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THE DETERMINATION OF EONIA RATE: The impact of the financial crisis and the effects of the changes in the monetary policy implementation framework

Master´s Thesis

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Eonia on markkinaperusteinen yli yön -korko, jonka rooli korkokäyrän alkupisteenä tekee siitä kriittisen muuttujan Euroopan keskuspankin euroalueen yhteisen rahapolitiikan toteuttamisessa. Vuonna 2007 alkaneen finanssikriisin aikana tämän keskuspankin operatiivisena tavoitteena pidetyn viitekoron määräytymismekanismi muuttui ratkaisevasti.

Tässä tutkielmassa tarkastellaan Euroopan keskuspankin rahapolitiikan toimeenpanokehikkoa ja siihen kriisin aikana tehtyjä muutoksia sekä rahamarkkinoiden häiriöitä. Eonia-korkoa mallinnetaan regressiomallin avulla, jossa muuttujina käytetään likviditeettitilannetta, jälleenrahoitustarvetta, huutokauppatuloksia sekä kalenterivaikutuksia. Ehdollinen volatiliteetti huomioidaan EGARCH-mallilla ja autokorrelaatio autoregressiivisellä prosessilla. Tulokset osoittavat, kuinka kriisin ensivaiheessa EKP menestyksekkäästi vastasi markkinoilla virinneisiin jännitteisiin likviditeettipolitiikallaan. Tutkielmassa arvioidaan lisäksi eonian reaktiota likviditeettiolosuhteisiin Lehman Brothersin konkurssin jälkeen käyttöönotetun täyden jaon -politiikan ympäristössä. Koron muodostumisessa oli havaittavissa selkeä ero periodien välillä. Saatujen tulosten valossa pohditaan epätavanomaisista toimista irtautumisen aiheuttamia haasteita.

ABSTRACT

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EONIA is a market based overnight interest rate, whose role as the starting point of the yield curve makes it critical from the perspective of the implementation of European Central Bank´s common monetary policy in the euro area. The financial crisis that started in 2007 had a large impact on the determination mechanism of this interest rate, which is considered as the central bank´s operational target.

This thesis examines the monetary policy implementation framework of the European Central Bank and changes made to it. Furthermore, we discuss the development of the recent turmoil in the money market. EONIA rate is modelled by means of a regression equation using variables related to liquidity conditions, refinancing need, auction results and calendar effects. Conditional volatility is captured by an EGARCH model, and autocorrelation is taken into account by employing an autoregressive structure. The results highlight how the tensions in the initial stage of the market turmoil were successfully countered by ECB´s liquidity policy. The subsequent response of EONIA to liquidity conditions under the full allotment liquidity provision procedure adopted after the demise of Lehman Brothers is also established. A clear distinction in the behavior of the interest rate between the sub-periods was evident. In the light of the results obtained, some of the challenges posed by the exit-strategy implementation will be addressed.

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Niko Herrala

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ABBREVIATIONS

ABCP	Asset-Backed Commercial Paper
ABS	Asset-Backed Securities
AF	Autonomous Factor
BM	Benchmark (liquidity)
bps	basis point = 0,01 percentage points
CA	Current Account holdings
CBPP	Covered Bond Purchase Program
CDO	Collateralised Debt Obligation
CDS	Credit Default Swap
DF	Deposit Facility
ECB	European Central Bank
EEA	European Economic Area
EONIA	Euro Overnight Index Average
Eurepo	Benchmark for secured money market transactions in the euro area
EURIBOR	Euro Interbank Offered Rate
EGARCH	Exponential AutoRegressive Conditional Heteroskedasticity
Fed	The Federal Reserve Board of Governors
FTO	Fine-Tuning Operation
FX	Foreign exchange
GARCH	AutoRegressive Conditional Heteroskedasticity
GLS	Generalized Least Squares
LTRO	Long-Term Refinancing Operation
MBR	Minimum Bid Rate
MBS	Mortgage-Backed Securities
MLF	Marginal Lending Facility
MP	Maintenance Period
MRO	Main Refinancing Operation
OIS	Overnight Indexed Swap
OMO	Open Market Operation
RR	Reserve Requirement

SF	Standing Facility
SIV	Special Investments Vehicle
SLTRO	Supplementary Long-Term Refinancing Operation
SMP	Securities Markets Programme
SPV	Special Purpose Vehicle
TAF	Term Auction Facility
TARGET	Trans-European Automated Real-time Gross Settlement Express Transfer System
VIF	Variance Inflation Factor

1. INTRODUCTION

Nearly 150 years ago the legendary economist Walter Bagehot wrote in his seminal book *Lombard Street* discussing financial crises, that to stave off a banking panic:

1) the bank supplying reserves *"must advance freely and vigorously to the public,"* 2) *"these loans should only be made at a very high rate of interest,"* and 3) *"at this rate these advances should be made on all good banking securities, and as largely as the public ask for them"* (1873, from Gecchetti & Disyatat, 2009 p. 12)

Amidst the most serious downturn in world economy since the great depression of the 1930s the financial crisis has brought about the necessity to use all measures at central banks' disposal to tackle the downturn and indeed resurrected the lessons of Bagehot. The crisis has called for unconventional and drastic measures to revitalise banks and the economy as a whole. As the traditional measure of lowering interest rates proved inadequate alone, monetary officials around the world resorted to expanding the monetary base through different measures. Some, like the European Central Bank (ECB), resembling closely the ideas put forth in the quote above, offered markets unlimited reserves at a low and fixed interest rate, while others like the Federal Reserve, Bank of Japan and Bank of England bought hundreds of billions worth of government, corporate and mortgage debt in a policy called quantitative easing, which effectively translates into printing money (creating reserves) for the economy. Monetary policy took a prominent role in the winding road to recovery.

The various measures of central bank interventions resulted in vast amounts of reserves in the monetary system pressing down interest rates further and stimulating the economy. The magnitude of excess reserves was nearly unheard of before 2007 and therefore provides some very interesting prospects for examining and understanding the functioning of the money market and overnight interest rates under these special circumstances. This unique opportunity should be seized in order to further improve the knowledge of the effects of central bank policy tools so that future crisis could be handled even more effectively. Our aim is to examine closely the impact the turmoil in interbank markets and the effects of the changes to the operational framework of the European Central Bank had on the behaviour of the short term overnight interest rate EONIA - the operational target of the ECB. To understand the dynamics of this particular rate is crucial as it is pivotal in guiding financial markets. The research is also relevant with respect to the exit-strategies currently implemented as the economy regains its footing step by step calling for mopping up of the excess liquidity in the market and normalizing the implementation of monetary policy. Specifically we shall examine the liquidity effect and the martingale hypothesis related to it together with other previously documented variables of relevance such as bidding behaviour and calendar effects. To give a backdrop to these effects we will provide a short analysis of the money market turmoil and measures taken by the ECB to tackle it. The research is divided into three regimes: 1. normal market conditions 12th of October 2005 – 6th of August 2007 2. the financial crisis 8th of August 2007 – 30th of September 2008 and 3. full allotment 15th of October 2008 – 4th of December 2009.

