frac{1}{\beta_{i,0}}\right)\tilde{r}_{1,t} - \frac{1}{\eta_i}(1+\delta)\lambda_{i,1}\tilde{r}_{2,t} - \\ & - \frac{\alpha_i}{\eta_i}\left(1+\lambda_{i,1}\right) E_{t_0}\tilde{Z}_{ai,t} - \frac{\alpha_i}{\eta_i}\frac{\beta_{i,1}}{2\beta_{i,0}}\left(1+\lambda_{i,1}\right) E_{t_0}\tilde{Z}_{an,t} - \\ & - \frac{1}{\eta_i}(1+\delta)\lambda_{i,1}\sum_{j=1}^{\infty}\lambda_{i,2}^{-j}E_{t_0}\tilde{r}_{2,t+j} + \\ & + \frac{\alpha_i}{\eta_i}\sum_{j=1}^{\infty}\pi_{i,t+j}E_{t_0}\left(-\frac{1}{2\beta_{i,0}}\tilde{k}_{t+j} + \frac{1}{\eta_i}\tilde{r}_{1,t+j} + \tilde{Z}_{ai,t+j} + \frac{\beta_{i,1}}{2\beta_{i,0}}\tilde{Z}_{an,t+j}\right) \end{aligned} \qquad \text{[A.32]}$$

Now, we use the following notation for the expression on $M_{i,2,t}$:

$-\lambda_{i,1}/2\beta_{i,0} = b_{i,k} > 0$,

$\lambda_{i,1}/\eta_i = b_{i,r1} > 0$,

$-\lambda_{i,1}(1+\delta)/\alpha_i = b_{i,r2} > 0$, and

$-\lambda_{i,1} = b_{i,zai} > 0$

For $M_{i,2,t}$ we use the following notation:

$(1+\lambda_{i,1})/(2\beta_{i,0}-\eta_i) = c_{i,k} > 0$,

$-(\alpha_i/\eta_i)(\lambda_{i,1}/\eta_i + 1/2\beta_{i,0}) = c_{i,r1} > 0$,

$(1/\eta_i)(1+\delta)\lambda_{i,1} = c_{ir,2} > 0$,

$-(\alpha_i/\eta_i)(1+\lambda_{i,1}) = c_{i,zai} > 0$, and

$-(\alpha_i/\eta_i)(\beta_{i,1}/2\beta_{i,0})(1+\lambda_{i,1}) = c_{i,zan} > 0$

Then, re-write equations [A.31] and [A.32]

Appendix A.4

The competitive market case, when there are no restrictions on the amount each bank can borrow in the interbank market, has a static solution that is obtained after maximising the objective function subject to the restrictions as in the Appendix A3, above. However, and in contrast to the analytical solution derived above, here $\eta_i = \xi_i = 0$. Market participants assume that no matter their actions the interest rates will be kept constant.

The Euler equations to the problem are

$$-2\beta_{i,0}M_{i,1,t} = k_t - \tilde{r}_{1,t} + 2\beta_{i,0}M_{i,2,t} + 2\beta_{i,0}M_{i,2,t-1} - 2\beta_{i,0}E_{t_0}\tilde{Z}_{ai,t} - \beta_{i,1}E_{t_0}\tilde{Z}_{an,t} \quad \text{[A.33]}$$

$$\begin{aligned} 2\beta_{i,0}M_{i,2,t-1} + (1+\delta)2\beta_{i,0}M_{i,2,t} + \delta 2\beta_{i,0}E_{t_0}M_{i,2,t+1} = \\ = (1+\delta)\tilde{r}_{2,t} - k_t - \delta E_{t_0}\tilde{k}_{t+1} + \\ +2\beta_{i,0}E_{t_0}\tilde{Z}_{ai,t} + \delta 2\beta_{i,0}E_{t_0}\tilde{Z}_{ai,t+1} + \\ +\beta_{i,1}E_{t_0}\tilde{Z}_{an,t} + \delta\beta_{i,1}E_{t_0}\tilde{Z}_{an,t+1} - \\ -2\beta_{i,0}M_{i,1,t} - \delta 2\beta_{i,0}E_{t_0}M_{i,t+1} \end{aligned} \quad \text{[A.34]}$$

and solving recursively the problem,

$$\tilde{r}_{1,t} + \delta E_{t_0}\tilde{r}_{1,t+1} = (1+\delta)\tilde{r}_{2,t} \quad \text{[A.35]}$$

Appendix A.5

Take the optimization conditions for each bank and add across the two banks. Note that $M_{A,2,t} = -M_{B,2,t}$, $M_{A,1,t} = -M_{B,1,t}$, and $\tilde{Z}_{an,t} = \tilde{Z}_{aA,t} + \tilde{Z}_{aB,t}$. After obtaining the expression for interest rates use the notation $(2\beta_{A,0} + 2\beta_{B,0}) = 2\beta_0$,

$2\beta_{A,0}+\beta_{A,1}-\beta_{B,1}=\beta_{aA,1}$, $2\beta_{B,0}+\beta_{B,1}-\beta_{A,1}=\beta_{aB,1}$, and $\eta_A=\xi_A=-2\beta_{B,0}$, and substitute into the Euler equations and obtain the following expressions for bank A.

$$\begin{aligned} M_{A,1,t} = & \frac{\beta_{aA,1}}{2\beta_0-\eta_A}E_{t_0}\tilde{Z}_{aA,t} - \\ & -\frac{\beta_{aB,1}}{2\beta_0-\eta_A}E_{t_0}\tilde{Z}_{aB,t} - \\ & -\frac{2\beta_0}{2\beta_0-\eta_A}M_{A,2,t}-\frac{2\beta_0}{2\beta_0-\eta_A}M_{A,2,t-1} \end{aligned} \qquad [A.36]$$

$$\begin{aligned} 2\beta_0 M_{A,2,t-1}+(1+\delta)(2\beta_0-\xi_A)M_{A,2,t}+\delta 2\beta_0 E_{t_0}M_{A,2,t+1} = & \\ =\beta_{aA,1}E_{t_0}\left(\tilde{Z}_{aA,t}+\delta\tilde{Z}_{aA,t+1}\right)- & \\ -\beta_{aB,1}E_{t_0}\left(\tilde{Z}_{aB,t}+\delta\tilde{Z}_{aB,t+1}\right)- & \\ -2\beta_0 E_{t_0}\left(M_{A,1,t}+\delta M_{A,1,t+1}\right) & \end{aligned} \qquad [A.37]$$

Note that formally the system is similar to the one discussed before for a single bank. Hence, the sequence of inter-bank market investments is defined exactly as before. The only difference is that now the interbank investments depend only on expected liquidity shocks. Interbank interest rates and the discount window rte are absent from the final solution when we consider the market equilibrium constraint.

$$\begin{aligned} M_{A,2,t} = & \lambda_{A,1}M_{A,2,t-1}-\frac{1}{2\beta_0}\lambda_{A,1}E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t}-\beta_{aB,1}\tilde{Z}_{aB,t}\right)+ \\ & +\frac{1}{2\beta_0}\sum_{j=1}^{\infty}\pi_{A,t+j}E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t}-\beta_{aB,1}\tilde{Z}_{aB,t}\right) \end{aligned} \qquad [A.38]$$

$$
\begin{aligned}
M_{A,1,t} = {} & \frac{\alpha_A}{\eta_A}\left(1+\lambda_{A,1}\right)M_{A,2,t-1} - \\
& -\frac{\alpha_A}{\eta_A}\frac{1}{2\beta_0}\left(1+\lambda_{A,1}\right)E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t}-\beta_{aB,1}\tilde{Z}_{aB,t}\right)+ \\
& +\frac{\alpha_A}{\eta_A}\frac{1}{2\beta_0}\sum_{j=1}^{\infty}\pi_{A,t+j}E_{t_0}\left(\beta_{aA,1}\tilde{Z}_{aA,t}-\beta_{aB,1}\tilde{Z}_{aB,t}\right)
\end{aligned}
\qquad [A.39]
$$

where

$$
\alpha_A = \frac{4\beta_0\beta_{B,0}}{2\beta_0+2\beta_{B,0}} = \frac{\left(2\beta_{A,0}+2\beta_{B,0}\right)2\beta_{B,0}}{\left(2\beta_{A,0}+2\beta_{B,0}\right)+2\beta_{B,0}},
$$

$$
\lambda_{A,1},\lambda_{A,2} = \frac{-\left[(1+\delta)\left(2+\frac{2\beta_{B,0}}{2\beta_{A,0}+2\beta_{B,0}}\right)\right]\pm\sqrt{(1+\delta)\left(2+\frac{2\beta_{B,0}}{2\beta_{A,0}+2\beta_{B,0}}\right)^2-4\delta}}{2\delta}, \text{ and}
$$

$$
\pi_{A,t+j} = -\lambda_{A,1}\left(\lambda_{A,2}^{-1}+\delta\right)\lambda_{A,2}^{-j+1}, \text{ for } j=1,2,3,...
$$

Chapter 5

Interbank Interest Rates Dynamics

1. Introduction

The importance of financial linkages for the propagation of monetary policy shocks can hardly be disputed. There are several factors playing an important role in the monetary policy transmission mechanism. The institutional features of interbank money markets and the connections among banks that arise within a reserve management framework might place a constraint on the effectiveness of monetary policy. In this paper we focus primarily on the ability of the monetary policy to shift the interbank money market yield curve. In particular, we analyse the validity of interest rate expectations in the Portuguese interbank money market when the central bank changes monetary policy instruments under different regimes. We want to know if interest rates of different maturities are linked by a no-arbitrage argument and how long does an initial shock take to propagate along the interbank money market yield curve. If the expectations hypothesis holds at the very short end of the term structure we add a new dimension to the factors behind interest rate determination in the financial markets and its relationship with the monetary policy. In other words, if we can find a stable a predictable relationship between interbank money market rates and the central bank monetary policy instruments, we might understand the effectiveness of monetary policy in determining economy wide interest rates.

We have in mind an interbank money market operating as a private cooperative arrangement providing insurance to banks against unanticipated shortages of central bank funds, i.e., liquidity shocks. Previous research shows that banks borrow and lend mostly overnight to compensate for unforeseen liquidity imbalances, which are likely to arise due to financial innovation, securitisation, and banks' specialization. We have shown in chapter 2 that interbank money market transactions in Portugal and according to literature are mostly overnight. However, banks we find that banks lend to each other for longer maturities also. We have shown that banks allocate interbank investments along the maturity spectrum – ranging from overnight up to one year – and in doing so, they attempt to match expected future liquidity imbalances and arbitrage the money market yield curve. Therefore, interest rates reflect the pattern of expected future liquidity shocks, while meeting the interest rate expectations hypothesis at the same time.

We argue also that the interbank money market is at the core of the monetary policy transmission mechanism. The monetary transmission mechanism is described as a channel through which the central bank implements monetary policy using a set of instruments, such as open market, reserve requirements and daily facility operations, in order to influence some goal variables via some intermediate targets. The ability of the central bank to achieve the economic goals depends on how interbank money market arrangements operate on the first place. Usually, central banks choose an interbank money market rate – overnight, weekly, or any other – as a primary intermediate target. It is assumed that the effects upon the target will spill over to longer maturities and ultimately will produce effects upon the real economy. The monetary policy effectiveness depends on how market frictions and other institutional constraints operate. These constraints might move the intermediate rate away from target and produce undesired effects upon money market rates and other economic variables.

The monetary policy transmission mechanism can be viewed from either a broad or a narrow perspective. The traditionally broad macroeconomic approach attempts to analyse how do monetary policy shocks affect the real economic variables – such as inflation, growth and unemployment. The narrow route highlights the importance of the early stages in the monetary policy transmission mechanism and the ability of the central bank to control the intermediate target. This latter approach emphasises the micro foundations of interbank money markets and allows us to explore the relationship between monetary policy shocks and the interactions between banks' reserve management strategies. In particular, we might use the term structure of money market interest rates to explore how interbank money rates respond to monetary policy instruments under interbank market institutional changing, and monetary policy regime shifts.

In this chapter, we test the validity of the interest rate expectation hypothesis in the Portuguese interbank money market in order to asses the ability of the central bank to control money market rates, in particular the whole money market maturity range. We want to find if there is perfect capital mobility between the shortest and the longest end of the interbank money market maturity spectrum, particularly when equilibrium is disturbed by monetary policy shocks. Empirically, the central bank's ability to change interest rates through day-to-day monetary policy is checked by means of a test for cointegration between short and long term interest rates. We estimate a vector error correction model using interbank rates. The maturity range covers the whole money market spectrum from the extreme short end of the yield curve – over night – up to 6 months.

The novelty of this paper is that it uses a multivariate cointegration technique in assessing the validity of interest rate expectations theory, whereas most authors use bivariate models and concentrate on two extremes of interbank maturity spectrum. Using cointegration and error correction modelling techniques we analyse the usefulness of the term structure for conducting monetary policy, shed some light on the interest rate adjustment, while accounting for cross-effects amongst interest rates of different maturities.

Our analysis is applied to a unique dataset never used for this purpose containing effective interest rates rather than quotes on interbank market loans.

The data cover overnight to 6-month Portuguese interbank money market rates[1] from the 1st January 1989 to the 31st December 1998. The time frame encompasses four different monetary policy regimes, which have been identified in chapter 2, representing shifts in monetary policy objectives and instruments, and allows us to analyse the effectiveness of monetary policy under a variety of institutional and monetary policy constraints.

After controlling for interbank market institutional features, we find that the forces generating long run equilibrium imply mean reversion, and it is suitable to use an error correction model to characterise the dynamic relationship between interbank interest rates. In general we find a single random walk even in regimes when credit constraints and capital controls were present and it was expected more than one factor driving interest rates. However, except for the most recent period, estimated coefficients in the cointegration vectors do not support the expectations hypothesis. Interest rates co-move, in a similar fashion to the expectations hypothesis, but the theory fails to hold in periods characterised by major credit constraints and capital controls.

We find that interbank institutional arrangements seem not to undermine interest rates adjustment in a similar fashion to the rational expectations

[1] We have shown in chapter 4 that the interbank money market is not very active for maturities beyond 6 months. Further most trading activity takes place for maturities up to one month, emphasising the liquidity management purpose of this market.

theory. On contrary, central bank lack of credibility – such as when it does not commit to a pre-announced target – jeopardizes the equilibrium relationship and allows time-varying risk premia. During certain periods we find the central bank committed to interest rate stabilization in the long term. In practice this is achieved with a stable interest rate target, and the central bank willingness to withstand liquidity shocks – i.e., availability to borrow or lend unlimited amount of funds, while keeping the target constant.

We document a new fact showing that each interest rate is subject to changes due to its long run equation – such as its own spread over the target – and, additionally, it reflects imbalances in the long run equilibrium equations of the remaining maturities. In short, effects can be grouped in two blocks. The first shows up to one-week rates closely intertwined, and the second links the longer maturity rates. One-week rates, of identical maturity as main refinancing operations, link these two blocks which reinforces the relevance of open market operations to build up expectations of interest rates for banks.

Taken together the results suggest that in a small open economy the expectations hypothesis serves as an accurate description of the behaviour of very short term interest rates when the central bank is credibly committed to an interest rate target. The remainder of the chapter is organized as follows. Section 2 provides a brief restatement of interest rates expectations models and its empirical applications. In Section 3 we model interest rates as a cointegration vector in error correction form and formulate the testing hypothesis. Section 4 describes the data set and variables used. Section 5 tests for the order of integration of interest rates as a previous step to estimate the cointegrated VAR, which we do in section 6. Section 7 proposes two identifications for the cointegration space and test the validity of interest rates spreads as cointegration vectors. Section 8 concludes.

2. Theory of the Term Structure

The role played by capital flows both spatially and across maturities in the adjustment process is highlighted by many authors. Under free mobility, capital flows to where interest rates are higher, leaving applications with lower returns while bringing nominal interest rates of identical maturity equal. The expectation hypothesis comes into play when we consider arbitrage between interest rates of different maturities. Shall changes in short-term interest rates affect the long end of the maturity spectrum, depends on the degree of capital mobility and investors' risk aversion. Uncovered interest rate parity, when short-term policy rates change will only hold if the central bank shows its commitment to interest rates in the long term and succeeds in changing investor's attitude regarding the longer rates.

2.1. The Expectations Hypothesis Theory of the Term Structure

There is a well established body of literature on term structure models. For general surveys see Cochrane (2001) Marsh (1998), Campbell and Shiller (1991), and Campbell (1995), among many others. The term structure of interest rates is defined as an array ("structure") of prices or yields on bonds with different terms to maturity. The structure can be computed from the observed prices of default-free bonds at any moment in time. The relationship between the rates – i.e., the term structure – varies over time. A number of authors argue that yields on bonds of different maturities move together because they are linked by the expectations hypothesis[2]. Arbitrage arguments augmented with risk considerations are generally used to justify such relationships.

In an equilibrium set up to asset pricing, bonds are treated as a single asset in an investor's portfolio. In standard analysis representative consumers are assumed to make their consumption portfolio decisions as to maximise the sum of their expected utility of consumption over time. Denote $P_{T,t}$ as the price at t of a pure discount bond with term to maturity $k = T - t$ and $u(C_t)$ the utility derived from consumption at time t. Equilibrium requires that the marginal utility from consumption in the current period equals the marginal utility if consumption is deferred until next period:

$$P_{T,t} u_C(C_t) = E_t\left[P_{T,t+1} u_C(C_{t+1})\right] \qquad [1]$$

define $m_{t+1,t} = u_C(C_{t+1}) / u_C(C_t)$ an re-write:

$$P_{T,t} = E_t\left[P_{T,t+1} m_{t+1,t}\right] \qquad [2]$$

[2] See Sarno and Thornton (2003) for a review.

The Euler equation [2] needs to hold between moment t and any other point in future, not just between t and $t+1$. It is a necessary condition on consumption and investment for individuals to maximize their expected utility of lifetime consumption. Therefore, considering the pure discount bond maturing at time T the price of a pure discount bound equals the marginal rate of substitution between consumption now and in the future. Defining $r_{k,t}$ as the zero coupon bond yield to maturity[3], and re-writing equation [2] we obtain:

$$P_{T,t} = E_t\left(m_{T,t}\right) \equiv \frac{1}{r_{k,t}^{\;k}} \qquad [3]$$

Thus, once we specify a time series process for the one-period discount factor $m_{t,t+1}$ we can in principle find the price of any zero coupon bond by chaining together the discount factors:

$$P_{t,T} = E_t\left(m_{t+1,t}, m_{t+2,t+1} \ldots, m_{T,T-1}\right) \qquad [4]$$

The Euler equations ignores potentially important factors influencing investors decisions such as transactions costs, borrowing constraints and lack of time-additivity in the utility function.