Structurally we shall begin with a stylized presentation of the functioning of a fractional-reserve banking based monetary system followed by a study of the basic characteristics of the ECB´s monetary policy implementation framework. In section 3 we focus on the sources and developments in the euro money market during the financial crisis accompanied by a look into the various steps taken by the ECB to restore orderly conditions in the money market. We then move on to present previous studies of overnight interest rate modelling focusing our attention on EONIA and subsequently in chapter 5 present the methodology adopted in our research. Section 6 presents the data and section 7 the results of the estimation exercise. Section 8 concludes the thesis.

2. MONETARY POLICY IMPLEMENTATION

Our aim here is to establish the basic principles of central banking and the flow of liquidity (reserves) in the monetary system with a stylized example. In section 2.2 the main characteristics of the framework of the ECB are depicted including balance sheet, demand and supply of reserves, standing facilities and excess liquidity.

2.1 Fractional-reserve banking

The term fractional-reserve banking is the key concept behind modern monetary systems. In principle it means, that a bank needs to hold a certain fraction of its liabilities on its current account (CA) in the central bank during a specified period. It can trade these so called reserves in the money market where the two main agents operating are the central bank and credit institutions[1]. Central bank reserves are referred to as narrow money or high powered money and together with currency in circulation represent the most liquid types of money constituting the monetary base and used for settlement of financial transactions.

Under traditional theories of money and banking the monetary base (currency and reserves held by banks) can be multiplied with lending operations through the money multiplier to form more low powered money. The categories of money according to the European Central Bank's definition are:

- M1 (narrow money): includes currency (banknotes and coins) and overnight deposits (current accounts at the central bank).

- M2 (intermediate money): M1 + deposits with a maturity of up to two years and deposits redeemable at a period of notice of up to three months. In some cases there may be restrictions involved, such as the need for advance notification, delays, penalties or fees.

[1] We use the terms bank, credit institution and Monetary Financial Institution interchangeably.

– M3 (broad money): M2 + marketable instruments issued by the Monetary Financial Institutions (MFI) sector. Certain money market instruments, in particular money market funds and repurchase agreements are included in this aggregate. (ECB Annual Report 2009, p. 265)

Next we will go through a simple stylized example of how the system operates between banks and how the money multiplier works. Consider two banks, A and B, which for simplification constitute the entire monetary system together with the central bank. The banks hold capital and deposits as liabilities. Their asset side of the balance sheet constitutes of central bank reserves, securities and loans, which they have extended to the public. Suppose for simplification, that the required reserve ratio is 10% of the deposit base and banks must hold this amount on average in their current account in the central bank each maintenance period (MP). The reserve requirement (RR) is calculated on a lagged basis so the subsequent changes in the deposit base do not affect the RR in the MP under review here. Both have therefore a RR of 10€. In order to incorporate incentives for interbank lending, suppose that bank B had larger lending opportunities[2]. The current level of interest rates affects the profitable lending opportunities. With higher interest rates fewer loans are profitable ceteris paribus. The initial balance sheets are presented in table 1.

[2] Note the difference in loans in the initial situation, which is countered by differences in reserves. One can imagine an initial trade before the RR determination, where the deposits and reserves of Bank B are deducted by 5€ and a matching increase in Bank A´s reserves and deposits is made.

Bank A

Assets		Liabilities	
Reserves	15	Deposits	100
Loans	85	Capital	10
Securities	10		

Bank B

Assets		Liabilities	
Reserves	5	Deposits	100
Loans	95	Capital	10
Securities	10		

Table 1. Initial characteristic balance sheets of the banks.

Since bank B's deposit base does not necessarily adjust to incorporate the larger amount of loans provided (outflow of deposits to Bank A increasing Bank A´s reserves by 5€) it needs to borrow additional funds from bank A to offset the deposit flow. This interbank loan constitutes an asset to Bank A and a liability to bank B. The loan drains 5€ from Bank A´s current account and credits Bank B´s account by 5€. The balance sheets after the interbank loan are pictured in table 2.

Bank A

Assets		Liabilities	
Reserves	10	Deposits	100
Loan to Bank B	5		
Loans	85		
Securities	10	Capital	10

Bank B

Assets		Liabilities	
Reserves	10	Deposits	100
Loans	95	Loan from Bank A	5
Securities	10	Capital	10

Table 2. Characteristic balance sheets of banks after an interbank loan.

The importance of the proper functioning of the interbank market is thus clarified. It accommodates the flow of funds to their most productive uses, and importantly, regardless of which bank receives the original deposit. Notice how both banks' RR is now fulfilled and total reserves amount to 20€. This normal situation has no excess reserves as all of them are required and employed fully to comply with the RR. (Keister & McAndrews, 2009, p. 3)

Now let us introduce a disruption of interbank lending to the system. Perhaps the loan from bank A was an overnight loan and bank A is reluctant to roll over the loan the next day. It might be uncertain about bank B's creditworthiness or is insecure about its own liquidity needs in the future and would rather hold excess reserves (5€) or use the deposit facility (DF) of the central bank instead. Bank B is now under considerable stress as it must obtain the financing from someone else in the interbank market (in this case there are no other private market counterparties). If this attempt fails, it has to reduce the size of its loan portfolio, sell securities, attract more deposits or increase its capital. If loans are decreased, borrowers - the citizens and firms etc, might be forced to collect their deposits from banks to repay the loans. Most certainly Bank B is reluctant to expand its lending further. Obviously this translates into a contraction in economic activity through reduced lending to finance investment and consumption.

The central bank has basically two ways to react to the problem leading us to see its raison d'être. It can mitigate the magnitude of the contraction by lowering the interest rate, which provides more lending opportunities to Bank A offsetting some of the reduced lending by Bank B. A direct response includes a straight loan to Bank B, which it can use to repay the interbank loan to Bank A (or as in this case an alternative to rolling over the interbank loan). This intervention by the central bank enables Bank B to continue its lending and weather the storm in the financial markets. Typically a central bank is a less liquidity constrained counterparty and is willing to extend liquidity support as deemed necessary to solvent and viable financial institutions against adequate collateral. After all, its role as a lender of last resort means precisely this and practically all central banks provide a lending facility for banks to acquire additional reserves temporarily. Table 3 presents the balance sheet effects of the loan from the central bank. Note that this loan also expands the central bank´s balance sheet and not just the banking sector as the loan increases the assets (loan to Bank B) and liabilities (reserve holdings of Bank B in its CA) of the central bank by 5€.

Bank A

Assets		Liabilities	
Reserves	15	Deposits	100
Loans	85		
Securities	10	Capital	10

Bank B

Assets		Liabilities	
Reserves	10	Deposits	100
Loans	95	Payables to CB	5
Securities	10	Capital	10

Table 3. Characteristic balance sheets of banks after the central bank´s intervention.

The loan is distributed to Bank B by crediting its reserve account by 5€. Bank B now owes 5€ to the central bank and Bank A holds the amount of the overnight interbank loan it did not renew as excess reserves since it is reluctant to lend it to Bank B. Therefore the amount of reserves is now 25€ in the banking system with 5€ of them excess reserves. There is no change in the RR as a result. The additional funds from the central bank helped maintain the flow of credit to the real economy. If the problem in the interbank market is relatively small, the central bank can sterilize the increase in reserves by selling for example bonds from its assets to Bank A, which would buy them using its excess reserves thereby bringing down the level of aggregate reserves precisely to the required level of €20. This solves the allocation problem at the same time as it is acting as an intermediary (table 4). The central bank´s balance sheet´s size is not affected but rather its composition as its asset side is reduced by the amount of securities sold and increased at the same time by the amount of loan given to Bank B. (Keister & McAndrews, 2009, p. 4-5)

Bank A

Assets		Liabilities	
Reserves	10	Deposits	100
Loans	85		
Securities	15	Capital	10

Bank B

Assets		Liabilities	
Reserves	10	Deposits	100
Loans	95	Payables to CB	5
Securities	10	Capital	10

Table 4. Characteristic balance sheets of banks after the central bank has sterilized its intervention with an asset sale.

Now suppose that Bank A decides to extend a new loan worth 5€ to Firm X, which also holds a deposit account in Bank A. This only results in an increase in Bank A's loans and a matching increase in Bank A's deposits. As deposit account is the base for the calculation of the RR, Bank A must hold more funds with the central bank in the next MP with lagged RR determination. If Firm X was to use these funds to buy goods from Firm Y with an account at Bank B, the payment would result in a deduction of Bank A's reserves and deposits, but on the other hand in an increase in Bank B's reserves and deposits. The overall level of the banking systems reserves does not change. This illustrates that actually the central bank has very limited control of lending. It is still committed to supplying adequate reserves to fulfil the increased RR of the monetary system in order to preserve control of short-term money market interest rates by preventing a liquidity squeeze. The demand for central bank reserves is characteristically largely determined by exogenous factors over which it has only limited and indirect control. With interest rate policy it can guide the incentives of the banking system to extend credit to the public. With interest rates it can also affect the constitution of the banks´ balance sheets as the valuation of assets is linked to interest rates. These two tools are known as bank lending channel and balance sheet channel, respectively. (Borio & Disyatat, 2009, p. 28, 33)

An individual bank can control the level of its reserves, but the banking system as a whole cannot. The example above points out, that no matter what banks do, nearly all newly created reserves end up being excess reserves if the central bank so desires. The outstanding amount of reserves is entirely depicted by the central banks actions although an increase in bank lending slowly changes the composition between required and excess reserves. A rise in lending through the money multiplier would inevitably reduce excess reserves as required reserves rise. In the above example the new loan worth 5€ will increase the required reserves by 0,5€ assuming a 10% reserve requirement. The central bank must then increase the amount of reserves to 20,5€ in the next MP as otherwise banks would not have enough reserves to fulfil their RR. (Keister & McAndrews, 2009, p. 7)

2.2 European Central Bank´s operational framework

Today it is common that the primary operational target of a central bank is to control the level of the short-term market interest rate in its day-to-day implementation of monetary policy (Bindseil, 2004, p. 8). The overnight interest rate emerges as an equilibrium solution balancing supply and demand of bank reserves in the interbank market. The central bank can achieve control of the interest rate as it is the sole monopolistic net-provider of reserves to the banking sector demanding them. The ECB has chosen to operate so that the banking sector faces a chronic liquidity deficit and therefore a refinancing need. (Moschitz, 2004, p. 8)

The reasons why overnight interest rates are seen so important are many fold. Firstly, they are the starting point of the yield curve, and according to the expectation hypothesis of interest rates, long-term interest rates are a function of future expected short-term interest rates. As Piazzesi (2003, p. 3) reminds, the central bank can with relative ease adjust the interest rate in the short-end of the yield curve, but what matters to the real economy are the long-term rates. These influence asset prices, companies in their investment decisions, consumers in their saving decisions and economists in their policy decisions. This transmission mechanism can thus eventually influence the ultimate goals of central banks, namely output and prices. (Moschitz, 2004, p. 8) Targeting the beginning of the yield curve also has the added upside of containing anomalies and volatility in the yield curve compared to targeting a longer maturity (Bindseil, 2004, p. 12). This paper will focus on the first step of the transmission mechanism, that is, the relationship between reserves (plus some other factors) and the overnight interest rate.

2.2.1 Central banks balance sheet

A good starting point for understanding the supply and demand of reserves is to take a look at the balance sheet of a central bank after we previously took a look at the simplified balance sheets of banks. The balance sheet can be divided roughly to two components. An autonomous part, whose elements are in day-to-day implementation of monetary policy beyond the control of the central bank and another part typically referred to as monetary policy operations, which are under direct discretion of the central bank. Table 5 gives a rough look at the balance sheet of most developed countries central banks including the ECB. Different elements of the monetary policy implementation framework are then described in subsequent sections from the perspective of the ECB´s framework. (Toporowski, 2006, p. 10)

Assets	Liabilities
1. Autonomous balance sheet	
Gold & Foreign currency	Banknotes in circulation
Investment assets	Government deposits
Other assets	Other liabilities
	Capital and reserves
2. Monetary policy operations	
OMO I (liquidity-injecting reserve operations – purchases)	OMO I (liquidity-absorbing reverse operations – sales)
OMO II (outright holding of securities from past liquidity injections)	OMO II (liquidity-absorbing central bank paper issued)
Liquidity-injecting standing facilities (lending facilities)	Liquidity-absorbing standing facilities (deposit facilities)
	Reserves of banks & monetary institutions
	Operational reserves