We define the forward rate $f_{j,t}$ as the rate at which we can contract today to borrow or lend money starting at $t+j-1$, to be paid back at $t+j$. Forward

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[3] Applying logarithms to equation [3] we obtain the logarithmic interest rate $\ln P_{T,t} = -kR_{k,t}$, $R_{k,t} = -\ln P_{T,t}/k$.

rates can be derived from the prices of zero coupon bonds $f_{j,t} = P_{t,t+j-1}/P_{t,t+j}$ and $F_{j,t} = \ln P_{t,t+j-1} - \ln P_{t,t+j}$, or their yields to maturity. Forward rates have the property that we can always express the price of a zero coupon bond as its discounted present value, using forward rates:

$$P_{t,T} = \left[\prod_{j=1}^{k} f_{j,t}\right]^{-1}, \ \ln P_{t,T} = -kR_{k,t} = -\sum_{j=1}^{k} F_{j,t} \qquad [5]$$

We can state the expectations hypothesis as $F_{j,t} = E_t R_{1,t+j}\left(+\text{Risk premium}\right)$ and let the forward rates imply the yield curve[4]. We start with the assumption that $F_{j,t} = E_t R_{1,t+j}$ and add up the forward rates over the maturity k:

$$F_{1,t} + F_{2,t} + \ldots + F_{k,t} = E_t\left(R_{1,t} + R_{1,t+1} + \ldots + R_{1,t+k}\right) \qquad [6]$$

The right hand side is the yield to maturity on a k-period zero coupon bond, that we are looking for, and combining with [3] we can write [6] as[5]:

$$R_{k,t} = \frac{1}{k}\sum_{j=1}^{k} F_{j,t} \qquad [7]$$

In case of pure discount bonds and under rational expectations the k-period interest rate is a constant plus a simple average of the current and expected future one period interest rates up to $k-1$ periods in the future[6]:

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[4] Alternatively, the rational expectations can be formulated as $R_{1,t+m} = E_t R_{1,t+m} + \eta_{t+m}$, where rational forecasts are unbiased and the forecast error η_{t+m} is uncorrelated with the information set used to condition the expectations at time $t+m$.

[5] See Cochrane (2001).

$$R_{k,t} = \frac{1}{k}\sum_{j=1}^{k} E_t R_{1,t+j-1} + \Phi_k \qquad [8]$$

The first term on the right hand side is the expectations component and the second term the premium component – term premium. The term premium may vary with bond maturity k but is assumed constant through time. E_t is the market expectations operator conditional upon information available at time t. Note that the sum of the coefficients of the on-period interest rates is one. The premium component captures the excess return derived from holding a long-term bond in relation to rolling over short-term (one period) bonds.

2.2. Single Equation Tests of the Expectations Hypothesis

Let $H_{k,t+1}$ be the realized return from holding a k-period bond for one period beginning at time t in excess of that from holding a one-period bond:

$$H_{k,t+1} = kR_{k,t} - (k-1)R_{k-1,t+1} - R_{1,t} \qquad [9]$$

By definition the expected excess return is the time varying term premium:

$$\Phi_{k,t} = E_t H_{k,t+1} = kR_{k,t} - (k-1)E_t R_{k-1,t+1} - R_{1,t} \qquad [10]$$

Inferences about the term premia are difficult because it is not observed directly. On contrary, the term premia is observed in conjunction with forecast errors. In fact, when compared against rolling over short-term investments, the

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[6] See Campbell and Shiller (1991), among others.

excess returns on a long term bond can be decomposed into the sum of a term premium and a one-period forecast error.

$$H_{k,t+1} = \Phi_{k,t} - (k-1)\left(R_{k-1,t+1} - E_t R_{k-1,t+1}\right) \qquad [11]$$

According to the expectations hypothesis, the spread between the long k-period yield and the short one-period yield – i.e., the yield spread – contains the markets' best forecast of the change in the long term interest rate, and the following single equation can be used to test the null of the expectations hypothesis plus rational expectations[7]:

$$(k-1)\left(R_{k-1,t+1} - R_{k,t}\right) = a_0 + a_1\left(R_{k,t} - R_{1,t}\right) + u_{t+1} \qquad [12]$$

where $\mathrm{H}_0 : a_0 = 0, a_1 = 1$. Note that $a_0 \neq 0$ if there are differential transaction costs or a constant term premium. Under rational expectations the variables on the right-hand side of [12] are independent of the forecasting error, and the model can be estimated using GMM to correct the co-variance matrix for the moving-average error and possible heteroskedasticity[8].

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[7] Different authors present slightly modified versions of the model. Cuthbertson, for example, presents the following single equation test $PFS_{k-1,t} = \alpha + \beta\left(R_{k,t} - R_{1,t}\right) + \gamma\Omega_t + \eta_t^*$, where $PFS_{k-1,t} = \sum_{i=1}^{k-1}\left(1 - i/k\right)\Delta R_{1,t+j}$ is the perfect foresight spread between the k-period and the 1-period bond; Ω_t is the information set available at time t, η_t^* is the forecasting error, and $\mathrm{H}_0 : \alpha = \gamma = 0, \beta = 1$

[8] See Hamilton (1994).

Yield spreads contain information regarding changes in the long term interest rate, and if the expectations theory is adequate to describe the term structure, then the long rates are dominated by the rational expectations of future short term interest rates. On the other hand if the expectations theory fails, predictable changes in excess returns must be the main influence moving the term structure[9]. Hardouvelis (1994) and Evan and Lewis (1994) show that under constant term premia the spread between short and long-term interest rates can predict the correct direction of future changes in short rates. Such predictive power is consistent with the expectations hypothesis, which claims that long rates are weighted averages of current and expected future short rates. The general approach to test the rational expectations theory of interest rates is regress the yield changes onto the interest rate spread, and test whether the coefficient equals one.

2.3. VAR Methodology and Error Correction Representation

More recently, some authors started using cointegration techniques to test the expectations hypothesis of interest rates. Campbell and Shiller (1991) propose a vector auto-regressive (VAR) approach to test the term structure of interest rates. They advocate the superiority of their approach over the regression of the perfect foresight spread onto the actual spread, which involves

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[9] Campbell and Shiller (1991: 495).

k-period overlapping errors. They assumed interest rate changes and interest rate spreads as stationary processes – $[\Delta R_{1,t}, R_{k,t} - R_{1,t}]'$ – represented as a p-th order VAR. Hall et al. (1992) argue in their seminal paper that the formal empirical analysis of the relationships between yields of different maturities is not straightforward because nominal yields are not generally stochastically stationary. It is possible that sets of non-stationary variables move together over time and, therefore, interest rates might be cointegrated. Taking $R_{k,t}$ the yield to maturity on a k-period pure discount bond, and $F_{k,t}$ as the forward rate, established at time t, to be made $(k-1)$-periods ahead – i.e., at $t+k-1$ – for one period duration, the relationship linking forward and spot rates is described as:

$$R_{k,t} = \frac{1}{k}\sum_{j=1}^{k} F_{j,t} \text{ for } k = 1,2,3,... \qquad [13]$$

Conventionally, forward rates are related to expected rates through a risk premium parameter which denotes investors' risk and preferences for liquidity – $F_{j,t} = E_t\left(R_{1,t+j-1}\right) + \phi_{j,t}$. The pure expectations hypothesis asserts that the premia parameters $\phi_{j,t}$ are zero, while other versions assume that the premia are constant over time. Assuming a time-invariant risk parameter and after some manipulation the interest rate spread between two interest rates of different maturities can be written as[10]:

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[10] See Campbell and Shiller (1992), Hall et al. (1992) and Cuthbertson (1996).

$$R_{k,t} - R_{1,t} = \frac{1}{k}\left[\sum_{i=1}^{k-1}\sum_{j=1}^{i} E_t \Delta R_{1,t+j}\right] + \Phi_k$$

$$R_{k,t} - R_{1,t} = E_t\left[\sum_{i=1}^{k-1}\left(1 - \frac{i}{k}\right)\Delta R_{1,t+j}\right] + \Phi_k \qquad [14]$$

Campbell et Shiller (1991) call the term under the expectations operator in equation [14] the "perfect-foresight spread", since it is be the spread we would obtain if there were perfect foresight about future interest rates and the term premia was zero. If over the next $k-1$ periods the short rates are going to rise, the k-period interest rate needs to be higher than the current short rate as to equate the yields on a k-period bond held to maturity and a sequence of one-period investments.

It is generally accepted that interest rates of any maturity are well described as I(1) processes. In principle, it is possible to find linear combinations of interest rates of different maturities that are stochastically stationary[11]. Under these circumstances the interest rates are said cointegrated and the linear combination parameters are the cointegrating vectors. Assuming that the rates on the left hand side of equation [14] are both integrated of order one, first differencing makes the variables stationary, and because interest rate spreads are weighted averages of interest rates changes, they also are stationary. Given that interest rate spreads $R_{k,t} - R_{1,t}$ are stationary linear combinations, a

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[11] See, among others, Campbell et al. (1988) and Hall et al. (1992). For a complete discussion on cointegration see Johansen (1995).

cointegration vector is $[1,-1]'$. This implies that and each rate is cointegrated with $R_{1,t}$ and there exists an error correction representation for interest rates such as that in the long run equilibrium the two interest rates differ by a constant risk premium only. The cointegration implied by model [14] is of very special type. It implies that any rate is cointegrated with the one period interest rate, but it can be shown that any alternative pair of interest rates can be used as a cointegrating vector[12].

If we have a vector of n rates of different maturities, the fundamental term structure relationship – i.e., the term structure expectations hypothesis – implies that each interest rate is cointegrated with the remaining rates, and the set has cointegrating rank $(n-1)$. Every of the $(n-1)$ spreads that can be formed is a cointegrating vector for each interest rate. Formally, the vector of interest rates $\mathbf{R}_t = \left[R_{1,t}, R_{2,t}, \ldots, R_{nt}\right]'$ has the following $(n-1)$ n-dimensional spread vectors as cointegrating vectors: $\left[(-1,1,0,\ldots,0)', (-1,0,1,..,0)', \ldots, (-1,0,0,\ldots,1)'\right]$. The spread vectors are linearly independent and span the cointegration space, which has rank $(n-1)$. It can be shown that under rational expectations any set of independent spread vectors – other than the spread with the one period rate – is a base for the cointegration space. Therefore, any set of n yields must have cointegrating rank of $(n-1)$.

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[12] See Hall et al. (1992).

2.4. Empirical Applications

Empirical evidence on the term structure is puzzling. There is some controversy about the term structure ability to forecast interest rate movements. Generally, tests of the theory imply rejection of the hypothesis, although many authors argue that yield spreads still contain useful information about future interest rate changes.

The expectations theory of the term structure of interest rates is often viewed as a joint hypothesis that agents hold rational expectations and the term premia are invariant. Hardouvelis (1994) agues that if economic agents are rational a rise in the long rate relative to the short rate must be due to the expectation of higher short rates in the future. There are alternative ways to test the theory: one might analyse the correlation between interest rate spreads and actual interest rates changes, i.e., the perfect foresight spread single equation regressions; use the Campbell and Shiller (1991) VAR approach; or employ cointegration techniques, as in Hall and al. (1992).

Many of the traditional applications use the perfect foresight spread regressions and research the properties of the term premia implicit in the term structure of interest rates. Failure concerning the magnitude of the coefficients in regressions of the short rate changes on the term spreads is found in many studies. Rejections of the expectations hypothesis are often attributed either to time-varying risk premia or forecast errors, which might destroy the predictive power of the spread. McCallum (1994) argues that rejections of the theory can be explained either by failure of the expectations theory or, another possibility, invalidity of the rational expectations hypothesis. However, he discards the last explanation arguing that it seems unlikely that the same general type of expectation error would prevail over different sample periods systematically. Engle (1982), Engle, Ng and Rothschild (1990), Lee (1995) and Hejazi et al. (2000), among others, found that taking into account conditional variances of the expected returns helps to explain some of the rejections of the theory. McCallum (1994) shows that failures can be rationalized by recognition of an exogenous autoregressive term premium plus the assumption that the monetary policy targets smoothing of the short term rate. Hardouvelis (1994) argues that the volatility of the risk premium needed to accommodate the puzzle is too high, and therefore it is not a reasonable explanation. He supports that deviations are more likely due to either an additive white noise error or investors' overreaction. Bekaert et al. (1997) document statistical problems with standard regression-based tests of the expectations hypothesis of the term structure of interest rates for small samples. Correcting for bias and dispersion in the small-sample distributions provides more consistent rejection of the expectations hypothesis. Mankiw and Summers (1984), Mankiw (1986), and Campbell and Shiller (1991) find a number of studies in which interest rate spreads predict interest rate movements in roughly the way implied by the expectations theory. Fama and Bliss (1987) observed that the forecasting power of the term structure for changes in the short rate improves as the forecast horizon increases from 2 to 5 years. Campbell and Shiller (1991) add that the reverse occurs when the forecast horizon is below one year.

Some authors use multivariate cointegration techniques and provide evidence that interest rates co-move in the long run. Engle and Granger (1987) first, and Hall et al. (1992) followed by many others, proposed using error correction models to test the interest rate expectations hypothesis[13]. Generally, they test the null that interest rates of different maturities are tied up, ruling out any arbitrage opportunities. Conceptually, this is equivalent to saying that interest rates of varying maturities move together and share a common underlying long run trend. If the null is accepted, the series are said co-integrated and the co-integrating vectors represent the long run equilibrium relationship. Again, evidence does not confirm the expectations hypothesis at all times. Some studies provide support to the theory at the short term end of the yield curve, while others confirm the long term end. Hall et al. (1992) show that monthly US Treasury bill yields from 1 to 11 months are governed by a single non-stationary common factor with cointegration vectors defined as the spreads between yields of different maturities. However, when identifying the cointegrating vectors, they find that the spreads do not span the cointegration space, unless the analysis is restricted to the shortest maturities. In the latter

[13] Earlier cointegration tests between long-term and short-term bond yields can be found in Campbell and Shiller (1987) and Engle and Granger (1987). Tests are incipient and leave thee question of how one might apply this to the term structure of interest rates unanswered.

case they report stationary risk premia for each maturity and conclude with the usefulness of an error correction model for forecasting changes in yields. Shea (1996) provides some support for the cointegration implications of the expectations hypothesis at the long end of the maturity spectrum. Cuthbertson (1996) uses weekly data for the UK interbank market to show that the expectations theory fails when the six-month and the twelve-month maturities are included. The rejection can be due to the presence of liquidity constraints or market segmentation or other market frictions. Johansen and Juselius (2001) using daily data find that the Federal Reserve is not able to control the 3 and 6 months Treasury bill rates using the federal funds rate. Sarno and Thornton (2003) re-examine the relationship between daily federal funds rate and the 3-month Treasury bill rate using a non-linear asymmetric ECM to find a long-run relationship remarkably stable across policy regimes. They add that the federal funds rate burdens most of the adjustment towards the long run equilibrium.

Most of the studies use U.S. term structure data, and the properties of the term structure in other countries are less well developed. We acknowledge growing recognition that rejection of the interest rates expectation hypothesis is to some extent specific to United States data. A number of studies outside the U.S. including Engsted (1996), Hardouvelis (1994), Johnson (1993) and Kugler (1990) find support for the expectations hypothesis. Engsted (1996) uses weekly data for 1-month to 6-month interest rates from the Danish money market. Hardouvelis (1994) uses quarterly data and test the rational expectations hypothesis in the G7 countries. He finds that spreads predict the wrong direction of interest rate change in the United States, but for the remaining countries predictions are consistent with the information in the term structure. Hejazi et al. (2000) reject the expectations theory using Canadian interest rates with one to three months to maturity. They show that similar to US rates the term spread implies positive excess returns on the long term rates. They insist this result as fundamentally wrong and show that the time varying term premia is predictable when the yield spreads and the conditional variance of excess returns are used. Fonseca (2002) presents supporting evidence of the expectations hypothesis theory using the Portuguese Treasury Bills yields, during a period of increased uncertainty and high turbulence in interest rates.

2.5. The Term Structure of Interbank Market Rates

The expectations hypothesis has seldom been tested at the extreme short end of the yield curve where maturities are measured in days and weeks and using high frequency data. Yet, using the money market rates are directly connected to monetary policy, and are therefore the appropriate rates to use when we want to investigate the effect of different monetary policies on the term structure.

There are a number of recent studies documenting the volatility of money market rates mostly in the context of reserve requirements. Starting with Hamilton (1996), most authors model money market rates as GARCH model, allowing volatility to change across the reserve maintenance period. They focus mainly on the overnight rate and its deviations from the policy rates and find its volatility to be highly persistent. Prati et al. (2003) model overnight rates in G-7 countries using E-GARCH, and Bartolini et al. (2000a, 2000b) find volatility peaks at the end of the reserve maintenance period. Other authors follow similar approaches and attempt to imply the volatility of money market rates from the overnight maturity. Very recently, a small body of literature started addressing the intraday behaviour of interbank money market rates[14].

A different group of studies tests the interest rates expectations hypothesis in the interbank money market. Longstaff (2000) finds support for the expectations hypothesis using overnight, weekly and monthly repo rates. The unconditional tests do not reject the simplest version of the expectation hypothesis in which the term premia are zero. He confirms the widespread market view that time-varying premia found by many studies on Treasury Bills rates are driven by other factors such as liquidity[15]. Repo rates are better measures of the short-term structure than Treasury Bills rates because they are risk free. A number of studies use the Federal Funds rates as a proxy for the short-term riskless rate to test for the expectations hypothesis in the very short end of the yield curve: Thornton (2004), Lee (2003), Balduzzi et al. (1997) and Roberds et al. (1996). Empirical results in general do not support the

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[14] See, among others, Murta (2002), Cyree and Winters (2001), Angelini (2000).

[15] Several authors document that Treasury Bills are special, offering a yield lower than the pure interest rate on a riskless loan. See Duffie (1996), Longstaff (1995).

expectations hypothesis. Longstaff (2000) argues that using the Fed Funds rates might be misleading for two reasons. First, Federal Funds rates are not default free. Thus, what appears to be a time premia in the Fed Funds rates might be a term premia. Second, because of its relationship with the monetary policy, the Federal Funds rates acquire a special nature. Indeed, he finds that the Federal Funds rates are sporadically below fully secured rates in recent years.

There are a few studies using European data. Engsted (1996) uses Danish data to find finds that interest rates spreads are more powerful predictors of future interest rates in periods with very high interest rate volatility. He draws weekly observations for 1-month to 6-mont rates from the CIBOR (Copenhagen Interbank Offered Rates) interbank market and finds that the slope of the term structure is a useful indicator of the tightness of the monetary policy. Using daily interbank rates for the UK, Wetherilt (2002) shows that the spread vectors between the interbank rates and the repo rate span the cointegrating space. Interest rates used range from over-night to 12 months. She finds that shocks affect immediately the two-week spread and are transmitted up the money market curve. Innovations to money market rates are in general weak and short lasting, except for the overnight rate. Cuthbertson (1996) uses weekly data spanning maturities between 1-week and 12 months for the UK interbank market. Using VAR and cointegration methodologies he reports failure of the expectations hypothesis when the six-month and the 12-month rates are included as a pair, but evidence is supportive of the theory at shorter horizons. Hurn and al. (1995) find support to the expectations hypothesis in the London

Interbank Market when using monthly data for one-month to twelve-month deposit rates over the period January 1975 to December 1991. Mylonidis and Nikolaidou (2002) use monthly data on Greek money market rates, and provide several tests of the expectations hypothesis with constant risk premia. They analyse six series of interest rates with different maturities, from 1- to 12-month, for the period January 1996 to December 2001. On basis of cointegration analysis their findings are inconsistent with the expectations hypothesis: they find less cointegrating vectors than predicted by the theory; the shortest money market rates are weakly exogenous to the long run parameters of the model; and the interest rates spreads do not span the cointegration space. Perfect foresight regressions results are also unfavourable to the theory. Using monthly observations for the Portuguese Money market from 1990 to 1998, Fonseca (2002) develops bivariate models to the 3-, 6-, and 12-month Treasury bill yields and finds stable long run relationships between the 3- and 6-month, and the 6- and 12-month rates, accepting that risk premiums are stable and monotonically increasing with the maturity of interest rates. Using a slightly different, although shorter, data set where the interbank over-night rate is included, Andrade and Fonseca (1997) find a single cointegration vector between the overnight rate and the Treasury bond yield from 1993 to 1995.