Table 5. A characterization of the balance sheet of a central bank. (Bindseil, 2004, p. 48, rearranged by Toporowski, 2006, p. 12)

2.2.1.1 Autonomous factors

The autonomous factors (AF) include all of the items under part 1 of the balance sheet in table 5. Forecasting the movements is of great importance for the liquidity management of the ECB as these changes affect the demand for reserves directly. Correctly forecasted changes can be accommodated by adjusting the allocated amount in open market operations (OMO), but unexpected movements result in liquidity shocks to the system, which can have interest rate implications. The AF items, which are most volatile and above all most unpredictable include in the case of the ECB currency in circulation and government deposits. (Gonzales-Paramo, 2007)[3]

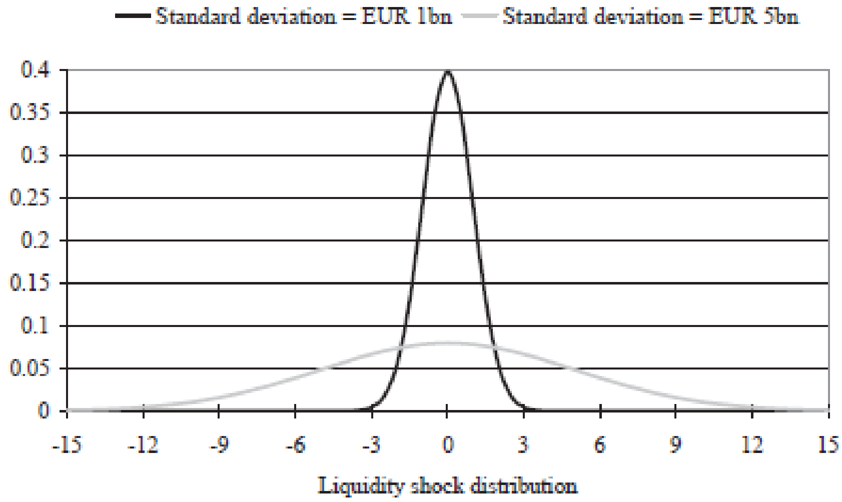
Demand for currency is dependent on nominal income and how much of that is required in cash. As the demand for currency increases it drains reserves from the system as the current accounts (CA) of banks requesting currency

[3] To highlight the differences in various central banks´ frameworks the Federal Reserve must take into account the check float in the system (Carpenter & Demiralp, 2004, p. 11).

to be handed out to the public are debited accordingly. Government deposits at Eurosystem´s national central banks (NCB) are also significant determinants of movements in AFs. Taxes and other revenues of governments and vice versa expenditures, which are transferred to the accounts of recipients in commercial banks decrease or increase the amount of reserves respectively. To reduce the liquidity shocks from government deposits the NCBs and their respective government treasuries have agreements in place to reduce the uncertainty in government deposit holdings (Gonzales-Paramo, 2007) (Toporowski, 2006, p. 11)

Table 5 clearly indicates that both the currency in circulation and government deposits are liquidity absorbing and since the AFs on the asset side of the balance sheet providing liquidity are smaller, the banking system of the euro area is facing a structural liquidity deficit. This is mainly due to large amounts of currency in circulation (currently roughly EUR 800 billion). Reserve requirements further increase this deficit. Thus open market operations need to be net providing. However, the impact of changes in the asset side should not be underestimated as it leads to corresponding changes in the reserves available to the banking sector. Despite this they are often overlooked as the changes are easy to predict due to the high degree of communication between the asset management and liquidity management of NCBs prior to the transactions. The movements can therefore be viewed as practically endogenous.

The amount to be allotted in open market operations (OMO) takes into account the forecast for AFs for the period covering the next main refinancing operation (MRO) and the prevailing liquidity imbalance accumulated earlier in the MP. The ECB aims to neutral liquidity conditions by balancing supply and demand of reserves. Neutral liquidity policy also requires the forecasts of AFs to be unbiased. (Gonzales-Paramo, 2007) Precise forecasts are important as they reduce the volatility of overnight rates (Disyatat, 2008, p. 12). Volatility could even travel up the yield curve into longer maturities, where it could lead into suboptimal interest rates for the economy. It could also hamper the signalling of the monetary policy stance and diminish the credibility of the ECB. (ECB Monthly Bulletin, February 2008, p. 5). Whitesell (2003, p. 8) shows how the increase in uncertainty over end of day balances will decrease the slope of the demand curve thus increasing the inelasticity of the interest rate to liquidity shocks. Välimäki (2008, p. 21-22) relates similarly the wider liquidity shock distribution (larger uncertainty) to increased inelasticity in the demand curve for liquidity. Thus the actual and perceived precision of AF-forecasts has interest rate implications. With accurate forecasts and deviations from neutral liquidity on the supply side (biased liquidity policy in MROs) the deviation from the policy rate is larger. If the liquidity shocks have a large standard deviation but counterparties have faith in the ECB´s ability to forecast these movements accurately on average through the life of the MRO, even large liquidity shocks should have a muted effect on the overnight rate (see figure 1).



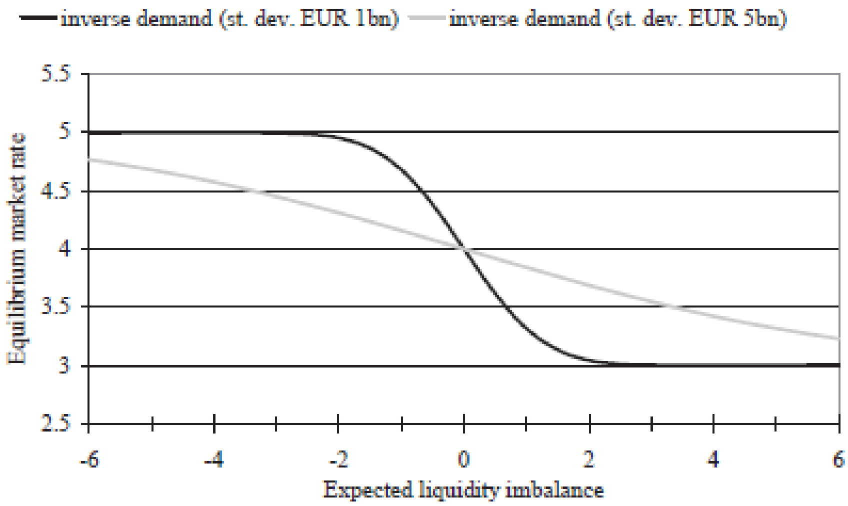


Figure 1. The relationship between liquidity uncertainty and corresponding inverse demand curves. (Välimäki, 2008, p. 22)

2.2.1.2 Minimum reserve requirements

The Eurosystem requires credit institutions to hold funds in relation to their reserve base as deposits with their respective NCBs. The most consequential feature of the reserve requirement (RR) framework is that counterparties are allowed to use averaging provisions. Their average current account (CA) during the maintenance period (MP) (roughly 1 month long) must equal their RR. This averaging contributes to the stability of market interest rates as it gives institutions themselves the incentive to smooth liquidity shocks by providing a buffer against unexpected payment-related movements (both individual and aggregate AF) in their reserve positions. (Ejerskov et al. 2003, p. 10) The liquidity on one day is a quasi-perfect substitute for liquidity on another day acting as a pre-requisite to the martingale hypothesis of interest rates during the MP. The martingale hypothesis basically equates the current market rate with the expected interest rate on the last day of an MP. Whitesell (2003, p. 20) shows theoretically how the large RR and relatively long MPs of the ECB contribute to the stability of interest rates as the inelastic part of the demand curve widens (see for example figure 6).

As a rule, the MP starts on the settlement day (typically Wednesday) of the MRO following the Governing Council meeting on monthly assessment of the monetary policy stance. These are scheduled on Thursdays and the changes to the monetary policy rates are adopted starting from the first day of the next MP. (ECB monthly bulletin April 2004, p. 8)

Required reserves are remunerated at the weighted average marginal rate of MROs over the MP to abolish opportunity costs and prevent reserve avoidance. Credit institutions established in Euro-area Member States and branches of other credit institutions are subject to RR. The reserve base itself is comprised of deposits and debt certificates with a maturity of less than two years. Liabilities vis-à-vis other institutions subject to the Eurosystem's minimum reserve requirements and the Eurosystem itself are excluded. (ECB, General Documentation 2008, p. 59-62) The ECB enforces lagged reserve accounting like the Federal Reserve and many others. The RR of the starting MP is determined by the reserve base outstanding at the end of a second to last calendar month. For example, a bank's RR for the MP starting June 24th is determined by liabilities on April 31 (Fecht et al., 2008, p. 17).

2.2.1.3 Standing facilities and the interest rate corridor

The interest rate corridor is comprised of the marginal lending facility (MLF) rate and the deposit facility (DF) rate. The evolution of the corridor is depicted in figure 2. The width of the ECB´s interest rate corridor has been +/- 1%, with the minimum bid rate (MBR) acting as the base. The width was narrowed to +/- 0,5% for a short period of time starting on the 9th of October.2008 (decision taken by the Governing Council on the 8th of October 2008). Then it was widened back to the original +/-1% starting the 21st of January 2009 (decision taken by the Governing Council on the 18th of December 2008) only to be narrowed again on 13th of May 2009 to the currently prevailing +/- 0,75% (decision taken by the Governing Council on the 7th of May 2009).

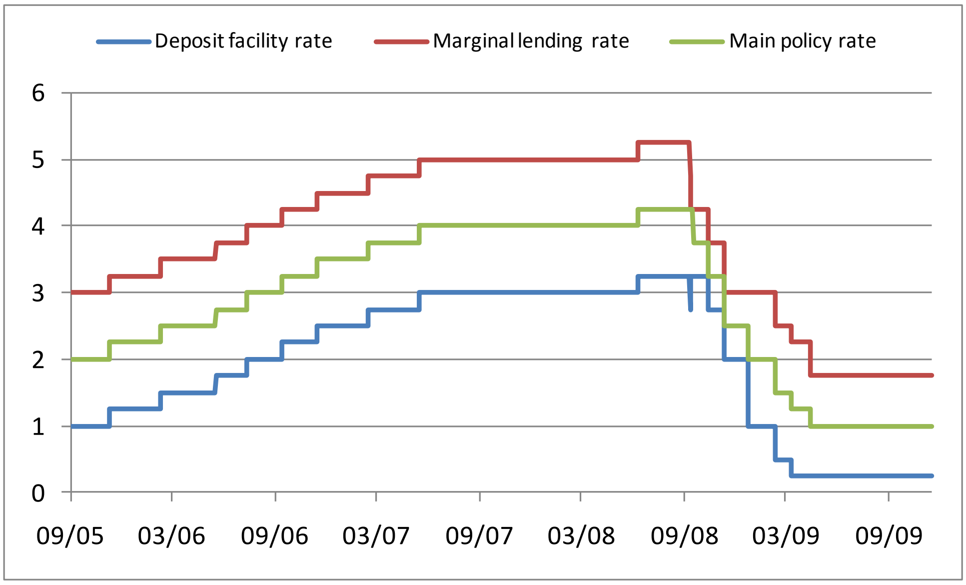


Figure 2. Monetary policy interest rates of the ECB in percentage points. (Source: Thomson Reuters)

The MLF of the ECB provides unlimited overnight liquidity against eligible collateral to its monetary policy counterparties at their own discretion. The marginal lending rate functions as the ceiling for the money market overnight rate as no market participant would pay more for overnight financing than the rate on MLF as financing from the central bank is always available at this rate. The analogy might however disrupt under some circumstances since money market transactions are uncollateralized whereas the central bank requires posting of collateral for its marginal lending facility. This may lead to a situation where the overnight rate exceeds the rate of the MLF. (Ewerhart, 2002, p.13)

Normally the use of MLF is limited to the last day of the MP as banks can obtain the financing cheaper from the market. However if the money market functioning is disrupted, banks in difficulties may face situations where interbank financing is impossible to be obtained at reasonable interest rates. In this case the bank in question must turn to the central bank. Also sometimes banks may tap the facility due to unforeseen liquidity shocks after the European money market has closed and overdrafts of current accounts trigger an automatic recourse to the facility. (ECB, General Documentation 2008, p. 20)

The DF on the other hand is a system where monetary policy counterparties can invest their excess funds overnight if desired and acts therefore as an absorbing facility. The rate of the DF provides the floor of the interest rate corridor as no bank is willing to invest its excess funds at a lower rate with other banks since it could earn higher risk free rates by depositing funds with the central bank. Money markets, as proven by the crisis, are not risk free by definition thus a small gap exists despite current abundant liquidity conditions. Both of the standing facilities (SF) have no limits to their use although the MLF requires the submission of collateral. (ECB, General Documentation 2008, p. 21)

Whitesell (2003, p. 12, 22) reminds, that market transactions and central bank deposits may not be fully substitutable as the cost of borrowing from the MLF is actually the rate on it plus the cost of providing collateral. Any stigma costs would further increase this as is the case especially in the Federal Reserve. Similarly for DF the actual return is the rate on it plus a private sector credit risk premium. These considerations imply an asymmetric corridor for market interest rates around the policy rate resulting in another possible reason for a positive policy spread between the overnight rate and the minimum bid rate (MBR) in MROs.