3. A VEC Model for the Interest Rates Term Structure

3.1. Modeling Cointegrated Interest Rates

In this section we describe the approach taken to model the behaviour of interbank interest rates. The purpose of the VAR methodology is not simply to test the expectations hypothesis. The main purpose is to analyse the dynamic behaviour of interest rates at a range of maturities and their interaction. We analyse the dynamic interactions between interbank money market rates modeling a VAR in error correction form. It should be noted, however, that the VECM representation measures the dynamics of rate changes but does not provide any guidance on causality. It can as such be used to quantify lead-lag relationships and measure adjustment over time of each interbank rate to deviations of the term structure from the monetary policy target.

Cointegrated variables are driven by the same persistent shocks, making the econometric model a suitable approach to analyze the impact in the very short run of monetary policy shocks when central bank is committed to withstand liquidity shocks and bind interest rates to fluctuate within a narrow corridor. If interest rates of varying maturities are cointegrated there is has an error correction form representation for interest rates, out of which we can derive common trends reflecting monetary policy choices and other variables not captured by the expectation hypothesis[16]. Formally, a p-th order vector autoregression, VAR(p), might be written as:

$$\mathbf{x}_t = \alpha + \sum_{i=1}^{p} \Gamma_i \mathbf{x}_{t-i} + \varepsilon_t \ , \qquad [15]$$

where $\mathbf{x}_t = [R_{1,t}, R_{2,t} R_{3,t}, \ldots, R_{n,t}]$ is the observed time series vector; α is the vector of intercepts; the Γ_i's are $(n \times n)$ matrices of parameters; and $\boldsymbol{\varepsilon}_t = [\varepsilon_{1,t}, \varepsilon_{2,t}, \varepsilon_{3,t}, \ldots, \varepsilon_{n,t}]$ is a vector of Gaussian white noise processes with covariance matrix Σ, $\boldsymbol{\varepsilon}_t \sim N(0, \Sigma)$.

Assuming the system is co–integrated equation [15] can be rewritten as [17]

$$\Delta \mathbf{x}_t = \kappa - \alpha \beta' \mathbf{x}_{t-1} + \sum_{i=1}^{p-1} \psi_i \Delta \mathbf{x}_{t-i} + \boldsymbol{\varepsilon}_t \qquad [16]$$

Co-integration between n integrated series exists if at least one co-integrating vector can be found. The greater the number of co-integrating vectors the greater the co-dependency between the processes and smaller the number of common trends. Assuming there are n maturity rates, there are at maximum $(n-1)$ spread vectors that span the co-integration space, and

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[16] Hamilton (1994) and Hall et al. (1992) argue similarly that cointegration implies a vector error correction representation.

[17] The estimated model is modified slightly for the period ending on 03/08/93, because value date transactions were introduced on July that year only. Thus a similar model is estimated dropping the tom-next interest rate. Further, because the four regressions correspond to equal number of monetary policy regimes, the target rate is defined accordingly.

interest rates changes are thus partially determined by long run relationships. Moreover, the expectations hypothesis implies the existence of exactly $(n-1)$ independent spread vectors[18]. Equation [16] is estimated by reduce rank regression. The problem in practice is to identify the cointegration vectors and test whether the cointegrating vectors may be expressed in terms of the rates spreads.

Term structure models imply that the cointegrating space is spanned by the interest rates spreads between each rate and the one period rate. When interest rates of a given maturity deviate from the equilibrium spreads, there is a reverse adjustment bringing them back to the long run equilibrium. Interest rates of different maturities adjust not only to their own equilibrium spreads, but also to other maturities spreads. Hall et al. (1992) point out that the error correction model does not necessarily imply that yields adjust because of spreads being out of equilibrium. Campbell and Shiller (1987, 1988) say that the interest rate spreads might measure anticipated changes in interest rates. Given the short and long rates, investors have more information in the short-long rate spread for forecasting changes in the short rate, than it is available in the history of short rates alone. Thus, the spreads reflect market's expectations regarding changes in yields and the error correction representation arises because of this forward looking behaviour.

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[18] See Hall et al. (1992).

The cointegrated representation of the term structure of interest rates, when there are $(n-1)$ linearly independent cointegration variables for a set o n I(1) variables, implies that each interest rate can be expressed as a linear combination of a single common factor and an I(0) component[19]. The rational expectations formulation implies a single common factor driving varying maturity interest rates. The observed long run movement of each interest rate is primarily due to the movement in the common factor, which thus determines how the entire yield curve changes over time. The other stationary I(0) factors affecting interest rates are dominated by the nonstationary factor. We can interpret the nonstationary common factor as the one period return, or for that matter, any of the other term rates. The common factor is assumed to account for something exogenous to the yield structure, such as expected inflation or other measures of monetary policy stance. If we find more than a single common trend a feasible decomposition of the common trends requires that we are able to link the left $I(1)$ interest rate processes with each of the underlying factors. If there is more than a common factor, the expectations hypothesis fails to hold as other factors might come into play, such as time varying maturity and liquidity premia or other market anomalies. Moreover, failure of the

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[19] See Hall (1992:118) and Stock and Watson (1988). Hall et al. (1992) argue that the existence of a common factor driving interest rates is not new in literature. In their general equilibrium model of real yields to maturity Cox, Ingersoll and Ross (1985) the instantaneous rate is common to all yields.

expectations hypothesis occurs also when we find evidence of a single common factor, but the interest rates spreads do not span the cointegration space.

3.2. The problem and testing hypothesis

In equilibrium money market rates are jointly determined by the central bank and the optimisation behaviour of banks participating in the interbank money market. We have shown in chapter 4 that banks weigh off the expected opportunity cost of holding central bank money and the expected costs of overdrafts. The objective function might be modelled as a quadratic loss function, and banks behaviour is then affected by expectations regarding future money market rates, bank and industry liquidity shocks, reserve requirements and standing facilities. On the other hand, market expectations are linked to the credibility and commitment of the central bank to a given monetary policy. According to Bartolini et al. (2002) this reserves an important role for the central bank explaining the interbank market trading dynamics, i.e., the behaviour of interest rates and trading volume.

It is widely argued that the objective of the central bank is to minimise deviations of the relevant money market rate from its policy rate[20], and under

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[20] See Wetherilt (2002), Goodfriend (1991) and Poole (1991). McCallum (1994) discusses the economic plausibility of central banks' proclivity for interest rate smoothing. He argues that despite the controversy there is "virtually no disagreement with the proposition that the Fed –

the monetary policy transmission mechanism, central banks use interbank short-term rates as instruments to control longer rates, mainly six and twelve months rates, which are generally taken for indexing floating rate notes issues and banks loans. The effectiveness of open market operations and other short-term rates, such as standing facilities, depends on how banks react to these signals and adjust the longer rates accordingly. Therefore, if the interbank interest rates of different maturities are co-integrated the central bank is able to forecast the direction of interest rates change.

The central bank has access to a wide range of instruments such as reserve requirements[21], open market operations (main refinancing and deposit operations), and standing facilities (such as the marginal deposit and lending facilities made available on a daily basis to banks). Usually, standing facilities reduce the fluctuation of the overnight rate, while main operations control the 1 to 2 weeks rates, as the operations are usually made for the reserve holding

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and other major central banks – have in practice employed such practices during most (if not all) of the last 40 years." (McCallum, 1994:5).

[21] Usually, reserve requirements are computed using an average procedure, according to which banks are required to hold an average minimum level of reserves over the reserve maintenance period. The length of the maintenance period is variable from central bank to central bank. In Portugal, during the sample period there were four reserve-holding periods of variable length each month. The averaging procedure to determine minimum reserves produces interesting results. Some authors argue with reduced volatility of overnight interest rates, removing the need for very frequent open market operations, e.g., Borio (1997). Others report cyclical effects on interest rates, e.g., Furfine (2000) and Hamilton (1996), which are characterised by a martingale property during the reserve holding period as banks are indifferent to borrowing in any day of this period, except for the final day.

period length[22]. Open market operations will not be successful if the central bank is not committed to keep consistent interbank money market rates with the policy rate. The choice of the policy rate affects the behaviour of interbank money market rates markets' expectations. Several central banks target the over-night rate, e.g. United States. Others choose a different maturity, while being concerned that the behaviour of short maturities is consistent with the policy objective. Eventually, the policy target may change over time, as in our case.

Interbank market frictions, such as the strategic behaviour of banks' reserve management might place a wedge between the very short and the longer maturities interest rates. Banks are required to adjust to regulatory rules, and hold minimum reserve balances at the central bank at the established reserve maintenance dates. Banks' risk-averse behaviour may under certain circumstances put into jeopardy the expectations hypothesis equilibrium. If they are more sensitive to the expected cost of liquidity shortages than to the possible gains from arbitrage, they might offer to pay higher rates than expectations of future interest rates suggest. Changes in term premia are arguably related to the assumption that most central banks target interest rate

[22] In our data, main refinancing deposits are likely to have a direct impact upon the 1-week rate, the length of the reserve holding period. After the introduction of Euro, the main operations have 2-weeks maturity, therefore, bearing a close relationship with the 2-week interbank money market rates. Nevertheless, and given arbitrage considerations, these operations are likely to impose a bound on the behaviour of interest rates of other maturities.

smoothing and attempt to control the spread between target and money market rates at longest end of the money market yield curve[23]. In a cointegrating system, market and other frictions might increase the number of common trends beyond unity and imply rejection of the expectations hypothesis. In fact, shall more than one common trend be found in the data and we need to be able to link the interest rate behaviour with the monetary policy and reserve management operational framework to identify the factors implying rejection of the expectations hypothesis.

In this paper we assess the effectiveness of monetary policy in Portugal. We test the interest rates expectations hypothesis in the Portuguese interbank money market using a vector error correction model.

We expect to find support for the term structure expectations hypothesis, unless banks perceive each other as pertaining to different risk classes. Further, money market rates might be affected by liquidity and other risk factors in case the central bank shows no commitment to a given interest rate target. On contrary, we expect the term structure theory to hold if the central bank is ready to borrow or lend freely to accommodate liquidity shocks while keeping

[23] See McCallum (1994), Wetherilt (2002).

interest rates within target[24]. Thus the expectations hypothesis has to be tested together with the credibility of central bank monetary policy, the effectiveness of central bank operations to offset industry wide liquidity shocks, and the frictions introduced by interbank market institutions[25].

In sum, we test the validity of the rational expectations hypothesis of the very short term end of the yield curve, where the term premia appears to be less relevant. Assuming that any at least two interest rates series can be used to construct co-integrating vectors, first we test the null that interbank money market rates share a single common trend. We also check whether interest rates spreads span the cointegration space in a similar fashion as predicted by the expectations hypothesis. Finally, we analyse the adjustment dynamics of interest rates of different maturities when responding to monetary policy socks[26].

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24 In practice the central bank requires banks to post collateral in the form of government securities when using the marginal and lending facilities.

25 In presence of credit rationing the interbank money market might be unable to compensate bank-specific liquidity shocks and in this case some banks are left with excess central bank funds, while others are in shortage.

26 Hall, Anderson and Granger (1992) have already shown that the longer maturity yields are co-integrated with the shortest maturity yield. This follows from term structure model where differences between the n-period yield and the one period yield are equal to the successive expected changes in the one period yield plus a premium.

We present results for maturities in the range from over-night to 6 months using data with high frequency. A daily series of overnight rates and other maturities up to 6 months is used. The choice of this range of maturities is determined by its implications for the conduction of monetary policy that we want to analyse. The high quality and high frequency of data in our dataset is likely to make additional contributions to the effectiveness of monetary policy and the rational expectations theory of the term structure controversy. Taking different monetary policy regimes allows us to exploit the relationship between the expectations hypothesis theory of the term structure and the money market institutional features. Rejection of the null – i.e., failure to confirm the expectations hypothesis – might therefore be attributable to market frictions and other anomalies.

4. The Data

Different studies use different economic methods, test different implications of the expectations theory, look at different interest rate maturities and use different datasets. Traditionally, researchers have used Treasury Bills and Treasury Bonds rates as measures of the riskless rates in empirical studies. Data is usually collected for weekly or monthly periods. This approach has many advantages, because interest rates are readily observable, and the markets are highly liquid.

We have shown that applications using uncollateralized interbank money market trades are scarce. We propose to extend empirical research using interbank money market rates as an alternative measure of the term structure. These rates are for uncollateralized transactions among banks only, and reflect the pure cost of borrowing and lending. Interbank loans are pure financial contracts, not traded on a secondary market, and therefore not affected by the various factors that drive the yields of publicly traded securities. Interbank market characteristics, as discussed in the previous chapters, allow us to discard the credit risk premia considerations as relevant.

The analysis has been conducted on the Portuguese interbank money market interest rates, collected from all transactions reported by all banks to The Banco de Portugal. The data set contains seven daily series on money market rates and one daily series on the target rate[27]. The seven money market rates series are the over-night rate [O/N], for over-night loans; the tom-next [T/N] rate, for overnight loans negotiated at time t but taking place at time $t+1$ only[28]; the 1- and 2-week rates [1W and 2W], for one and two week loans,

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[27] Full details on how the dataset was collected and constructed are given in Chapter 4. We drop the one-year interest rates series intentionally due to insufficient observations. Indeed, interbank trades of this maturity are very infrequent and its inclusion might bias results. Had we included one year interest rates and several restrictions would be needed in order to estimate robust parameters. See Johansen and Juselius (2001).

The number of interbank interest rates is reduced to 6 for the period ending on the 12^{th} July 1993, when value-date transactions were allowed.

[28] "Tom-Next" stands for "tomorrow-next". Banks negotiate the loan today, but the funds are made available to the borrowing bank tomorrow only. Finally, it has to redeem the loan on the

respectively; the 1-, 3- and 6-month rates [1M 3M and 6M] for loans with maturities one, three and 6 months. The target rate series contains the monetary policy immediate target, which changes across monetary regimes[29]. We consider four different monetary policy regimes and use control variables to remove calendar and any special effects related to monetary policy and reserve maintenance considerations that can be found in interbank market rates. The choice of different monetary policy regimes is suggested by some empirical studies, on the basis that the extreme short end of the term structure is closely implied by the operational procedures undertaken by the central bank when conducting monetary policy[30]. Monetary policy regimes are distinguished by the chosen interest rate target and the operational monetary policy undertaken by The Banco de Portugal. Interest rates have experienced a sharp decline during the whole period, mainly when The Banco de Portugal implemented a tight

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next working day. The tom-next market operates as a forward market, and its rate is a very short term forward rate agreement.

[29] The target rate has been calculated as the mid point between marginal lending and marginal deposit operations, similar to the mid point between the main refinancing and lending rates. See Chapter 2 for a description of the monetary regimes.

[30] McCallum (1994: 14) suggests that one possible way of conducting tests on the expectations theory of interest rates "would be to consider different monetary policy regimes corresponding to different time periods for the United States and to different nations." Hall et al. (1992) use different monetary policy regimes to account for different monetary policy operating procedures. The regimes are distinguished by the degree of interest rate targeting undertaken by the Federal Reserve.

monetary policy to curb inflation and bring the Portuguese economy to converge with other EU member states as to join the single currency in 1999.

Contrary to other studies we use real trade data instead of quotes to re-examine the relationship between interest rates at a range of maturities. These data is particularly appropriate for an investigation of the term structure of interest rates at the extreme short end of the yield curve. The raw data have been neither interpolated over time nor interpolated over maturities. Interest rates are expressed in percentages and standardized using money market conventions in Portugal in the period: "actual/365" basis. By using data on a discount basis we avoid the approximation that is needed when using zero coupon yields or the "par-yield" approximation for coupon paying bonds. The sample consists of 2486 daily observations for the period from 1st January 1989 to 31st December 1998.

Summary statistics are presented in Tables 5.1 and 5.2. The data is split in four groups, corresponding to the four different monetary policy regimes. All variables are positively skewed and have fat tails, which are common features in presence of time varying means and variances. First differencing the data does not fix the problem. Interest rates might have conditional means and possibly time-varying heteroskedasticity. Jarque-Bera and Shapiro-Wilk tests reject the null of normality of interest rates levels for almost the whole maturity spectrum, and across policy regimes. Over-night, tomorrow-next and one-week rates are highly skewed while over two-week interest rates have quasi-symmetric probability distributions and negligible skewness. First differencing emphasises skewness, which is not surprising considering that interest rates have been decreasing during the sample period.

Table 5.1 – Interest Rates: summary statistics

Maturities		Obs.	Mean	Std. Dev.	Skewness	Kurtosis	Minimum	Maximum	Median
Over-Night	1	437	12.695	2.345	0.185	11.242	2.598	23.548	12.405
	2	702	15.720	5.741	2.813	24.137	1.039	68.414	15.314
	3	441	10.606	2.280	5.306	52.059	8.318	36.571	10.326
	4	906	6.363	1.646	0.062	1.831	2.865	9.221	6.231
Tomorrow-Next [a]	1								
	2								
	3	441	10.780	2.619	6.327	65.297	8.417	40.000	10.511
	4	906	6.395	1.645	0.074	1.813	3.053	9.208	6.259
1 Week	1	437	13.189	1.871	2.043	15.501	3.149	24.312	12.746
	2	702	16.267	4.384	4.007	35.564	7.960	59.909	15.911
	3	441	10.794	2.220	5.374	57.453	8.548	37.776	10.702
	4	906	6.411	1.653	0.091	1.812	2.986	9.286	6.268
2 Weeks	1	437	13.687	1.280	2.022	10.420	9.000	20.385	13.388
	2	702	16.506	2.942	3.072	29.780	10.700	50.000	16.520
	3	441	11.018	1.787	1.823	7.968	8.837	20.000	10.954
	4	906	6.467	1.676	0.139	1.841	3.000	9.625	6.295
1 Month	1	437	14.425	1.107	0.555	4.074	12.533	19.547	14.560
	2	702	16.850	2.011	-0.130	4.772	10.979	27.509	17.265
	3	441	11.171	1.605	1.548	6.429	9.007	20.027	11.099
	4	906	6.474	1.719	0.226	1.889	3.352	9.875	6.276
3 Months	1	437	15.046	1.506	0.199	1.844	10.487	18.106	14.808
	2	702	16.721	1.851	-0.818	3.376	11.091	21.000	17.102
	3	441	11.085	1.044	1.150	4.805	9.536	15.160	11.006
	4	906	6.431	1.820	0.353	2.004	3.300	10.250	6.141
6 Months	1	437	15.462	1.700	0.144	1.589	12.688	18.500	15.125
	2	702	16.738	2.239	-0.373	2.532	10.688	21.063	16.625
	3	441	11.000	0.795	0.682	4.278	9.133	13.500	10.966
	4	906	6.368	1.980	0.491	2.131	3.370	10.625	5.912
TB Yield	1	437	14.376	0.329	-2.288	6.234	13.500	14.500	14.500
	2	702	16.381	2.645	1.330	7.540	10.750	27.860	16.500
	3	441	10.927	1.068	1.436	5.322	10.000	14.903	10.625
	4	906	7.198	1.715	0.115	1.972	3.000	10.000	7.250

It is important to recognize that the data period comprises different policy regimes identified by numbers one to four. During the 1989–1998 period The Banco de Portugal shifted the monetary policy orientation and its operational targets.