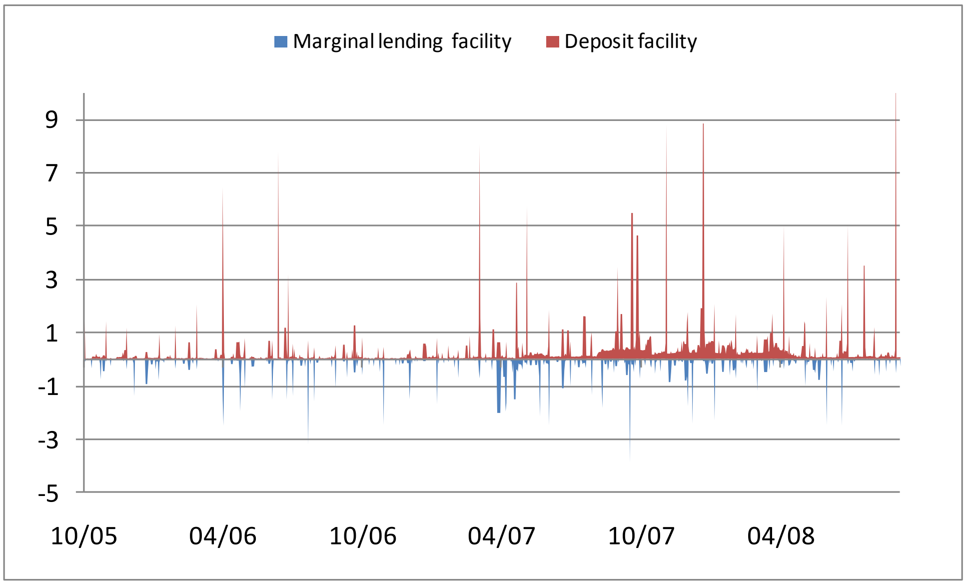


Figure 3. Daily use of standing facilities in EUR billions before the collapse of Lehman Brothers. (Source: Bloomberg)

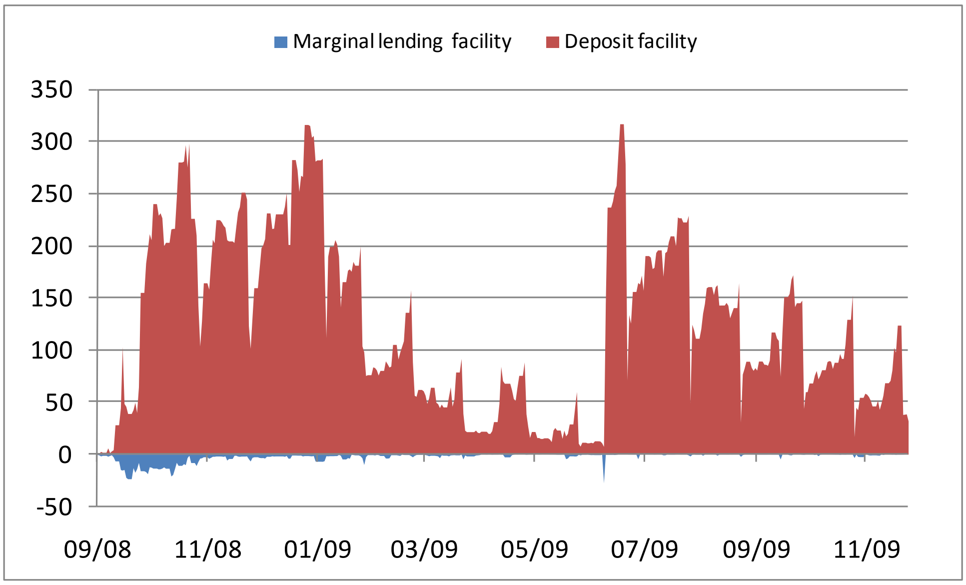


Figure 4. Daily use of standing facilities in EUR billions after the collapse of Lehman Brothers. (Source: Bloomberg)

2.2.1.4 Open market operations

The ECB allots, at its initiative, reserves to the banking system through its open market operations (OMO). Figure 5 shows the dispersion of liquidity by operation type. This liquidity is required to cover the sustained liquidity deficit of the banking system caused by the reserve requirement (RR) and autonomous factors (AF). The main refinancing operation (MRO) is traditionally the main tool for steering market interest rates. The MRO has a maturity of 1 week although in the early days of the Eurosystem (before March 8, 2004) the maturity was 2 weeks, which caused the weekly MROs to overlap by 1 week. Another category of liquidity provision are the long-term refinancing operations (LTRO), which have since the start of the financial crisis various maturities although originally there was only one monthly operation with a maturity of 3 months allotted on the last Wednesday of the month (ECB monthly bulletin April 2004, p. 18).

All OMOs are collateralized i.e. they require the counterparties to submit adequate collateral according to the rules to protect the ECB from suffering losses in its credit operations. The collateral rules also make sure that sufficient collateral is available to market operators so that they can obtain liquidity from the mentioned tender operations. (ECB monthly bulletin July 2009, p. 77)

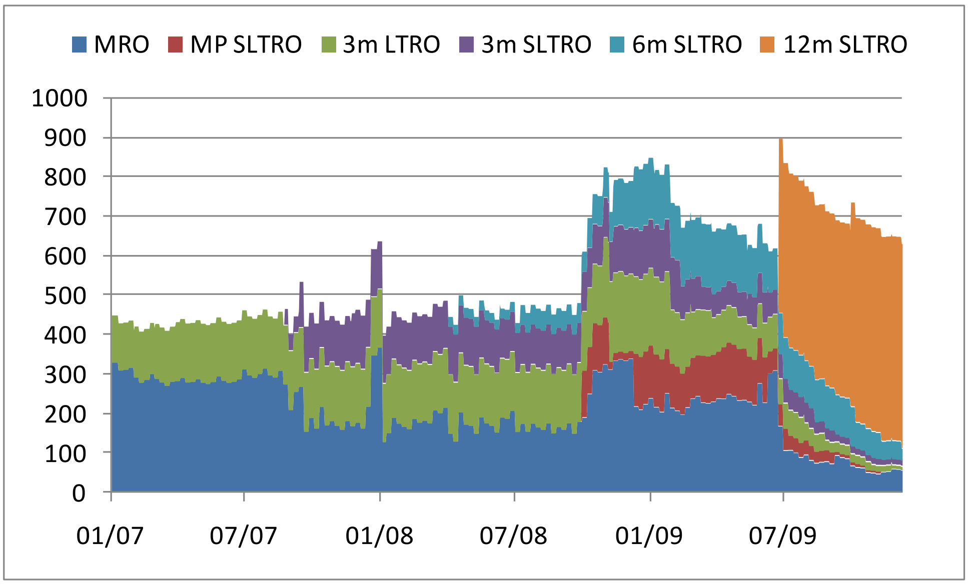


Figure 5. Outstanding OMOs by type of operation in EUR billions. (Source: Bloomberg)