[a]Deferred value–date transactions were only introduced on 12/07/93.

Table 5.2 – Interest Rates Changes: summary statistics

Maturities		Obs.	Mean	Std. Dev.	Skewness	Kurtosis	Minimum	Maximum	Median
Over–Night	1	436	0.008	1.760	0.451	13.594	–8.987	9.544	0.000
	2	702	–0.003	4.531	–0.534	31.150	–43.466	34.278	–0.135
	3	441	–0.011	1.346	–6.554	126.950	–20.379	8.285	–0.032
	4	906	–0.007	0.111	0.914	10.230	–0.609	0.737	–0.010
Tomorrow–Next [a]	1								
	2								
	3	441	–0.012	1.526	–4.918	159.686	–23.376	16.820	–0.006
	4	906	–0.006	0.082	0.789	12.168	–0.386	0.576	–0.003
1 Week	1	436	0.010	1.372	0.342	21.810	–9.692	9.480	0.012
	2	702	–0.003	3.338	–1.723	59.890	–36.941	29.337	–0.032
	3	441	–0.012	1.285	–6.670	155.881	–20.208	10.894	–0.019
	4	906	–0.007	0.074	–0.855	13.246	–0.638	0.359	–0.004
2 Weeks	1	436	0.009	0.858	0.648	18.124	–4.625	6.000	0.000
	2	702	–0.003	1.894	–3.303	91.590	–27.756	18.571	0.000
	3	441	–0.011	0.557	1.439	24.345	–3.438	4.566	0.000
	4	906	–0.007	0.127	–0.440	20.993	–1.025	0.969	0.000
1 Month	1	436	0.008	0.646	–1.210	16.627	–5.090	2.915	0.000
	2	702	–0.002	0.844	0.107	25.410	–6.712	6.625	0.000
	3	441	–0.010	0.535	0.947	22.368	–3.855	3.569	–0.025
	4	906	–0.007	0.098	–0.555	8.683	–0.567	0.406	–0.003
3 Months	1	436	0.008	1.056	0.154	10.151	–5.563	5.951	0.000
	2	702	–0.004	1.039	0.253	11.812	–5.242	5.376	0.000
	3	441	–0.007	0.335	–0.065	20.074	–2.664	2.204	0.000
	4	906	–0.008	0.121	–0.596	62.281	–1.608	1.496	0.000
6 Months	1	436	0.011	0.886	–0.150	7.886	–3.625	3.750	0.000
	2	702	–0.008	0.940	0.072	17.527	–6.005	6.005	0.000
	3	441	–0.004	0.265	–0.182	18.188	–2.000	1.750	0.000
	4	906	–0.008	0.101	–0.347	10.665	–0.555	0.625	0.000
TB Yield	1	436	0.002	0.048	20.809	434.002	0.000	1.000	0.000
	2	702	–0.001	0.774	0.985	213.889	–12.552	12.860	0.000
	3	441	–0.009	0.215	6.084	132.284	–1.625	3.225	0.000
	4	906	–0.008	0.061	–7.939	84.337	–0.750	0.400	0.000

It is important to recognize that the data period comprises different policy regimes identified by numbers one to four. During the 1989–1998 period The Banco de Portugal shifted the monetary policy orientation and its operational targets.

[a]Deferred value–date transactions were only introduced on 12/07/93.

The autocorrelation coefficients remain high after long lags showing persistency. The partial autocorrelation function shows weak evidence of seasonality, though we suspect there might be reserve maintenance calendar effects.

The tables illustrate the similar behaviour of interest rates over the sample period for the whole maturity range of our dataset. In particular, under each regime, interest rates seem to move together and exhibit similar volatility patterns. Interest rates are more volatile under regimes 2 and 3 when the financial system is under stress, because either the central bank is less committed to an interest rate target or the exchange rate mechanism turmoil. Persistence of interest rates in levels is increasing over time[31]. Under regimes 1 and 2 – i.e., until mid-1991 – the autocorrelation function decays fast towards zero after 10 to 20 working days, suggesting that interest rates might appropriately be represented as AR(1). On the contrary, during regimes 3 and 4 and consistently with empirical literature interest rates are found to have a large characteristic root, allowing an I(1) representation. The low persistence found in the earlier monetary regimes might be due to fast decreasing and highly volatile interest rates. The stabilization policies undertaken by The Banco de Portugal, allowing interest rates to fluctuate freely and fast decrease towards the European average, stressed the banking system and the interbank money market, in particular. Close to zero partial autocorrelation coefficients show weak evidence of seasonality, though we might suspect there should be a reserve holding period effect[32].

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[31] We do not report the autocorrelation functions and associated Q-tests.

[32] Reserve maintenance periods are time changing. Cf. Chapter 2.

5. Unit Root Tests and Stationary

Appropriated augmented Dickey–Fuller [ADF] test statistics were computed for each interest rates series. As there is nothing in economic theory suggesting that nominal interest rates should exhibit a time trend we excluded trend stationary processes and concentrated on a drifting random walk only[33].

$$R_{i,t} = \alpha_i + \rho_i R_{i,t-1} + \xi_{i,1}\Delta R_{i,t-1} + \ldots + \xi_{i,p-1}\Delta R_{i,t-p+1} + \varepsilon_{i,t} \qquad [17]$$

We first differenced [17] and estimated the following equation[34]:

$$\Delta R_{i,t} = \alpha_i + (\rho_i - 1) R_{i,t-1} + \sum_{j=1}^{n} \beta_{i,j}\Delta R_{i,t-j} + \varepsilon_{i,t} \qquad [18]$$

There is no evidence against the null that the individual series are I(1) for regime 4 . However, evidence for regimes 1 to 3 is not as conclusive. Particularly, we cannot accept the null for the shorter rates, though rejections are marginal and the estimated coefficients suggest that interest rates levels are highly persistent.

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33 The persistent downward trend in the nominal interest rates, particularly after mid 1993, may be due exactly to a negative drift term on the random walk generating process.

34 Hamilton (1994) argues that there is no need based on asymptotic distribution theory for differencing the data before estimating the autoregression. Many researchers recommend differencing the data only to reduce small sample bias and small sample mean squared errors of the estimates. Lagged terms up to order p are used to remove any autocorrelation in residuals. In our case, we had to use lags up to 15 trading days.

Table 5.3 – ADF Unit Root Tests for level Interest Rates

	Regime 1		Regime 2		Regime 3		Regime 4	
	$\hat{\rho}-1$	t-ratio	$\hat{\rho}-1$	t-ratio	$\hat{\rho}-1$	t-ratio	$\hat{\rho}-1$	t-ratio
Over-Night	-0.280	-4.21 **	-0.333	-4.53 **	-0.211	-5.28 **	-0.020	-2.72
Tomorrow-Next							-0.021	-2.68
1 Week	-0.133	-3.17 *	-0.241	-4.12 **	-0.204	-5.16 **	-0.017	-2.36
2 Weeks	-0.137	-4.44 **	-0.216	-4.23 **	-0.087	-4.09 **	-0.006	-1.95
1 Month	-0.062	-2.04	-0.084	-2.07	-0.049	-3.71 **	-0.006	-1.85
3 Months	-0.096	-2.53	-0.249	-3.23 *	-0.024	-1.69	-0.002	-1.19
6 Months	-0.080	-2.66	-0.105	-2.27	-0.019	-1.39	-0.001	-0.65

Augmented Dickey–Fuller tests for unit roots were used. The number of lags was chosen as to eliminate any remaining serial correlation in residuals. The t-ratio is the Dickey–Fuller test statistic for the corresponding specification. Coefficients marked with ** (*) are significant at the one (five) percent level and denote null hypothesis rejection, i.e., the corresponding series are not integrated of order one. Probabilities are obtained using MacKinnon approximation.

Given that Phillips–Perron tests are seen as more robust to time dependent heteroskedasticity we tested the joint null hypothesis that the series is nonstationary – i.e., $H_0 : \alpha_i = 0, \rho_i = 1$ – using the following equation[35]:

$$R_{i,t} = \alpha_i + \rho_i R_{i,t-1} + u_{i,t} \qquad [19]$$

Table 5.4 – Phillips–Perron Unit Root Tests for level Interest Rates

	Regime 1		Regime 2		Regime 3		Regime 4	
	$\hat{\rho}$	Z_t	$\hat{\rho}$	Z_t	$\hat{\rho}$	Z_t	$\hat{\rho}$	Z_t
Over-Night	0.484	-11.58 **	0.610	-8.31 **	0.759	-8.26 **	0.959	-4.28 **
Tomorrow-Next							0.953	-4.79 **
1 Week	0.787	-6.53 **	0.684	-7.20 **	0.723	-8.87 **	0.964	-3.97 **
2 Weeks	0.820	-5.69 **	0.706	-6.87 **	0.902	-4.93 **	0.991	-2.52
1 Month	0.812	-5.36 **	0.798	-5.36 **	0.957	-3.44 **	0.993	-2.16
3 Months	0.721	-7.35 **	0.469	-10.65 **	0.950	-2.62	0.997	-1.33
6 Months	0.826	-5.03 **	0.706	-6.87 **	0.946	-2.62	0.998	-0.95

Phillips–Perron tests for unit roots were used. Z_t is the t-statistic adjusted with the Newey–West estimator to take account of serial correlation and potential heteroskedasticity in disturbances. The number of Newey–West

[35] Hamilton (1994: 507) and Enders (1995: 239). In practice one usually performs both ADF and Phillips-Perron tests.

lags was set to 6. Coefficients marked with ** (*) are significant at the one (five) percent level and denote null hypothesis rejection, i.e., the corresponding series are not integrated of order one. Probabilities are obtained using MacKinnon approximation.

Philips-Perron confirms ADF rejections of the null during regimes 1 to 3, and produces a larger number of rejections also. In particular, it extends rejections to the whole interbank term structure. However, when applied to the differenced data both tests clearly reject the null hypothesis that there is a unit root in any of the series[36]. Both tests suggest that level interest rates have a unit root in Regime 4.

The results for regimes 1 to 3 appear to contradict mainstream empirical literature, which finds or assumes that interest rates are adequately described as I(1) processes[37]. The ambiguity of our results might be due to the weak power of the unit root tests when the true data generating process is a near unit root. If we increase the number of lags, we obtain evidence in favour of a unit root in most cases, and the remaining rejections are few and significantly not very important[38]. Hamilton (1994) and Enders (1995) show that Phillips-Perron tests

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[36] Results not presented.

[37] The conclusion that interest rates are I(1) cannot be strictly true, as this would imply unbounded interest rates, while nominal rates are bounded below by zero. However, given the statistical properties of interest rates and the high degree of persistency found in levels it is appropriate to treat these rates as if they were integrated processes.

[38] Hamilton (1994: 516) reports Monte Carlo simulations that actually rejected the null hypothesis in every sample, though the null hypothesis is true. Rodrigues and Osborn (1999), Rodrigues (2000) and Lopes (2000) say that when the data contains stochastic seasonal unit

in the presence of negative moving average terms tend to reject the null of a unit root, whether or not the actual data generating process contains a unit root. Enders (1995) argues that integration is not always a theoretical property of economic data but a convenient way to distinguish between the short-run and the long-run variation in data. Therefore, a process can be arbitrarily well approximated either by an ARMA or an I(1) process[39]. When the data set is long enough and the variables cross several times its mean level, it is possible that we find data stationary. However, when the time span is limited, and the variable does not cross the mean value except on a few occasions, the data might be better described by a nonstationary process. If we apply a nonlinear unit root test, as suggested by Elliot, et al. (1996), we find support for a unit root in all series[40].

The results found in regimes 1 to 3 might also be due to the high frequency and high variability of the over-night and the one-week and two-week rates. This feature is, however, not observed in the longer rates, which show higher

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roots, the ADF test can be validly used provided the test regression is sufficiently augmented with lags of the dependent variable to account for the presence of such non-stationary components. Otherwise, serious over-rejections of the unit root null might arise.

39 In the short run, both models have similar forecasting performance. First differencing the data uncovers other sorts of relationships for autocorrelation and moving average terms. However, as the forecast horizon expands the precise form of the trend becomes increasingly important, while stationary implies the absence of a trend and a long-run mean reversion.

40 Elliot et al. (1996) propose a GLS demeaned version of the ADF test, which substantially improves the power properties of the standard ADF test. Lopes (2003) finds that the ADF test is not invariant to deterministic seasonality.

stability and for which the unit root hypothesis is not rejected or, at most, is rejected only marginally. Using data on the UK interbank market, Wetherilt (2002) also finds that standard unit root tests reject the null for the overnight and the one-week rates, while rejections are not possible for level rates beyond one week[41]. If we were to sample our data set weakly – thus eliminating much of interest rate seasonality – unit root tests would not reject the null of integration. Additionally, if we choose to represent the shortest rates as AR(1) processes, we find that the autocorrelation coefficients are quite high, thus denoting high degree of persistence in interest rates.

Further explanations for the puzzling results can be found in the fast decreasing interest rates during the early regimes. During the early regimes, structural monetary policy operations, increasing financial market integration and the converging process towards the Euro pushed interbank market rates downward, but introduced volatility in the very short term end of the interbank market yield curve, in particular the over-night and one week rates. During periods of turmoil the financial downward trend was abandoned, just to be resumed later. This produced high fluctuation in interest rates forcing the series to cross the mean several times. Additional time varying volatility and calendar

[41] To the extent of our knowledge there studies using daily overnight and one-week rates abundant and we are not able to provide additional evidence in our support. Also, and contrary to most studies we are using transaction data instead of quotes, which is uncommon due to the lack of data.

effects may explain this deviation in the autocorrelation coefficient. If we account for volatility changes, the autocorrelation coefficient is likely to increase, approaching unity. This did not happen in the last regime, when EMU was consolidated and the financial market integration completed, and because of this the unit root tests are consistent with mainstream empirical literature.

Following mainstream literature we assume that treating interest rates as I(1) gives a reasonable approximation to the true process[42]. Treating interest rates as nonstationary and exploiting the cointegration property on data, gives us the opportunity to find out if interest rates share the same stochastic trend. From the economic perspective, the approach offers a test of the interest rates rational expectations hypothesis: first, we must find a single random walk – i.e., a unique common trend driving all interest rates series – and, secondly, interest rates spreads must span the cointegration space.

6. Interbank Interest Rates as a Cointegrated VAR

We estimate the vector error correction model described by equation [20].

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[42] See Hall et al. (1992). Sarno and Thornton (2002) mention the "apparent conflict between conventional economic and finance theory, which often assumes that interest rates are stationary processes, and the mainstream empirical literature, which [...] either assumes or finds that interest rates are nonstationary processes." They go on to conclude that very persistent series with a quasi unit root are better approximated by an I(1) process rather than a stationary process.

$$\Delta \mathbf{x}_t = \kappa - \Pi \mathbf{x}_{t-1} + \sum_{i=1}^{p-1} \psi_i \Delta \mathbf{x}_{t-i} + \varepsilon_t \qquad [20]$$

Unrestricted level and impulse dummy variables, reflecting periods of foreign exchange market turbulence affecting the Portuguese Escudo within the ERM[43], are used to account for extraordinary shocks affecting target and interbank rates. We also account for end of the week and end of the reserve holding period effects. Quite likely, dummies lie out of the cointegration space as they affect all the rates in the same direction and cancel out[44].

The number of lags used in the VECM [16] is chosen according to the multivariate Schwartz Information Criterion[45]. Misspecification tests shows that increasing the number of lags does not improve the model performance in any substantial way. Interest rates still exhibit strong autocorrelation. One way of dealing with this leftover autocorrelation is to introduce moving average terms

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43 We tried alternatively the Escudo exchange rate against the Euro to account for external shocks, but results were not significant. This may happen because the currency is under pressure well before the central bank decides to increase interest rates. Further, when the Banco de Portugal finally decides to devalue the currency interest rates dropt abruptly with no change whatsoever on the exchange rate. A better measure would be measuring the deviation from central parity. Results remain unchanged using this alternative.

44 Shift dummies in a dynamic VAR turn into blip dummies when the system is written in differences. Thus, we need to include both in the model to be estimated: an unrestricted blip dummy in the equations; and a shift dummy in the cointegration relations. If the cointegration variables are affected equally by the shift dummy the effects cancel out and it can be set to zero.

45 The number of lags used is 5 in all Regimes.

leading to a class of VARMA models. However, and referring to Lutkepohl and Saikkonen (1999), the LR cointegration tests remain valid if the data generating process is a VARMA or an infinite VAR, as long as the lag order is selected by a suitable model selection criteria. Residuals exhibit significant ARCH effects. As the estimation results are generally robust to ARCH effects and excess kurtosis we will disregard the non–normality problem here (Johansen and Juselius, 2001 and Rahbek et al, 2002).

We test the number of cointegration relationships using Johansen's methodology[46]. Theoretically, if a co–integrating relationship exists amongst the variables, the dynamic behaviour of at least one variable must be restricted by the values of the other variables in the system[47].

6.1. Long run behaviour and potential cointegration vectors

We start estimating the unrestricted VAR(p) in the error correction form:

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[46] Johansen's procedure uses full information maximum likelihood (FIML) to estimate the linear space spanned by the co-integrating vectors. The method is preferred to Engle-Granger, as it has less bias when the number of variables is greater than two, and it seeks the most stationary linear combination whereas the Engle-Granger tests seek the linear combination having minimum variance.

[47] We must recall that the co-integration technique does not require the equilibrium to be generated by market forces or the behavioural rules of individuals. Indeed, the equilibrium relationship may arise from behavioural or simply reduced form relationship amongst similarly trending variables. We must, therefore impose a priori a sustainable economic reason for the variables to be co-integrated. As a practical matter, when we find more than one co-integrating relationship it is not possible to identify the behavioural relationships from the reduced form. A structural form must be imposed first on the model.

$$\Delta \mathbf{x}_t = \kappa - \Pi \mathbf{x}_{t-1} + \sum_{i=1}^{p-1} \psi_i \Delta \mathbf{x}_{t-i} + \Phi D_t + \varepsilon_t \qquad [21]$$

Estimates of model [21] with 5 lags for regimes 1 to 4 are given in Table 5.5 and next. Interbank interest rate generating processes are mean reverting for all maturities and across all the monetary policy regimes. The diagonal elements of the four Π matrices are all negative and highly significant. Across the four monetary regimes, the target rate became progressively more important constraining the over-night rate[48].