2.2.1.5 Benchmark allocation

Since June 2000 the ECB has published its forecast of average AF on each MRO announcement day. To further improve its communication of monetary policy stance and transparency it started to publish an updated forecast on the allotment day of the MRO[4]. To complement this it started to publish a benchmark allotment at the same time to its MROs on both days. Ewerhart et al. (2004, p. 21) develop a theoretical model, where they show the importance of communicating the expected liquidity situation only coupled with the MRO and not between operations. This lack of transparency smoothes money market rates as banks do not react to liquidity shocks as violently.

Benchmark allotment figure is critical, when compared to the actual allotment as it expresses the liquidity stance of the central bank, i.e. whether it provides a surplus, deficit or neutral amounts of liquidity. A neutral amount would normally allow counterparties to fulfill smoothly their RR until the settlement of the next MRO resulting in an overnight rate close to the minimum bid rate

[4] Allotment day is the day following the announcement. Operations (except fine-tuning operations) settle the day after the allotment.

(MBR) and zero net recourse to the standing facilities (SFs). That is, neutrality refers to quantities supplied - not prices paid. In the calculation the following items need to be taken into account:

- Liquidity supplied via other LTROs and other market operations (fine-tuning operations, outright purchases, foreign currency operations etc.)
- Previously accumulated liquidity imbalances in the same MP
- Forecast of AF
- Forecast of excess reserves

(ECB monthly bulletin April 2004, p. 17)

By explicitly expressing its benchmark allotment figure on the day of the allotment, the ECB aims to reduce uncertainty in the markets with respect to its intentions regarding liquidity. Before March 2004 the AF forecast was only available to the market on the announcement day and therefore if the ECB changed its allotment form this forecast, the market participants could not be sure whether the change was due to a change in the forecast on the allotment day or a deliberate liquidity policy change. The precise formula for the calculation of the benchmark allotment can be found from the April 2004 issue of the monthly bulletin. All of the figures required are published by the ECB except for the forecast of excess reserves. (ECB monthly bulletin April 2004, p. 18) The following figures 6 and 7 portray the emerging equilibrium from supply and demand of liquidity determining the overnight interest rate.

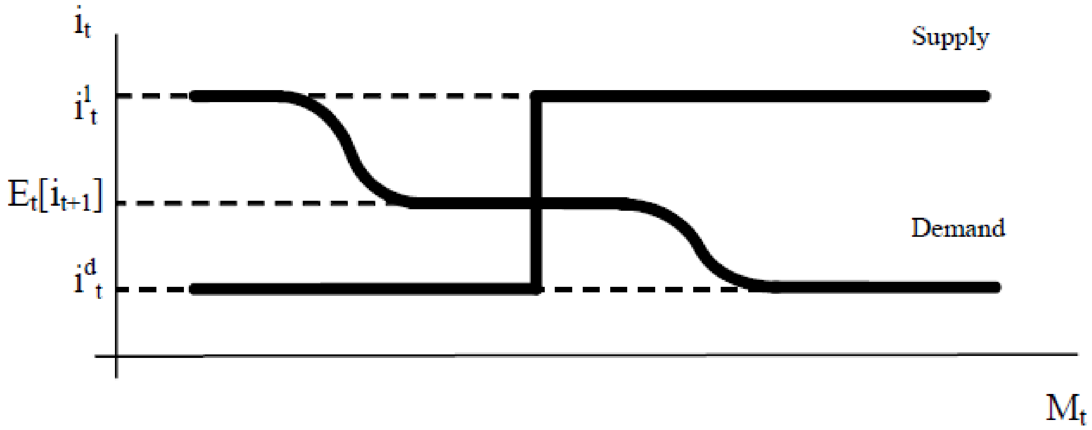


Figure 6. Theoretical demand and supply of bank reserves at days other than the last day of the MP. M_t denotes current reserve holding. The overnight rate is denoted by i_t and marginal lending and deposit rates by i_t^l and i_t^d, respectively. (Moschitz, 2004, p. 49)

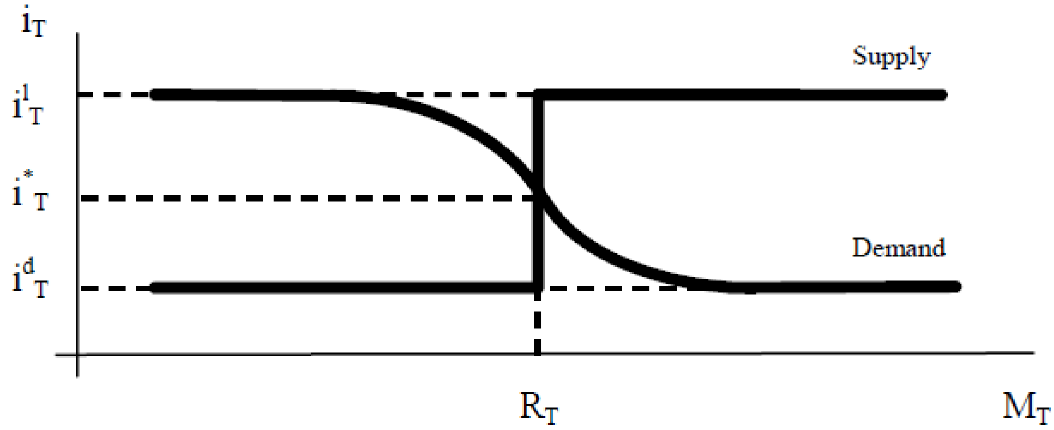


Figure 7. Theoretical demand and supply of bank reserves at the last day of the MP. M_T denotes current reserve holding and R_T the amount of reserves necessary to fulfil the reserve requirement for the entire MP. The overnight rate is denoted by i_T, marginal lending and deposit rates by i_T^l and i_T^d, respectively, and the policy rate by i_T^*. (Moschitz, 2004, p. 48)

2.2.2 Tender procedures

Despite a reasonably short history of central banking, the ECB has gone through major changes in its implementation of monetary policy operations. The main changes made have been to the terms of OMOs. Now we shall go through the two categories of tender procedures the ECB has used in conducting liquidity providing money market auctions.