Table 5.5 – Estimated long-run coefficient matrix Π

Regime 1: 01/01/89 to 09/10/90

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{trg}
ΔR_{on}	**-0.637 ****		**0.427 ***	-0.056	0.211	0.030	0.023	0.118
ΔR_{w1}	-0.017		**-0.435 ****	0.160	0.227 +	-0.054	0.023	-0.118
ΔR_{w2}	-0.046		0.044	**-0.291 ****	**0.297 ****	-0.043	-0.008	0.021
ΔR_{m1}	0.033		0.000	0.054	**-0.303 ****	-0.004	-0.002	0.179 **
ΔR_{m3}	0.089		-0.139	0.039	0.077	**-0.332 ****	0.099 +	-0.019
ΔR_{m6}	0.012		0.064	-0.068	-0.041	0.015	**-0.218 ****	0.103 +
ΔR_{trg}	0.001		0.000	0.000	0.002	-0.003	0.001	**-0.001**

Regime 2: 10/10/90 to 12/07/93

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{trg}
ΔR_{on}	**-0.448 ****		0.031	0.237	-0.079	0.186	-0.191	**0.242 ****
ΔR_{w1}	0.087		**-0.589 ****	**0.321 ****	0.027	0.073	-0.108	**0.166 ****
ΔR_{w2}	**0.205 ****		-0.132	**-0.523 ****	**0.478 ****	0.043	-0.090	**0.047**
ΔR_{m1}	**-0.057 ***		0.081 +	**0.119 ****	**-0.337 ****	**0.097 ***	0.034	**0.049 ****
ΔR_{m3}	-0.021		0.012	0.040	**0.165 ****	**-0.401 ****	**0.159 ****	**-0.013**
ΔR_{m6}	**0.087 ****		**-0.138 ****	-0.036	**0.226 ****	0.009	**-0.178 ****	0.008
ΔR_{trg}	-0.059 +		**0.171 ****	-0.049	-0.015	-0.005	0.080 **	**-0.087 ****

48 Dummy variables were used to correct for day-of-the week and first and last day of reserve holding period effects. Results are not reported here.

Table 5.5 – Estimated long-run coefficient matrix Π (continued)

Regime 3: 02/08/93 to 09/05/95

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{trg}
ΔR_{on}	−0.916 **	0.843 **	−1.062 **	1.007 **	0.413 *	−1.020 **	0.372 **	0.181 *
ΔR_{tn}	0.407	0.140	−1.877 **	1.336 **	0.399 +	−0.882 **	0.293 +	0.039
ΔR_{w1}	0.115	0.724 **	−1.860 **	0.871 **	0.324 *	−0.546 **	0.274 *	0.007
ΔR_{w2}	0.272 +	−0.014	−0.160	−0.697 **	0.789 **	−0.415 **	0.028	0.162 **
ΔR_{m1}	0.042	0.054	−0.139	0.043	0.059	−0.281 *	0.208 *	0.034
ΔR_{m3}	0.120	0.028	−0.267 *	0.021	0.309 **	−0.459 **	0.150 **	0.083 **
ΔR_{m6}	−0.066	0.187 **	−0.204 *	−0.082	0.180 **	0.053	−0.175 **	0.070 **
ΔR_{trg}	−0.001	−0.176 **	0.146 +	0.125 *	0.013	−0.152 **	0.137 **	−0.105 **

Regime 4: 10/05/94 to 31/12/98

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{trg}
ΔR_{on}	−0.595 **	0.430 **	0.104	−0.022	0.024	−0.038	0.001	0.093 **
ΔR_{tn}	0.166 **	−0.754 **	0.499 **	0.061	0.046	−0.062	0.009	0.033 *
ΔR_{w1}	0.151 *	−0.023	−0.255 **	0.021	0.114 *	−0.023	−0.004	0.018
ΔR_{w2}	0.036	0.166	0.223 +	−0.749 **	0.304 **	0.085	−0.033	−0.034 +
ΔR_{m1}	0.104	0.006	0.088	0.031	−0.375 **	0.161 **	0.009	−0.025
ΔR_{m3}	−0.014	−0.043	0.176	−0.100	0.229 **	−0.587 **	0.290 **	0.041 *
ΔR_{m6}	−0.013	0.062	0.030	−0.079	−0.097	0.223 **	−0.112 **	−0.012
ΔR_{trg}	−0.125 *	0.270 **	−0.088	−0.072 +	0.033	0.014	−0.005	−0.024 *

Coefficients marked with ** (*) are significant at the one (five) percent level. Further, coefficients only marginally significant at 10% are market with "+". Coefficients are estimated fitting to data a VAR(5) in ECM representation. Both impulse and level dummy variables were used to account for the first and last period of the reserve holding period, and day of the week effects Additional dummy variables were used to account for foreign exchange market turbulence. Finally, we have estimated a VAR(9) for Regime 4 without the TOM/NEXT interest rate, but results are unchanged.

The Π matrices estimates across the four regimes are consistent with the modernization of the Portuguese financial system, in general, and the banking sector, in particular. There might be several cointegration vectors linking interest rates of different maturities, as we find a cascade effect between interest rates of neighboring maturities. Notice the highly significant parameters along the main diagonal. One–week and over–night rates appear tied up together, most probably due to the fact that the reserve–holding period is approximately one–week long[49]. This is particularly true for regime 4, where all parameter estimates clustered along the main diagonal are all highly significant. Odd estimates for regime 3 are partly related to the turmoil in the exchange rate mechanism just before the introduction of Euro.

The estimates reflect the monetary policy stance and changes in the choice of the immediate target also. In regimes 1 and 2 the Banco de Portugal was more concerned with controlling the 6 months rate than the short-term end of the interbank yield curve. Consequently, the over-night and up to one week rates fluctuated almost randomly. In regime 1 the target rate was set as the weighted average of last 12 Treasury Bills auctions with maturities ranging from 90 days up to 1 year. In fact, the financial system was still under strict control and existing arbitrage opportunities could not be exploited. Financial institutions were starting to compete through prices, but retail interest rates and loan volume were controlled directly by Banco de Portugal. Except for interbank money market, banks did not have feasible alternatives to invest excess reserves and, as a consequence, the interbank market was seldom used to manage daily reserves or meet calendar reserve requirements. The interbank

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49 These results are also consistent with Wetherilt (2002), who finds that overnight interest rates are anchored to the two-week repo rate, which is equivalent to the one-week rate for the Portuguese Banking system. We recall chapter 2, when it has been said the reserve holding period is approximately one week long.

market was diverted from its original functions. Newly established private banks, in need of funds, used interbank loans to fund their expansion plans, while existing government banks – locked in structurally long central bank balances – were willing to lend for longer maturities and avoid the high transaction costs of sequential renewals. It is, however, surprising why banks did not arbitrage the term structure of interest rates during regimes 1 and 2, rolling over short-term investments in the interbank money market. The interbank money market became fully efficient in regime 4 only. The banking system is freed from legal and operational constraints, the excess liquidity disappeared, and the interbank money market could finally revert to its original functions: provision of liquidity for the very short term and a channel for the transmission of monetary policy shocks. In fact, given the pace of the privatization in the banking industry, and the process towards an integrated financial market across the European Union[50], Portuguese banks became efficient and internationally competitive in the early 90's only.

The target rate coefficients for each maturity equation reveal the effects of changing the immediate target upon the adjustment process. It is clear that when the target rate was associated with long term instruments, it affected the longer maturities, whereas when the monetary policy shifted the focus to open

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[50] The process consisted mostly in fully implementation of international capital mobility, and transposition of European Union directives regarding investment services and banking coordination policies.

market operations and standing facilities, the target became more effective binding the shortest rates. During regime 1 The Banco de Portugal has been able to condition the longer rates through the target rate, as it can be seen by a highly significant coefficient on the one-month rate change. This happened because banks could arbitrage directly between the target rate and the Treasury bills market, which was used as a basis to calculate the target rate[51].

Over time, the target rate became increasingly more important in explaining the short-term adjustment of interest rates. However, the impact is quite small, and the results suggest that the best candidates for the cointegration vectors are the spreads between neighbouring interest rates. Both the size and significance of the unrestricted estimates favour this solution. This is true for all regimes except 3, where the upper triangular unrestricted long run matrix shows highly significant coefficients. During regime 3, changes in the shortest rates are explained by interest rates of all maturities, whereas a small number of factors is needed to explain changes in the longest rates. This might be related to the foreign exchange turmoil during this period, when banks placed speculative investments in both the domestic and the Euroescudo interbank markets.

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[51] The target rate was the Treasury-bill reference yield, computed as a weighted average of interest rates from the last twelve auctions of Treasury bills maturing between one and twelve months.

Other target rates, rather than the daily intervention in the interbank market, are also important in explaining interest rates changes. Notice the relevance of the one–month interest rates across all regimes, which is highly correlated with the Treasury Bills auctions rates of identical maturity. Day–to–day intervention seems of little importance except when determining the availability of liquidity to banks. Short term rates adjust mainly to deviations from their neighbours. Take, for example, regime 4. We might propose the spread between the over–night and the tom–next rate as a good candidate for the first cointegration vector, while the second row of matrix Π proposes the spread between tom–next and one-week rates as another possibility. The first cointegration vector is probably the main responsible for driving over–night rates, while the second explains most of the adjustment seen in the tom–next rates. Notice that the target rate coefficient, though highly significant, is of small magnitude as compared to the others[52].

6.2. Short run dynamics of interbank interest rates

The short–term coefficient matrix – ψ_1 – is presented in Table 5.6. Apparently, the short run dynamics links rates of similar maturity, except for regimes 2 and 3, when interest rates of different maturities appear to move randomly and have impact on each other simultaneously. A similar effect was

52 However, this might also signal the high correlation between these variables.

found in the long run matrix. Again, and consistently with the modernization of the Portuguese financial system, the target rate became obviously more important during regimes 3 and 4. When the target switched to focus on the very short–term end of yield curve – i.e., during regime 4 – up to one–week rates became significantly more responsive to changes in monetary policy targets.

Table 5.6 – Estimated short–run coefficient matrix ψ_1

Regime 1: 01/01/89 to 09/10/90

	ΔR_{on}	ΔR_{tn}	ΔR_{w1}	ΔR_{w2}	ΔR_{m1}	ΔR_{m3}	ΔR_{m6}	ΔR_{trg}
ΔR_{on}	0.191		0.030	0.004	0.058	–0.068	0.049	0.057
ΔR_{w1}	**0.235** *		–0.025	–0.113	0.042	–0.021	0.013	0.162
ΔR_{w2}	**–0.144** **		**0.336** **	–0.087	–0.064	–0.024	0.032	–0.082
ΔR_{m1}	0.013		0.014	–0.018	**–0.333** **	0.011	–0.061	–0.147
ΔR_{m3}	–0.060		0.140	–0.125	–0.155	**–0.414** **	–0.129	0.197
ΔR_{m6}	0.056		–0.130	0.041	0.052	–0.008	**–0.369** **	0.147
ΔR_{trg}	0.000		–0.001	0.001	–0.002	0.000	0.000	0.004

Regime 2: 10/10/90 to 12/07/93

	ΔR_{on}	ΔR_{tn}	ΔR_{w1}	ΔR_{w2}	ΔR_{m1}	ΔR_{m3}	ΔR_{m6}	ΔR_{trg}
ΔR_{on}	–0.066		0.189	–0.162	**1.000** **	0.075	**–0.391** *	0.212
ΔR_{w1}	0.080		–0.152	–0.144	**0.913** **	0.027	–0.267	0.106
ΔR_{w2}	–0.030		**0.141** *	–0.071	–0.037	**–0.169** *	**–0.225** **	0.098
ΔR_{m1}	**0.082** **		–0.023	–0.043	–0.018	–0.044	–0.045	0.175
ΔR_{m3}	–0.041		0.031	0.039	–0.094	**–0.243** **	**–0.153** **	0.046
ΔR_{m6}	–0.060		**0.122** **	0.056	**–0.385** **	–0.009	**–0.426** **	0.079
ΔR_{trg}	0.027		–0.019	–0.015	**–0.117** **	0.008	–0.009	0.030

Regime 3: 02/08/93 to 09/05/95

	ΔR_{on}	ΔR_{tn}	ΔR_{w1}	ΔR_{w2}	ΔR_{m1}	ΔR_{m3}	ΔR_{m6}	ΔR_{trg}
ΔR_{on}	–0.241	**0.420** *	0.319	0.094	**–0.624** **	**0.723** **	**–0.393** *	–0.199
ΔR_{tn}	**–0.527** *	0.406	**0.647** *	0.058	–0.452	0.506	–0.323	–0.108
ΔR_{w1}	**–0.337** *	**0.494** **	0.199	–0.012	**–0.522** **	**0.549** **	–0.104	–0.103
ΔR_{w2}	**–0.295** *	0.238	0.096	0.142	**–0.555** **	**0.410** *	0.188	**0.405** **
ΔR_{m1}	–0.178	0.215	0.080	0.194	**–0.697** **	**0.419** **	0.126	**0.373** **
ΔR_{m3}	**–0.156** *	0.080	**0.287** **	0.058	**–0.215** **	–0.084	–0.023	**0.136** *
ΔR_{m6}	0.009	**–0.128** *	**0.271** **	0.038	**–0.127** *	0.062	**–0.262** **	**0.202** **
ΔR_{trg}	–0.035	**0.177** **	–0.122	–0.101	0.033	**0.274** **	**–0.134** *	–0.036

Table 5.6 – Estimated short–run coefficient matrix ψ_1 (continued)

Regime 4: 10/05/95 to 31/12/98								
	ΔR_{on}	ΔR_{tn}	ΔR_{w1}	ΔR_{w2}	ΔR_{m1}	ΔR_{m3}	ΔR_{m6}	ΔR_{trg}
ΔR_{on}	−0.032	**0.472** **	0.069	0.014	−0.099	0.046	0.006	**−0.102** *
ΔR_{tn}	−0.019	**0.331** **	0.003	−0.076	−0.042	0.078	0.040	**−0.093** *
ΔR_{w1}	−0.004	**0.429** **	**−0.333** **	−0.018	**−0.100** *	0.063	0.049	0.055
ΔR_{w2}	−0.116	0.196	−0.088	0.063	**−0.233** **	0.000	**0.130** **	**0.217** **
ΔR_{m1}	−0.054	0.120	0.013	0.015	**−0.369** **	0.075	**0.126** **	**0.112** *
ΔR_{m3}	0.016	0.032	−0.105	0.095	−0.079	**−0.177** **	−0.042	0.113
ΔR_{m6}	−0.088	0.108	−0.079	0.024	**0.188** **	−0.089	**−0.306** **	0.109
ΔR_{trg}	0.021	−0.063	0.141	0.020	−0.076	0.028	0.027	−0.014

Coefficients marked with ** (*) are significant at the one (five) percent level. Further, coefficients only marginally significant at 10% are market with +. Coefficients are estimated fitting to data a VAR(5) in ECM representation. Both impulse and level dummy variables were used to account for the first and last period of the reserve holding period, and day of the week effects Additional dummy variables were used to account for foreign exchange market turbulence. Finally, we have estimated a VAR(5) for Regimes 3 and 4 without the TOM/NEXT interest rate, but results are unchanged.

Nevertheless the change in the target, the central bank kept control of long-term interest rates using a short–term rate. Changes in the target rate have positive effects upon longer maturities rates. Short run coefficients for regimes 3 and 4, show that the longer rates react in the same direction as do changes in the target, while the shorter rates change in the opposite direction. This might occur as banks rearrange their portfolio between short and long-term investments due to an unanticipated interest rate shock. The tom–next and one–month rates are important pivots conveying information between the short–term and long–term ends of the yield curve. In regime 4, the lagged tom–next rate had a positive effect upon up to one–week rates, signaling that interest rates were about to increase in the next days. We find an opposite direction effect between one–month rates on the 3 month rates. A positive change in the lagged one–month triggers a rate decrease across all maturities, except the six–

month rate, reflecting mean reverting returns, as shocks are netted out and interest rates adjust to the former levels.

Considering estimates in Table 5.5 and Table 5.6 we might argue that banks use longer rates to build expectations and adjust the short–term rates, and assume the central bank is able and willing to offset unexpected aggregate liquidity shocks. The reputation issue often associated with the use of the discount window is absent here, as banks do not avoid avoiding using the marginal lending and deposit facilities if necessary. Hence, daily facilities do effectively bound the over night rates[53].

We also produced estimates for day of the week effects and reserve holding period effects. Those are reported in Table 5.7. Short rates are slightly sensitive to weekday effects. Mainly, tom/next rates increase on the last day of the reserve–holding period and decrease on Fridays. However, the effects are negligible and seem not to impact the rate adjustment process for the longer maturities. During regime 4 overnight rates have decreased on the first and last days of the reserve period, while no similar effect were found for any other day of the reserve holding period.

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[53] This is contrary to the argument that banks avoid using the discount window, because there is a widespread opinion that the central bank regards its use as resulting from mismanagement of bank reserves and, therefore, should be subject to a penalty. We must stress, nevertheless, here is no equivalent to marginal lending and deposit facilities in the US Federal Reserve system. However, we assume with no loss of generalization that the discount window provided by the Federal Reserve System is similar to the marginal lending facility.

Table 5.7 – Estimated contemporaneous coefficient matrices Γ and Φ

	Regime 1: 01/01/89 to 09/10/90		Regime 2: 10/10/90 to 12/07/93	
	ΔD_{hp_dl}	ΔD_{friday}	ΔD_{hp_dl}	ΔD_{friday}
ΔR_{on}	0.041	0.003	**−0.963** *	0.703
ΔR_{w1}	0.061	0.069	−0.121	−0.075
ΔR_{w2}	0.054	0.108	0.218	−0.229
ΔR_{m1}	**−0.208** *	−0.024	0.053	0.164
ΔR_{m3}	−0.074	−0.139	0.166 +	−0.016
ΔR_{m6}	−0.043	−0.333 +	0.077	**0.449** **

	Regime 3: 02/08/93 to 09/05/95		Regime 4: 10/05/95 to 31/12/98		
	ΔD_{hp_dl}	ΔD_{friday}	ΔD_{hp_dl}	ΔD_{hp_d1}	ΔD_{friday}
ΔR_{on}	0.063	−0.291 +	**−0.017** *	**−0.133** **	**−0.026** *
ΔR_{tn}	**0.424** **	**−0.612** **	**0.042** **	−0.064 +	**−0.022** *
ΔR_{w1}	0.141 +	−0.246 +	−0.003	−0.039	−0.010
ΔR_{w2}	−0.031	−0.177 +	−0.001	−0.113 *	−0.019
ΔR_{m1}	0.023	−0.110	−0.015 +	0.029	0.001
ΔR_{m3}	−0.014	0.014	−0.004	0.023	−0.011
ΔR_{m6}	−0.054	−0.028	−0.013	0.019	0.009

Coefficients marked with ** (*) are significant at the one (five) percent level. Additional coefficients market with + are significant at the 10% level. Coefficients are estimated fitting a VAR(5) in ECM representation to the data. Both impulse and level dummy variables were used to account for the first and last period of the reserve holding period. Additional dummy variables were used to account for foreign exchange market turbulence. Impulse dummy variables ΔD_{hp_dl} and ΔD_{hp_d1} represent the last and first–day of the reserve holding period and ΔD_{friday} represents the last trading weekday. The variables take the value 1 if the day is the last (first) day of the reserve holding period, -1 the next day, and 0 elsewhere. The regression has been run using the remaining days of the week, but results were not overall significant.

6.3. Misspecification tests

Multivariate LM tests on the residuals suggest the chosen number of lags fits the data well as no significant autocorrelation is left in residuals. The LM–test statistic for regimes 1 to 4 is $LM(1):\chi^2(49)=17.0$, $LM(1):\chi^2(49)=18.5$,

$LM(1): \chi^2(49) = 74.1$, and $LM(1): \chi^2(49) = 24.7$[54]. Test procedures for determination of lag length – Akaike, Schwartz and Hannan–Quinn – offer similar results. Finally, graphs and histograms of standardized residuals, autocorrelation and cross–correlation functions, not presented here, show that autocorrelation is not a problem for any of the four regime periods.

The error distribution, however, departs from normality due to excess kurtosis, which is related to ARCH effects. Skewness and kurtosis results are similar to those reported by Lee (2003) for the Federal Funds and the overnight Eurodollar market; and Wetherilt (2002) for the UK interbank market. The VAR(5) representation proposed in [21] is stable and the roots of the companion matrix lie inside the unit circle, though close to one. Results are consistent with the ADF and Phillips–Perron tests, where a unit root representation of variables was found feasible. However, simulation studies have shown that the cointegrated VAR estimates are robust against moderate ARCH effects in the residuals. This is particularly the case when the residuals are relatively symmetrical and the sample size is large.

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[54] The LM statistic is asymptotically distributed as χ^2 with 49 degrees of freedom, for regimes 1 and 2; 64 degrees of freedom for regimes 3 and 4, suggest no significant autocorrelation is left in the model at lags 1 or 4. Also, The LM(4) and LB(4) statistics, distributed as χ^2, with degrees of freedom equal to the number of dependent variables squared – 49 and 64, for each case – are rejected at 1% level for all regimes, except for regime 3.

7. Cointegration Tests and Cointegration Vectors

We search for the number of cointegration relations between interbank interest rates using the Johansen–Juselius procedure. Results are summarized in Table 5.8 for each of the 4 monetary policy regimes.

Table 5.8 – Johansen–Juselius co–integration rank tests

Null Hypothesis about rank r	Regime 1: 01/01/89 to 09/10/90					Regime 2: 10/10/90 to 12/07/93				
	λ_i	λ_{max} Test statistic	Prob.	λ_{trace} Test statistic	Prob.	λ_i	λ_{max} Test statistic	Prob.	λ_{trace} Test statistic	Prob.
$r = 0$		68.8	0.000	252.0	0.000		143.1	0.000	496.0	0.000
$r \leq 1$	0.141	60.2	0.000	183.2	0.000	0.324	100.1	0.000	352.9	0.000
$r \leq 2$	0.117	49.2	0.001	123.0	0.000	0.247	95.6	0.000	252.7	0.000
$r \leq 3$	0.073	29.9	0.089	73.8	0.005	0.184	77.7	0.000	157.2	0.000
$r \leq 4$	0.048	19.4	0.289	43.9	0.038	0.179	41.6	0.000	79.4	0.000
$r \leq 5$	0.038	15.2	0.189	24.4	0.073	0.132	26.9	0.002	37.8	0.001
$r \leq 6$	0.000	9.3	0.169	9.3	0.169	0.088	10.9	0.093	10.9	0.093

Null Hypothesis about rank r	Regime 3: 02/08/93 to 09/05/95					Regime 4: 10/05/95 to 31/12/98				
	λ_i	λ_{max} Test statistic	Prob.	λ_{trace} Test statistic	Prob.	λ_i	λ_{max} Test statistic	Prob.	λ_{trace} Test statistic	Prob.
$r = 0$		158.5	0.000	569.6	0.000		190.0	0.000	730.2	0.000
$r \leq 1$	0.296	115.0	0.000	411.0	0.000	0.197	156.3	0.000	540.1	0.000
$r \leq 2$	0.249	82.4	0.000	296.0	0.000	0.165	152.8	0.000	383.8	0.000
$r \leq 3$	0.176	80.0	0.000	213.6	0.000	0.162	119.4	0.000	231.0	0.000
$r \leq 4$	0.148	57.5	0.000	133.7	0.000	0.129	81.2	0.000	111.6	0.000
$r \leq 5$	0.123	37.2	0.001	76.2	0.000	0.090	19.2	0.092	30.5	0.042
$r \leq 6$	0.061	25.9	0.003	39.0	0.000	0.022	9.3	0.270	11.3	0.199
$r \leq 7$	0.042	13.1	0.038	13.1	0.039	0.011	2.0	0.159	2.0	0.159

These results were obtained from testing for co–integration in a VAR(5) comprised of Over–night, one–week, two–weeks, one–month, three–months, six–months, one year and an unrestricted constant term. The post 13 July 1993 sub sample includes the tom–next rate additionally. The test determines the rank of the co–integrating space, together with the coefficients for the co–integrating equations. The eigenvalues are presented under the column head λ_i .

Using the trace statistic and a level of significance of 1%, we find a single random walk for regimes 2 and 3, and three for regimes 1 and 4. If we increase the level of significance to 10%, the number of random walks decreases from three to two for regimes 1 and 3.

The pure rational expectations theory of interest rates requires that all interest rates share a single common trend, which might then be linked to monetary policy. In case we find support for the theory, we might argue that when changing the target rate the central bank is able to shift interbank rates at different maturities – i.e., the yield curve. Given our results, there is weak evidence in favour of rational expectations hypothesis for all regimes when the cointegration space is not restricted. First, we find that the number of random walks is one in regimes 2 and 3, when interest rates are more volatile. Other authors report similar results, which seems counterintuitive[55].

Second, the potential ambiguity of the unit root tests results might bias our conclusions, which we discuss next. Acceptance of the null of a unit root is not clear for all rates series, and we know from theory that when we add a stationary variable to a cointegrated VAR, the dimension of the cointegration space increases by one (Johansen, 1995: 37). Nevertheless, there is compelling evidence showing the weak power of unit root tests when a large autoregressive root is involved, and although there are no economic arguments in favour of interest rates as I(1) – because interest rates are bounded below by zero whereas

[55] Engsted (1996), Mankiw and Miron (1986) suggest that the predictive power of yield spreads is stronger under monetary targeting than under interest rate targeting.

I(1) processes are unbounded – we obtain support to represent interest rates as unit root processes in empirical literature. Wetherilt (2002) and Hardouvelis (1994) show similar unit root results in their UK and G7 applications and model interest rates as a cointegrated VAR. Unit roots are convenient approximations for series that exhibit high persistence.

Several authors argue that interest rates series exhibit long memory and might alternatively be represented as a fractionally integrated process. Near unit root processes have strong implications upon cointegration tests. Although cointegration restrictions cannot be rejected in bivariate systems, tests in multivariate systems often indicate the presence of several common stochastic trends underlying the yield curve, at least in some time periods. These results follow directly from the assumption that interest rates are I(1). Lanne (2000) shows that traditional tests tend to over-reject the cointegration vectors when the underlying processes have large unit roots, as it is likely to be the case with interest rates. He argues that even minor deviations from the exact unit root lead to spurious rejection of the hypothesis of the spreads spanning the cointegration space. Lardic and Mignon (2004) refer to the concept of fractional cointegration relationship between short-term and long-term interest rates, and show that it is consistent with the long run implications of the expectations hypothesis. Smallwood and Norrbin (2004) that the variances of the estimates of the cointegration vectors can be excessive leading to rejection of the cointegration relationship.

The application of cointegration techniques is still possible if we bear in mind these caveats. Elliot (1998) shows that point estimates of cointegration vectors remain consistent, but the commonly applied hypothesis tests no longer have the usual distributions. Therefore we can still derive long run inference from interest rates spreads.

7.1. Cointegration space: long run equilibrium

An over identified structure of the long–run relations – β' matrices – is reported in Table 5.9. The adjustment coefficients matrices – α – are presented in Table 5.10. In general, the cointegration equation coefficients sum up to one, suggesting that various interest rates spreads are part of the long–term adjustment space[56]. If we take regime 4, for example, it is easy to show that the first vector of the cointegration space can be written as a weighted combination of spreads over the over-night rate.

Table 5.9 – Co–integrating space: long–run matrices β'

Regime 1: 01/01/89 to 09/10/90

	R_{on}	R_{tn}	R_{w1}		R_{m1}	R_{m3}	R_{m6}	R_{trq}
CV1	1.000		-1.799	0.324	0.635	-0.413	0.167	-0.643
CV2	-1.767		1.000	0.050	1.061	0.407	0.198	-0.278
CV3	0.251		-0.545	1.000	1.240	0.131	0.056	0.188
CV4	3.511		-5.092	-1.171	1.000	10.381	-7.119	-1.687
CV5	0.314		-0.578	1.490	0.845	1.000	1.340	-2.475

56 Hall e al. (1992) argue that the spread between any two yields can be written as a linear combination of two spreads over the shortest yield.

Table 5.9 – Co–integrating space: long–run matrices β' (continued)

Regime 2: 10/10/90 to 12/07/93

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{tra}
CV1	1.000		–0.710	–1.639	2.579	0.735	–0.178	–0.263
CV2	1.030		1.000	1.790	–5.048	–0.507	2.983	–1.119
CV3	1.955		–3.632	1.000	1.423	–0.749	–0.462	0.215
CV4	–0.947		0.688	1.013	1.000	–3.444	1.400	–0.203
CV5	–0.493		–0.008	1.401	1.968	1.000	–2.878	–0.940
CV6	0.103		–0.296	–0.101	1.144	0.037	1.000	–1.163

Regime 3: 02/08/93 to 09/05/95

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{tra}
CV1	1.000	–0.602	1.337	–2.435	0.456	0.780	–0.463	0.135
CV2	–2.172	1.000	1.446	–0.767	0.383	–0.352	–0.144	0.485
CV3	0.123	–0.685	1.000	–0.116	–0.359	0.188	–0.029	–0.061
CV4	–0.679	0.793	–0.321	1.000	–1.514	1.183	–0.042	–0.321
CV5	–3.940	–17.034	29.396	8.104	1.000	–48.703	40.718	–6.576
CV6	–0.923	–0.445	1.626	–0.882	0.900	1.000	–0.763	–0.876
CV7	0.302	–0.061	–0.100	–0.924	0.226	0.268	1.000	–0.670

Regime 4: 10/05/95 to 31/12/98

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}	R_{tra}
CV1	1.000	–5.493	3.663	1.295	–0.138	–0.740	0.215	0.188
CV2	–0.964	1.000	–0.087	0.031	–0.010	–0.099	0.030	0.099
CV3	–0.118	–0.345	1.000	–1.360	1.377	–0.955	0.341	0.048
CV4	0.404	0.685	–1.879	1.000	0.705	–1.963	0.913	0.119
CV5	0.171	0.634	–1.818	0.123	1.000	0.269	–0.395	0.029
CV6	0.067	–15.278	28.460	4.953	12.062	1.000	–5.368	–23.928
CV7	0.020	–0.267	0.293	–0.133	–1.191	0.129	1.000	0.119

The lines of the long–run matrices correspond to the cointegration equations. There are at most 5 cointegration equations for Regime 1, 6 for Regime 2, and 7 for Regime 3. Johansen tests suggest Regime 4 might have no more than 6 cointegration equations, leaving two random walks in data. Coefficients along the diagonal are standardized to 1, according to conventionally adopted formats.

Given the previous discussion regarding the unit roots ambiguous results, we presented more cointegration vectors than those suggested by the Johansen-Juselius cointegration tests for regimes 1 and 4. Therefore, we allowed two random walks for regime 1, and a single random walk for regime 4. Next we will discuss whether the cointegration vectors, and particularly the interest rates spreads, enter significantly in the error correction representation for interest rates.

The cointegration relationships are stable within each policy regime. To ensure robustness of our results we applied repeatedly the test, starting with the initial 100 observations and then running it on the sub–samples obtained by adding one additional observation.

7.2. Adjustment to long run equilibrium

All cointegration vectors, except the last vector in regime 4, are candidates to explain changes observed on each interest rate. There is a weighting matrix describing the adjustment forces that are activated when the processes are out of the steady state. Long run adjustment matrices are presented next.

Table 5.10 – Co–integrating space: adjustment coefficients matrices α

Regime 1: 01/01/89 to 09/10/90

	CV1		CV2		CV3		CV4		CV5	
ΔR_{on}	–0.028		**0.328**	**	0.037		–0.006		–0.067	+
ΔR_{w1}	**0.330**	**	**0.212**	**	0.128		0.003		–0.052	+
ΔR_{w2}	0.078	+	0.040	+	**–0.228**	**	0.001		**–0.037**	*
ΔR_{m1}	–0.040		–0.025		**0.146**	**	–0.002		**–0.035**	**
ΔR_{m3}	**0.132**	*	–0.030		–0.021		**–0.021**	**	–0.022	
ΔR_{m6}	–0.075		**–0.051**	*	–0.014		**0.009**	*	**–0.046**	*
ΔR_{trg}	0.001		–0.001		–0.001		0.000		0.000	

Regime 2: 10/10/90 to 12/07/93

	CV1		CV2		CV3		CV4		CV5		CV6	
ΔR_{on}	**–0.327**	**	**–0.150**	**	0.015		0.022		–0.045		0.046	
ΔR_{w1}	**–0.222**	**	**–0.077**	**	**0.178**	**	–0.014		**–0.045**	*	0.053	
ΔR_{w2}	**0.201**	**	**–0.030**	**	–0.021		**–0.059**	**	**–0.043**	**	–0.016	
ΔR_{m1}	**–0.078**	**	**0.013**	**	–0.004		–0.016		–0.010	+	**–0.027**	**
ΔR_{m3}	**0.045**	**	0.007		0.010		**0.101**	**	–0.008		–0.014	
ΔR_{m6}	**0.053**	**	–0.007		**0.026**	*	–0.010		**0.031**	**	**–0.031**	**
ΔR_{trg}	0.029	+	**0.017**	**	**–0.049**	**	0.007		0.010	+	**0.033**	**

Table 5.10 – Co–integrating space: adjustment coefficients matrices α (continued)

Regime 3: 02/08/93 to 09/05/95

	CV1	CV2	CV3	CV4	CV5	CV6	CV7
ΔR_{on}	**-0.551** **	**0.239** **	**-0.669** **	**-0.249** *	0.001	-0.061	0.043
ΔR_{tn}	**-0.627** **	**-0.296** **	**-0.453**	**-0.475** **	-0.005	-0.099 +	0.048
ΔR_{w1}	**-0.269** **	**-0.186** **	**-1.175** **	-0.094	0.000	-0.058 +	0.025
ΔR_{w2}	**0.110** **	0.046	**-0.416** **	**-0.382** **	-0.001	-0.026	**0.079** *
ΔR_{m1}	0.002	0.002	-0.160	-0.028	0.003 +	-0.057 +	0.021
ΔR_{m3}	-0.011	-0.030	**-0.326** **	**-0.157** **	**0.004** **	**-0.027** *	**-0.042** *
ΔR_{m6}	0.016	0.028	**-0.240** **	-0.045	**-0.003** **	**0.023** **	**-0.041** **
ΔR_{trg}	**-0.064** **	-0.045 +	0.096	-0.025	0.003 **	0.057 +	0.007

Regime 4: 10/05/95 to 31/12/98

	CV1	CV2	CV3	CV4	CV5	CV6	CV7
ΔR_{on}	**0.037** *	**0.641** **	0.036	-0.040 +	0.035	-0.001 +	0.007
ΔR_{tn}	**0.125** **	-0.056	**0.049** *	-0.032 +	0.032	-0.001	0.006
ΔR_{w1}	-0.002	**-0.129** *	0.006	0.029	**0.101** **	-0.001 +	0.006
ΔR_{w2}	**-0.119** **	**-0.267** **	**0.319** **	**-0.145** **	**-0.035**	-0.001	0.006
ΔR_{m1}	**-0.053** **	**-0.192** **	**-0.115** **	**-0.023**	**-0.195** **	-0.001	0.005
ΔR_{m3}	0.008	0.042	**0.195** **	**0.176** **	**-0.166** **	0.000	-0.008
ΔR_{m6}	-0.028	-0.050	-0.034	**-0.087** **	-0.011	0.001	-0.021 *
ΔR_{trg}	**-0.039** **	0.086 +	0.018	-0.005	-0.001	0.001 +	0.005

The elements on each row are the adjustment coefficients to the long–run equilibrium described by the corresponding cointegration equation. Coefficients marked with ** (*) are significant at the one (five) percent level. Additional coefficients market with + are significant at the 10% level. CV1 to CV7 stand for cointegration equation numbers.

A common feature to all regimes is the existence of two blocks: an upper block containing up to two-week rates, and a lower block with the remaining maturities. The first block is more responsive to the first three cointegration vectors while the latter reveals a weaker, yet statistically significant, adjustment to the last two long run trends. In general, the overnight and up to two weeks rates adjust much faster to long run trend than do longer maturities. This may be due to a wide fluctuation on short–term interest rates, which quite often deviate from the steady state in response to liquidity shocks originated either domestically or in the foreign exchange market. Results are consistent with

Wetherilt (2002), Johansen and Juselius (2001), and Hall, Anderson and Granger (1992) who find the federal funds rate adjusting faster than the Treasury bill rates. We do not find shorter rates requiring more cointegration vectors than longer rates. But, we find that interest rates on the extreme short-end of the interbank yield curve are important factors explaining the behaviour of the interbank long-term rates. This is a consistent behaviour with the rational expectations hypothesis. Further, it indicates that the central bank might be right using the short term rates to control and stabilize the long rates.

Excluding regime 4, which reflects both a new institutional framework, and a change in monetary policy instruments and operational targets, adjustment matrices are quite similar apart from the coefficients' size. The largest coefficients adjusting the system back to equilibrium are clustered along the main diagonal. However, the lower block coefficients are much smaller than those of the upper block. The longer rates are sensitive to the last vectors spanning the cointegration space only. This makes the adjustment burden to fall on the shorter rates. In fact, the adjustment coefficients for short rates – the first rows of successive panels of Table 5.10 are in general greater than those for the longer maturities.

The adjustment matrix for regime 4 seems to confirm the existence of three random walks, as suggested previously by the Johansen-Juselius trace statistic. The adjustment coefficients associated with the last two cointegration vectors are significantly not different from zero. It is possible however that the number of common trends is only two if the level of significance is raised to 10%. This evidence might result from the power of the central bank to implement the monetary policy and set interest rates. In fact, The Banco de Portugal enjoys the power to fix both the daily facilities and the open market rates. There is also the foreign exchange market which might act as an additional source of uncertainty, as it is always possible to the central bank to operate an independent monetary policy under financial market liberalization[57].

In regime 4, and compared to the previous regimes, the longer rates adjust faster to long term imbalances. Switching to permanent deposit and lending facilities, whose rates are within the corridor defined by main refinancing operations, yielded highly stable over-night and tom-next rates. Making the central bank available to buy and sell overnight funds at pre-announced interest rates has the effect of not only offsetting liquidity shocks, but signalling interest rates levels also. Deviations out of equilibrium are corrected very fast. Interest rates are brought in level with the marginal facilities, mainly because banks do not regard its use as a penalty, and take it as a perfect substitute to buying funds from other banks[58]. Therefore, any credit rationing effect that might be

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[57] The constant with negative sign in the cointegration vectors might signal a stochastic trend as domestic rates and its spreads converged to German interbank rates.

[58] The argument is that overnight interest rates closely follow the daily facilities, making no adjustment required because the rates are not likely to deviate significantly from the long run equilibrium at any time. Not even in case when there are strong liquidity shocks or at the end of the reserve holding period. However, this behaviour turns the central bank as a lender of last resort as long as the banks have enough collateral to post against daily borrowing. Clearly there

present in interbank money markets is mitigated by The Banco de Portugal, who acts as a market maker of last resort, willing to offer banks' liquidity at the cost of keeping interest rates within its limits. This is only possible to the extent that the central bank commitment is credible to market participants. Notice the strong adjustment of the over night rates to the second cointegration vector which might certainly be related with the spread between the target and the tom-next. The tom-next rate is used as a good proxy for next day overnight rates. When there is an imbalance, banks are willing to sell short in the tom-next market and hedge the position next day with an overnight transaction.

Overall, each interest rate is affected by multiple trends, or cointegration vectors. A negative sign signals that after a positive shock interest rates return to previous levels. However, we observe positive and negative effects upon each interest rate, depending on which cointegration vector is considered. The extreme short end of the yield curve adjusts fast to long term imbalances, at least more recently. One and two–week rates articulate the interbank short and long term blocks and are responsive to the overnight cointegration equation. This feature recognizes the importance of the weekly reserve holding periods and the fact that at the beginning of each period The Banco de Portugal makes

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is an incentive for banks not to use the interbank market and use the central bank instead, which can be viewed as a market maker buying funds at the deposit rate and selling funds at the borrowing rate. In practice, the interbank market becomes internalized and the central bank might end up offering credit risk insurance to all banks in the interbank markets.

funds available with exactly the same maturity as the reserve holding–period length.

7.3. Phillips's Triangular Representation

Since any linear combination of the co–integrating vector is also a co–integrating vector, the system $\mathbf{\Pi}$ has a Phillips's triangular representation[59]. There is an economic interpretation for this formulation, which splits the variables between endogenous and exogenous, where the latter are the random walks out of the control of market participants. The choice is much arbitrary and we kept the initial ordering of variables from the shortest to the longest maturity.

The reduced form beta matrix, presented in Table 5.11, imposes just-identifying restrictions in the long run matrix. Results are not all consistent with the expectations hypothesis, except for the most recent regimes. If theory holds, interest rates adjust to interest rates spreads and the triangular representation yields close to unity estimates. This is not however the case, except for the shortest maturities. Whilst the coefficients of the cointegration

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[59] The basic idea is to test whether we can use for each variable an error correction representation based on the co-integrating vector $(1,-1)$. In case beta coefficients are close to unity in absolute value, than we can use the spread of each interest rate over the target. On contrary, we should exercise caution and use the exact long-term relationships. Results suggest that except for the most recent regimes, the long run relationship is far from being represented by the vector $(1,-1)$.

vectors are close to unity, at most recently, standard likelihood ratio tests reject the hypothesis that they are actually equal to one. This is a well known documented fact in empirical investigation. Departure from unity might be regarded as rejection of the expectation hypothesis. It might also be attributed to the presence of time varying risk-premia and asymmetric adjustment to the equilibrium spreads[60].

Table 5.11 – Reduced form Beta matrix. Phillips triangular representation

Regime 1: 01/01/89 to 09/10/90

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}
R_{m3}	5.616 **		5.274 **	5.940 **	3.716 **
R_{m6}	-3.129 **		-3.130 **	-3.788 **	-2.269 **

Regime 2: 10/10/90 to 12/07/93

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}
R_{trg}	0.882 **		0.845 **	0.807 **	0.701 **	0.545 **	0.582 **

Regime 3: 02/08/93 to 09/05/95

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}	R_{m6}
R_{trg}	0.848 **	0.884 **	0.959 **	1.112 **	1.249 **	1.121 **	1.010 **

Regime 4: 10/05/95 to 31/12/98

	R_{on}	R_{tn}	R_{w1}	R_{w2}	R_{m1}	R_{m3}
R_{m6}	-0.040	-0.008	0.024	0.132	0.274 **	0.597 **
R_{trg}	0.979 **	0.942 **	0.911 **	0.798 **	0.665 **	0.365 **

The estimated coefficients on each column are the cointegrated vectors written in the form $(-1, 0, ..., 0, \beta)$, where beta is the target rate coefficient. In case there are two random walks, the coefficients change. In regime 4 the cointegrated vector is $(-1, 0, ..., \beta_1, \beta_2)$ using the target and the 6-month rate, while in regime 1 they represent the 3 and 6-month rates, due to the fact that the target rate does not seem to enter the cointegration space. Notice, we kept the ordering of the variables from the shortest to the longest maturity. Coefficients marked with ** (*) are significant at the one (five) percent level. Additional coefficients market with + are significant at the 10% level.

[60] Cf. Sarno and Thornton (2002)

The two random walks in regime 4 suggest we proceed with caution. Nevertheless it is interesting to notice, that in regime 4 the shortest rates might be driven by the spreads over the target, while the longer rates can be explained both by the six-month and the target rates, whose coefficients add up to one. This might allow us to write the adjustment to long-term equation as a weighted average of two interest rate spreads. The remaining regimes, probably with exception of regime 3 are hopeless. Limits on capital mobility and financial markets constraints might explain why the hypothesis fails to hold for the other regimes.

Considering the coefficients' size we will assume next that the spreads form a basis of the cointegration space. One must bear in mind, however, that regime 1 is clearly an exception and that such formulation is discarded by standard statistical tests. The excess liquidity in the banking system and the tight control operated by The Banco de Portugal over the interest rates, as explained in chapter 2, justify why the target rate was not binding. The signals conveyed to the market through the monetary policy were confusing and not to trust by banks participating in the market.

7.4. Interest rate spreads as cointegration vectors

Term structure of interest rates theory and empirical research suggest using rate spreads as cointegration vectors. The triangular representation presented above fits partly within this argument. When spreads deviate from long term level, multiple adjustment forces bring interest rates back to long run equilibrium. Without binding restrictions, buyers and sellers of interbank funds interact in such a way that the equilibrium spread is restored once it has been violated. The equilibrium spread can be interpreted as a liquidity premium, and, additionally, it might reflect investors' risk aversion to lock into longer positions while not being able to anticipate future liquidity shocks. If interest rates were allowed to free fluctuate the spread could reflect expectations regarding future liquidity shocks. However, when the central bank is willing to buy and sell funds at a predetermined rate – i.e., marginal deposit and lending facilities, the impact of expected liquidity shocks to the system is mitigated, and interest rates vary according to how credible the monetary policy is and the commitment of the central bank to the target rate[61].

Given the whole maturity spectrum, there are several rate spreads natural candidates to span the cointegration space. We use the spread between each interest rate and the target. Hall et al. (1992) consider that any Treasury bill yield is cointegrated with the shortest maturity – in his model, the one month Treasury bill. Further they show that any yield can be used to construct the cointegration vectors, as the spread between any two yields can always be

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[61] In fact, and assuming that individual banks' ability to borrow from the marginal lending facility is not jeopardized by insufficient collateral or past bad behaviour, the daily deposit and lending rates work as buffers, which prevent interbank rates to drift away from the current levels. This leaves the interest rate spread to be driven mainly by the expectations regarding central bank manipulation of monetary policy instruments and the cost of early liquidation – i.e., a transaction cost – in case of an unanticipated liquidity shock.

written as a linear combination of two spreads over the one-month yield. Wetherilt (2002) defines the cointegration vectors as the spreads between each rate and the two-week repo rate, the Bank of England's policy target. Contrary to Portugal and other European countries, the Bank of England does not target the overnight rate.

In a similar fashion as Wetherilt (2002), we assume that all spreads between each interest rates and The Banco de Portugal's target rate span the cointegration space. In general, we confirm the unrestricted model results, but we need a larger number of cointegration vectors for regimes 1 and 4. Results are presented in Table 5.12. We find that each interest rate responds mainly to its own spread, while the remaining cointegration equations have a limited role in explaining the rates dynamics. Generally, the cointegration vectors enter significantly at their own and neighbouring maturities only. For example, in regime 4 the one-month spread contributes to changes in the two-week, one-month and three-month rates.

Table 5.12 – Impact matrices, when interest rate spreads span the cointegration space

Regime 1: 01/01/89 to 09/10/90						
	$R_{on} - R_{tra}$	$R_{w1} - R_{tra}$	$R_{w2} - R_{tra}$	$R_{m1} - R_{tra}$	$R_{m3} - R_{tra}$	$R_{m6} - R_{tra}$
ΔR_{on}	**-0.567** **	0.361	-0.060	0.105	-0.041	-0.054
ΔR_{w1}	-0.022	**-0.411** **	0.150	0.195	-0.049	0.018
ΔR_{w2}	-0.039	0.040	**-0.292** **	**0.278** **	-0.050	-0.019
ΔR_{m1}	-0.012	0.047	0.047	**-0.246** **	0.044	0.042
ΔR_{m3}	0.046	-0.091	0.040	0.130	**-0.287** **	**0.146** **
ΔR_{m6}	-0.058	0.138	-0.076	0.045	0.089	**-0.148** **

Table 5.12 – Impact matrices, when interest rate spreads span the cointegration space (continued)

Regime 2: 10/10/90 to 12/07/93

	$R_{on} - R_{tra}$	$R_{w1} - R_{tra}$	$R_{w2} - R_{tra}$	$R_{m1} - R_{tra}$	$R_{m3} - R_{tra}$	$R_{m6} - R_{tra}$
ΔR_{on}	**−0.387** **	−0.051	0.202	0.016	0.272	**−0.299** *
ΔR_{w1}	0.115	**−0.620** **	**0.295** *	0.077	0.146	−0.162
ΔR_{w2}	**0.182** **	−0.104	**−0.519** **	**0.457** **	0.039	−0.078
ΔR_{m1}	**−0.054** *	0.075	**0.117** **	**−0.333** **	**0.121** **	0.030
ΔR_{m3}	−0.018	0.007	0.039	**0.172** **	**−0.361** **	**0.179** **
ΔR_{m6}	0.050	−0.087	−0.028	**0.190** **	0.015	**−0.116** **

Regime 3: 02/08/93 to 09/05/95

	$R_{on} - R_{tra}$	$R_{tn} - R_{tra}$	$R_{w1} - R_{tra}$	$R_{w2} - R_{tra}$	$R_{m1} - R_{tra}$	$R_{m3} - R_{tra}$	$R_{m6} - R_{tra}$
ΔR_{on}	**−0.560** **	**0.519** **	**−0.886** **	**0.970** **	0.291	**−1.249** **	**0.568** **
ΔR_{tn}	**0.810** **	−0.227	**−1.794** **	**1.416** **	0.349	**−1.292** **	**0.551** **
ΔR_{w1}	**0.376** *	**0.419** **	**−1.635** **	**0.813** **	**0.292** *	**−0.738** **	**0.327** **
ΔR_{w2}	**0.365** *	−0.049	−0.207	**−0.635** **	**0.693** **	**−0.418** **	0.127
ΔR_{m1}	0.103	0.039	−0.160	0.059	−0.006	−0.246	**0.161** *
ΔR_{m3}	**0.195** **	0.021	**−0.376** **	0.088	**0.313** **	**−0.549** **	**0.249** **
ΔR_{m6}	0.014	**0.168** **	**−0.264** **	−0.042	**0.115** *	0.058	**−0.079** *

Regime 4: 10/05/95 to 31/12/98

	$R_{on} - R_{tra}$	$R_{tn} - R_{tra}$	$R_{w1} - R_{tra}$	$R_{w2} - R_{tra}$	$R_{m1} - R_{tra}$	$R_{m3} - R_{tra}$	$R_{m6} - R_{tra}$
ΔR_{on}	**−0.595** **	**0.430** **	0.104	−0.020	0.027	−0.030	−0.008
ΔR_{tn}	**0.166** **	**−0.754** **	**0.498** **	0.063	0.050	−0.052	−0.003
ΔR_{w1}	**0.151** *	−0.024	**−0.254** **	0.022	**0.116** *	−0.019	−0.010
ΔR_{w2}	0.036	0.166	0.222 +	**−0.747** **	**0.308** **	0.095	−0.045
ΔR_{m1}	0.104	0.006	0.087	0.033	**−0.372** **	**0.169** **	−0.001
ΔR_{m3}	−0.015	−0.037	0.169	−0.092	**0.242** **	**−0.548** **	**0.245** **
ΔR_{m6}	−0.013	0.059	0.033	−0.081	−0.100	**0.213** **	**−0.102** **

Elements on each row are the adjustment coefficients to the corresponding long–run equilibrium described by interest rate spreads. The cointegration vectors are defined as spreads over the target rate. Coefficients marked with ** (*) are significant at the one (five) percent level.

Overall, the adjustment is much in line with the rational expectations hypothesis. When interest rates deviate from their long–run path an adjustment process restores the equilibrium. Cross effects reflect potential arbitrage opportunities within neighbouring interest rates. Take for example the long run imbalance between target and tom–next rates, which has a positive impact upon the over–night rates, suggesting that investors will shift investments to the closest maturity. This adjustment forces an imbalance in the neighbouring interest rates. The impact is much weaker upon distant maturities, which can be justified on the grounds of risk aversion and due to transaction costs.

Given the restrictions imposed upon the cointegration vectors the impact matrix is not completely consistent with the unrestricted long run matrix. We cannot accept the null hypothesis that interest rate spreads span the cointegration space, except for regime 4. And, also, the number of spreads used in each regime leaves aside a single random walk for all regimes, which is contrary to the conclusions derived from the Johansen-Juselius tests on the number of cointegration vectors. Even accounting for other factors in the cointegration space, such as exchange risk and capital mobility there are periods when interest rate spreads are not stationary, and we must essay alternative behaviour for interest rates.

7.5. Less than perfect interest rates spreads as cointegration vectors

As it has just been discussed, regimes 1 to 3 have cointegration vectors, which are not equivalent to interest rate spreads. Beta coefficients are distinct from unity, signalling that either the monetary policy was not fully credible to market participants[62], or the exogenous uncertainty triggered by foreign exchange risk placed a wedge between interest rates in levels. This means an additional risk premium is placed between short and long-term rates, and the expectation hypothesis fails to hold due to imperfect adjustment.

Failure of interest rates spreads for regimes 1 to 3 can be related to institutional factors and capital market constraints, which prevent full arbitrage to occur. First, the structurally high excess liquidity, and more recently, the few episodes when the ERM was under attack and capital mobility restrictions have been imposed, are good candidates to explain additional sources of uncertainty, other than monetary policy itself. It is also a fact that under certain circumstances The Banco de Portugal has withdrawn temporarily from the market, allowing interest rates to fluctuate freely. Also, there are episodes of restrictions on capital movements being restored, breaking the link with external markets while, at the same time, The Banco de Portugal kept its commitment to join the European Monetary Union during the first phase.

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[62] Banks cast some doubt about The Banco de Portugal commitment to keep exchange rates fixed and at the same time manage the convergence process – i.e., a sharp interest rate decrease –towards construction of the European Monetary Union.

Allowing beta coefficients to be different from unity[63], produces the restricted long run matrix in Table 5.13[64]:

Table 5.13 – Impact matrix for the reduced beta matrix

Regime 3: 02/08/93 to 09/05/95	$R_{on}-0.848R_{trg}$	$R_{tn}-0.884R_{trg}$	$R_{w1}-0.959R_{trg}$	$R_{w2}-1.112R_{trg}$	$R_{m1}-1.249R_{trg}$	$R_{m3}-1.121R_{trg}$	$R_{m6}-R_{trg}$
ΔR_{on}	**-0.916 ****	**0.843 ****	**-1.062 ****	**1.007 ****	**0.413 ***	**-1.020 ****	**0.372 ****
ΔR_{tn}	0.407	0.140	**-1.877 ****	**1.336 ****	0.399 +	**-0.882 ****	0.293 +
ΔR_{w1}	0.115	**0.724 ****	**-1.860 ****	**0.871 ****	**0.324 ***	**-0.546 ****	0.274 *
ΔR_{w2}	0.272 +	-0.014	-0.160	**-0.697 ****	**0.789 ****	**-0.415 ****	0.028
ΔR_{m1}	0.042	0.054	-0.139	0.043	0.059	**-0.281 ***	**0.208 ***
ΔR_{m3}	0.120	0.028	**-0.267 ***	0.021	**0.309 ****	**-0.459 ****	**0.150 ****
ΔR_{m6}	-0.066	**0.187 ****	**-0.204 ***	-0.082	**0.180 ****	0.053	**-0.175 ****

Elements on each row are the adjustment coefficients to the corresponding long run equilibrium described by less than perfect interest rate spreads, which are identified in column headings. Coefficients marked with ** (*) are significant at the one (five) percent level.

An interesting result stands out for Regime 4. Johansen tests suggest there are 6 cointegration vectors. However, we are not able to replicate the long run matrix, unless we use all the spreads over the target rate as cointegration vectors. Hence, this suggests that the seven spreads form a basis for the cointegration space. Only under such circumstances, we can accept the null that the long run impact remains unchanged when we impose restrictions to identify the long run matrix.

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63 Cf. Table 5.11.

64 Regimes 1 and 2 share common features with regime 3. When we use interest rate spreads, the long run matrices show that significant coefficients are the same as compared to when we allow the beta coefficients to fluctuate. Results are not presented.

7.6. Long run adjustment to spreads over the one-week rate

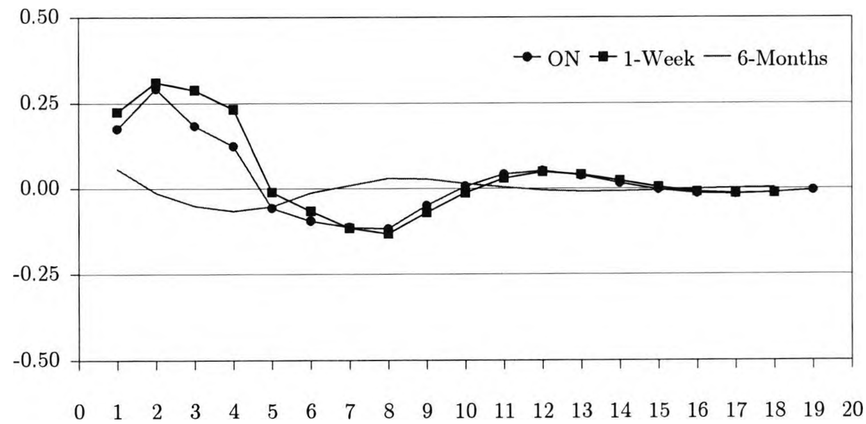
We also tested the hypothesis that interest rates were anchored in levels to the one-week rates. The estimates, not presented here, remain mostly unchanged and are not very informative on this respect. Albeit one could argue that the longer rates are more likely to respond to open market operations, and therefore be more responsive to the spreads over the one-week rates, the results do not to confirm this hypothesis. Results are as expected. As it is also supported by Hall e al. (1992), any interest rate is a good candidate to compute the spreads, because any spread between two interest rates can be written as a linear combination of other interest rates spreads. Therefore, for example, the one-month spread over the one-week rate can also be written as a linear combination of the one-month and one-wee spreads over the target rate.

7.7. Impulse response functions

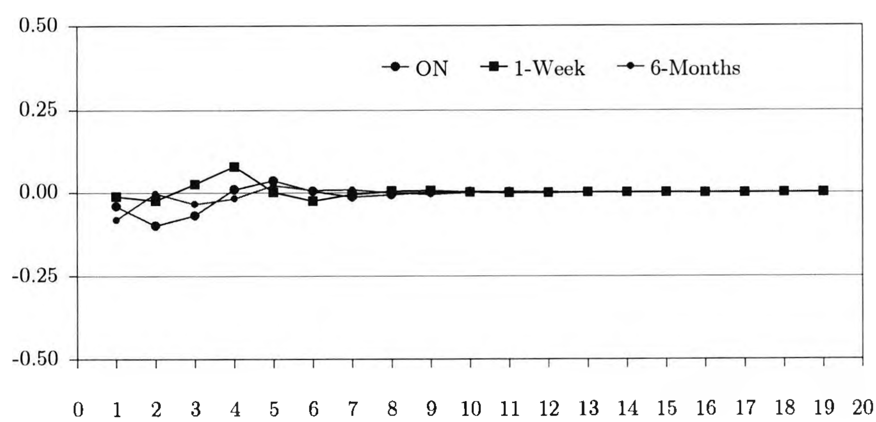
We computed the impulse response functions for the over identified system. Results show that shocks to a given interest rate will most likely be absorbed by itself, while the effects upon the remaining maturities fade out increasingly as they are further away in the term structure spectrum. Also, shocks to long rates have a stronger impact upon the short rates, forcing most of the short-term adjustment to burden on short rates. Figure 5.1 plots some results.

Figure 5.1 – Impulse-Response Functions: Responses to a shock in Over-Night rates

Panel a. Regime 1



Panel b. Regime 4



Under the different regimes the shocks to interbank rates of various maturities are small and very short lasting. During regimes 1 and 2, the short-rates absorbed most of the impact of monetary policy shocks. Changes in target rate were quickly absorbed by over night and one-week rates, while long-term rates were kept fairly stable. Progressively, along with the changes introduced during regimes 3 and 4 in monetary policy and capital controls operational framework, The Banco de Portugal succeeded in stabilizing the short-term end of the yield curve also, and effects due to interest rates shocks became less and less pronounced. This reflects the fact that interest rates were increasingly isolated from banks' liquidity shocks, while at the same time the central bank had no effective policy to ration out credit to banks with enough collateral.

8. Conclusion

We provide a useful background to analyse the effectiveness of central bank's monetary policy operations, given its objective is to minimize deviation of interest rates from target, while at the same time permitting the interbank money market to regularly function as a private arrangement to insure participating institutions against specific liquidity shocks. Changes on the tactical level of monetary policy have significant implications upon interest rate adjustment. When the Central bank shows a credible commitment to a given target, interest rates seem to follow the rational expectation hypothesis. Prior to that, investors are reluctant to arbitrage the term structure of interest rates.

Using a comprehensive data set containing daily interbank market transactions the Portuguese interbank money market from 1989 to 1998 and a multivariate error correction model, we are able to show that the rational expectations theory of interest rates fails to hold when there are institutional arrangements that prevent banks from arbitraging the yield curve, and also when there is uncertainty regarding the commitment of the central bank to pre-announced monetary policy targets.

The adjustment to the long run equilibrium and the ability to produce effects across the whole maturity spectrum varies according to which instruments the central bank uses when implementing monetary policy. We found that the central bank was highly successful in stabilizing the short rates, mainly after switching to weekly open market operations together with standing deposit and lending facilities. Shocks to the various interest rates are rapidly absorbed and short lived, at least for the shortest maturities. The introduction of daily facilities sets a target for the over night rate, and prevents it to fluctuate, because market participants do not consider its use as a penalty as long as they post enough collateral to borrow from the central bank. Also, the information content of the long-term rate becomes less important, as banks are more concentrated on the signals sent by the central bank when manipulating the immediate targets.

We find that interest rates respond to several long run factors, thus validating our model. Though each interest rate is more responsive to its own cointegration vectors, it is also affected by neighbouring maturities. Our results emphasise two blocks of interest rates moving together: the short term block on one hand, with maturities up to 2 weeks; and the long term block, on the other hand, comprising the remaining maturities.

Most research uses single cointegration vectors, showing that interest rates are integrated with the spread over the target. However, when neglecting the effect of other maturities' spreads over the interest rate adjustment, the approach is missing a richer framework. The argument that a spread between any two longer rates can be decomposed into a combination of two spreads with the short rate is misleading, because each one of these shortest spreads has a different adjustment coefficient, making the decomposition not feasible. Therefore, we might gain additional insight into interest rates dynamics by looking at broader decomposition of the yield curve.

Simple spreads over the target rate might explain the short-term behaviour of interest rates, only under certain circumstances, which can be linked to cases when the central bank is credibly committed to a pre-announced target and pursues interest rate stabilization. Impulse-response results show that when this is the case, the impact of the shocks on interest rates is generally weak and short lasting, meaning the adjustment process is fairly efficient in absorbing shocks.

Finally, additional insight can be gained from modelling the whole interbank money market spectrum. Usually, empirical research concentrates on the longer end of the interbank money market maturity spectrum. However, very short–term interbank rates are important in determining the longer rates – such as 3 and 6-month rates – which are often used to denominate floating rate notes and other variable rate instruments. Day–to–day monetary policy and interbank money market activity is therefore important and should be used to signal expected interest rates. We provide a framework to analyse for how much and how long do interest rates adjust to monetary policy shocks.

Appendix

Appendix A.1 – A Term–structure model of interest rates

The one period return $R_{1,t}$ on k–period zero coupon bonds is related to prices $P_{k,t}$ in a particularly simple way:

$$\left(1+R_{1,t}\right)=P_{k-1,t+1}/P_{k,t} \qquad [A.1]$$

Similarly, the $(k-1)$–period ahead forward rate $F_{k,t}$[65] is defined as to preclude arbitrage and to satisfy:

$$\left(1+F_{k,t}\right)=P_{k-1,t}\,/\,P_{k,t} \qquad [A.2]$$

Solving [A.2] recursively backward

$$P_{k,t}=\left[\prod_{i=1}^{k}\left(1+F_{i,t}\right)\right]^{-1} \qquad [A.3]$$

Defining the interest rate at horizon k as $P_{k,t}=\left(1+R_{k,t}\right)^{-k}$, and re–writing [A.3]:

$$\left(1+R_{k,t}\right)^{-k}=\left[\left(1+F_{1,t}\right)\left(1+F_{2,t}\right)\ldots\left(1+F_{k,t}\right)\right]^{-1} \qquad [A.4]$$

The first–order expansion of [A.4] provides

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[65] This is equivalent to the rate of return from contracting at time t to buy a one period pure discount bond, which matures at time $t+k$. Hence, the contract must be exercised at time $t+k-1$.

$$1 - kR_{k,t+1} \simeq \left(1 - F_{1,t} - F_{2,t} - \ldots - F_{k,t}\right) \qquad [A.5]$$

$$R_{k,t} \simeq \frac{1}{k}\left[\sum_{i=1}^{k} F_{i,t}\right] \qquad [A.6]$$

Typically, forward and one–period expected interest rates differ from actual realizations. So, if we want to test the assumption of rational expectations, we may write the future one period rate as the sum of the expectation and a forecast error. Forward rates are assumed to be equal to expected interest rates plus a risk premium that accounts for risk factors:

$$F_{j,t} = E_t\left(R_{1,t+j-1}\right) + \phi_{j,t} \qquad [A.7]$$

If we assume that investors have preferences about liquidity or their risk preferences do not make them indifferent between investing long and rolling one period investments we can re–write [A.6] using [A.7]:

$$R_{k,t} \approx \frac{1}{k}\left[\sum_{i=1}^{k}\left(\mathrm{E}_t R_{1,t+i-1} + \phi_{i,t}\right)\right] \qquad [A.8]$$

Hence, the expectation hypothesis (EH) of the term structure of interest rates holds that current interest rates of varying maturities are weighted averages of one period expected interest rates plus a risk premium.

$$R_{k,t} = \frac{1}{k}\sum_{i=1}^{k} R_{1,t+i-1} + \Phi_{k,t} \qquad [A.9]$$

for $k = 1,2,3,\ldots$, and where $\Phi_{k,t} = \frac{1}{k}\left[\sum_{i=1}^{k}\phi_{i,t}\right]$. Interest rates of different maturities move together as there are common underlying factors. The pure expectations theory establishes that the term premium $L(k,t)$ is zero, while term–structure theories attempt to establish some properties for this term premium. Hall and al. (1992) argue that equation [A.9] is not indicated to test empirically for term structure theories, because empirical studies have shown that yields are integrated rather than stationary processes. Thus "conventional statistical analysis is not necessarily appropriate in this context"[66].

Hence, if interest rates are integrated processes, they are possibly cointegrated. We can, thus, re-arrange [A.9] and obtain:

$$R_{k,t} - R_{1,t} = \frac{1}{k}\left[\sum_{i=1}^{k-1}\sum_{j=1}^{i} E_t \Delta R_{1,t+j}\right] + \Phi_{k,t} \qquad \text{[A.10]}$$

where $\Delta R_{1,t+j} = R_{1,t+j} - R_{1,t+j-1}$. If the right-hand side of equation [A.10] is stationary, then the left hand-side is also stationary, and interest rates $R_{k,t}$ and $R_{1,t}$ are said cointegrated, with cointegration vector $(1,-1)'$. One can find many other representations of [A.10] taking interest rates of varying maturities, and constructing other yield spreads of the form $S_{i,j,t} = R_{i,t} - R_{j,t}$[67].

Hall et al. (1992) propose a very specific cointegration space where any yield is cointegrated with the one period yield. Given n yields, $(n-1)$ linearly independent vectors span the cointegrated space, which therefore has rank

[66]Hall et al. (1992:117)

[67] Hall et al. (1992) show that the spread between any two yields is cointegrating. Further, Hamilton (1994) shows that any linear combination of cointegration vectors is still a cointegrating vector, allowing for a multiplicity of cointegration vectors.

$(n-1)$, i.e., there is a single common trend underlying the interest rates data generating process:

$$[(-1,1,0,\ldots,0)',(-1,0,1,\ldots,0)',\ldots,(-1,0,\ldots,-1)']$$

The common stochastic factor, assumed the one–period rate in Hall et al. (1992), fluctuates randomly and constrains the remaining yields. They think of this common factor as something exogenous to the system of yields, such as inflation or measures of monetary growth. Thus, the cointegration implies an error correction representation for interest rates, where the vector of spreads establishes the long–run relationships between yields, implying that short–term changes in interest rates are adjusting to the equilibrium spread, i.e., in the long run, yields of different maturity move together.

Chapter 6

Conclusion

1. Introduction

This chapter reviews the main results and policy implications, and concludes with some avenues for further research. Section 2 defines the objectives of this thesis and its motivation. In section 3 we present the main findings and discuss policy implications. Finally, section 4 proposes topics and extensions for further research, which due to time and space constraints were not investigated here.

2. Objectives and Motivation

The objective of this thesis is a critical assessment of the effectiveness of the interbank money market for liquidity risk management when banks are subject to shocks stemming from the payments system, and its relation with the monetary policy at the tactical level.

A considerable amount of theoretical research has been directed towards the allocation of liquidity performed by interbank markets and its implications for banks' reserve management problem. However, there are only a few empirical studies identifying the institutional features that might improve existing reserve management models. This is primarily due to the unavailability of data, which the central banks are reluctant to disclose. We use a unique dataset made available from The Banco de Portugal's interbank trading platform after obtaining permission from market participants. The data set had to be completed manually gathering records on monetary policy open market operations, target rates, interbank market regulations and other institutional milestones.

The uniqueness of this thesis is two fold: first, it contributes to extend banks' reserve management models; and secondly offers new empirical evidence as a direct result from the exclusive high frequency dataset used.

3. Main Findings and policy implications

Interbank money markets are usually considered as cooperative arrangements to insure banks individually against idiosyncratic liquidity shocks. We have shown that interbank market frictions have implications for banks' reserve management and the conduction of monetary policy, as they jeopardize the ability of the central bank to manage liquidity and interest rates in the banking system.

Our strategy has been to model optimal individual bank decisions in presence of idiosyncratic and common liquidity shocks in a consistent way with intermediate monetary policy goals. We then used data on the Portuguese interbank money market to describe the market micromechanics and show to what extent institutional arrangements might cause the market outcome to deviate from the optimal allocation of liquidity. We linked the effectiveness of central bank monetary policy operations to the interbank institutional features and monetary policy regimes. And we showed that the ability to stabilize interest rates on the long-term end of the yield curve depends on the central bank commitment to the announced goals, and its willingness to withstand aggregate and idiosyncratic shocks.

The conclusions of this research are important to the conduct of monetary policy and to the design of a regulatory framework addressing systemic risks in the interbank market. A smooth functioning of the interbank money market is essential for the effectiveness of monetary policy and the accuracy of the transmission mechanism. However, this benefit might come at a cost as it increases systemic risk. The risk is that any persistent bilateral exposures might heighten the real channels of contagion, which might ultimately require the central bank to step in as lender of last resort. Overall we find that a non-frictionless interbank market and a not fully committed central bank extend the lag response of interest rates to shocks initiated either in monetary policy instruments or in the payments system, while decreasing the accuracy of predictions.

The scale of open market operations conducted by the central bank is in direct relation to the ability of the interbank market to distribute liquidity amongst banks at low cost. In general, the volume of central bank reserves held in the banking system as a whole is subject to little change and fairly predictable. Take the European Central Bank, for example. The ECB is able to control regularly the sources of liquidity change and design adequate open market policies to compensate for undesired aggregate fluctuations. However, when there are market frictions the choice of the instrument to provide liquidity to the system has not a clear-cut answer. The interbank micromechanics might ration out those banks that do not have direct access to open market auctions, and produce undesired effects on interest rates levels and volatility.

We find that, contrary to expectations, the interbank market might resolve industry-wide liquidity shocks, particularly in presence of a lender of last resort and averaging reserve maintenance arrangements. Banks expecting reverting liquidity shocks might well arbitrage the yield curve, by lending today and borrowing later. This increases the dependency of the interbank market on the lender of last resort, who allows reserve accounts below minimum requirements, possibly against posting collateral for overnight borrowing while the liquidity shock does not fade away. This might turn the central bank in a "market maker of last resort", buying banks' assets when prices are low.

In exploiting the institutional features of the Portuguese interbank money market, we offer contributions to the small body of empirical literature. Our results are similar other studies covering the Federal Funds and a few European interbank markets. We also find that rates deviate from the martingale property. There are several institutional features – such as bank's size, reserve maintenance arrangements and credit rationing considerations – that prevent the interbank market to efficiently net out liquidity shocks. Previously unexplored issues, such as the ability to borrow and lend at a range of maturities, are found to be important in explaining banks' behaviour and interest rate dynamics. This feature smoothes the effects of liquidity shocks upon market interest rates and flows, and should be considered both from the monetary policy and regulatory perspective.

4. Future Research

Some other issues remain unexplored and deserve further attention, and possibly a modified analysis both theoretically and empirically. Conclusions from our research suggest ways and extensions to approach the interaction between the interbank money market and banks' liquidity management problem, .

Extensions of the theoretical model might be grounded on our empirical insights. Our model links liquidity shocks with the payments system, however we do not say much about the implications of the payments system arrangements – such as the comparison between netting and gross settlement – for the functioning of the interbank money market, the amount of liquidity traded and ultimately the overall interbank bilateral exposures and potential systemic threats. Additionally, we might allow banks to explicitly choose a given term-structure of interbank loans, incorporating risk aversion as to explain why banks might have a preference for overnight loans or any other maturity, apart from arbitrage considerations. Other institutional features – such as minimum capital requirements, credit rationing and quasi-contemporary averaging reserve maintenance system – are natural extensions of the model. In particular, credit rationing when banks based on asymmetric information have insufficient knowledge about their counterparts might extend interbank market gridlocks to cases when liquidity shocks are bank specific. Finally, it would be of independent interest to compute the insurance value of the safety net offered by the interbank market arrangements, and in a similar fashion to the pricing of deposit insurance determine the value of the lender of last resort under different market circumstances.

Empirically, the micromechanics of the interbank money market deserve further attention, as there are remaining unresolved issues. Using our panel data we might extend and improve the analysis exploring the intensity of trading of each bank with each other and search for privileged relationships. The procedure could be used to analyze pricing and trading persistency and search for the impact of individual characteristics on trading terms.

We can extend our work with the payments system database, which we have for the last four years, and relate the interest rate dynamics to shocks observed in the payments system. Econometric methodologies to model level and volatility of interbank interest rates – such as ARCH and GARCH models within a VECM framework – might offer promising results. The intraday mechanics of the Portuguese interbank market, interest rates and trading volatility, and its links to the real time gross settlement payments system are still to be analysed.

A concurrent view of the dynamics of bilateral exposures each bank has against each other in the banking system and its evolution over time can offer additional insights, particularly suited to assess the systemic threat to economic stability derived from the interbank money market alone.

A final remark regarding the relevance of the data used is required. The dataset we use is quite unique. Its access is restricted and it comprises a complete characterization of all trades in the Portuguese interbank market for the 10-year period ending on the 31st December 1998.

In 1999 open market operations became the responsibility of the European Central bank, and Euro-zone banks became an important source of overnight and short term funding to Portuguese banks. Trades with other non-Portuguese European banks use the real time gross settlement system, which are not recorded by The Banco de Portugal trading platform. So it is no longer possible to create a database as comprehensive as that used in this thesis. Additionally, central banks do not disclose such detailed information except with a long lag neither do they give unrestricted access the payments system databases so reconstruction of interbank trades is possible.

Despite the changes that accompanied entry to the Eurozone, our conclusions remain relevant, for two reasons. First, at least for the most recent periods which we identify as regimes 3 and 4 in our research, the institutional features of the interbank money market and monetary policy operational framework remain mostly unchanged, apart from the fact that the reserve maintenance period has been extended from approximately one week to one month. Secondly, the dataset offers an opportunity to test the impact of changing regimes upon the monetary policy transmission mechanism and gauge the effectiveness of the interbank market to allocate liquidity in the banking system, and these lessons are of very general validity. The scarcity of data, together with increasing concerns about systemic risks and the resilience of banking industry to payments systems arrangements, stress the usefulness of these results for policy makers and regulators.

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