2.2.2.1 Variable rate

In a variable rate auction used by the ECB after its first 18 months of operation and since the main refinancing operation (MRO) settled on June 28, 2000 and up until fixed-rate full allotment policy was adopted starting from the MRO settled on October 15, 2008 (ECB Press release on the 8th of October 2008). This type of operation is carried out as an American auction[5] with a fixed amount of liquidity to be provided. The counterparties submit volumes and corresponding interest rates, which will be aggregated from National Central Banks and then accepted by the ECB starting from bids with higher interest rates. As it reaches its desired allocation amount (typically close to the benchmark) it cuts off rest of the bids at this marginal rate. If too many bids to ECB's liking were submitted at this marginal rate pro-rata scaling takes place.[6]

ECB publishes a benchmark allotment for the operation but retains the right to deviate from this benchmark in its allocation decision. It´s role is therefore merely indicative of the liquidity conditions observed by the ECB. The ECB also specifies a minimum bid rate (MBR) for the operation, which corresponds to its policy rate in colloquial language. (Ewerhart, 2002, p. 12)

Variable rate tenders suffered from underbidding during their first year or so as expectations of interest rate cuts prompted banks to bid insufficiently in the operations. They were hoping to reduce their funding costs in the subsequent operation with a lower MBR. This obviously led to overbidding in the next operation creating undesired fluctuations to liquidity conditions, bidding volumes and money market rates. (Ewerhart, 2002, p. 15)

[5] In an American auction each counterparty is required to pay the interest of its own average volume-weighted bids instead of a unilateral price for all counterparties in the Dutch auction.

[6] For example, from a total of EUR 10 billion of bids by 10 banks only EUR 5 billion are to be allotted. Each of the 10 banks would then receive half of the amount they bid for at the marginal rate.

This variable rate tender with fixed pre-announced allotment volume was also used in all long-term refinancing operations until the fixed-rate full allotment policy was adopted to these simultaneously with the MROs. The ECB was a pure rate taker, i.e. there was no MBR so as not to convey any information on future short-term policy rates. (Välimäki, 2008, p. 13)

2.2.2.2 Fixed rate

In a fixed rate tender the ECB calls counterparties to bid for volume of funds given a fixed interest rate. The funds are then allocated at a pro-rata basis again. This type of an auction was in use at the beginning of the Eurosystem up until the adoption of variable rate tenders. During the financial crisis the fixed-rate procedure was resurrected, except that this time the bids were satisfied fully instead of a pro-rata procedure.

The use of traditional fixed rate tenders led to unintended bidding behaviour (dubbed overbidding) in the early days of the Eurosystem. Banks were bidding for increasingly high volumes to the extent, that eventually allotment ratios (accepted bids from total bids received) declined to just above 0%. ECB tried to counter this by allotting above benchmark and teaching the banks a lesson (Nautz & Offermanns, 2006, p. 17). An explanation endorsed by Ayuso & Repullo (2001, p. 4) associates the overbidding problem to the central banks perceived asymmetric loss function, which creates a natural spread between the overnight rate and the fixed rate luring banks to overbid the tender. Välimäki (2003) however established that the main underlying problem was the combination of fixing both the price and quantity under rate hike expectations.

2.2.3 Unremunerated reserves

In ECB terminology funds held in current accounts, which more than cover the reserve requirement (RR) (taking averaging into account) are referred to as excess reserves. These are not to be confused with excess liquidity, which manifests itself by counterparties increasing their recourse to the deposit facility (DF). In essence the Eurosystem can have massive amounts of excess liquidity (use of DF) and still have only marginal amounts of excess reserves. Banks naturally prefer to use the DF to park their funds as these are remunerated, whereas excess reserves are not. (See section 2.2.4 for a more thorough discussion) [7]

Excess reserves are mainly structural and amount on average to EUR 0,7 billion per maintenance period (MP) day (Moschitz, 2004, p. 15). The excess reserves in the Eurosystem are only rational if the bank deems the cost of staying behind in the office until 18.15[8] to be larger than the profit from transferring the funds to the remunerated DF. They are therefore sensitive to the interest rate on the DF. Banks with no RR (lump sum allowance of EUR 100 000) accumulate excess reserves randomly throughout the MP whereas the bulk of the excess reserves is accumulated towards the end of the MP from banks which have already fulfilled their RRs and do not take recourse to the DF with their excess current account (CA) balances. (Bindseil et al., 2004, p. 14-15) Other reasons for excess reserves are unexpected payment shocks, operational errors or conscious buffers on the last day to make sure that the RR gets fulfilled (ECB Monthly Bulletin October 2005, p. 26).

Ejerskov et al. (2003, p. 17) confirm in their study that the relevance of excess reserves to the benchmark allocation is small as they are predictable and stable. A reason identified is the large RR, which reduces the benefit of holding excess reserves for liquidity services[9] on the margin to virtually zero.

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[7] Throughout this paper we use the term excess liquidity to describe the liquidity surplus in order to avoid confusion. In official Fed terminology excess liquidity is known as excess reserves. The Fed does not have standing facilities per se, which complicates the matter somewhat and therefore to simplify the terminology, the excess reserves at the Fed are referred to as excess liquidity similarly.

[8] Target2 closes at 18.00 CET after which counterparties have 15 minutes to submit requests to use the standing facilities. The timeframe is extended by additional 15 minutes on the last day of an MP.

[9] Large RR accommodates payment flows more easily as overdrafts are forbidden.

2.2.4 Excess Liquidity

"The word liquidity has so many facets that it is often counter-productive to use it without further and closer definition." – Charles Goodhart, Banque de France, 2008 (Nikolaou, 2009, p. 8)

Nikolaou (2009, p. 10) defines three different types of liquidity:

- Central bank liquidity
- Market liquidity
- Funding liquidity

Market liquidity relates to the ability to trade in the markets whereas funding liquidity refers to the market participants´ ability to fund their trading positions. In this paper we focus on central bank liquidity, which covers the liquidity provided to the public by the central bank in the form of currency in circulation and bank reserves (M1 = monetary base). (Nikolaou, 2009, p. 12)

Excess liquidity is a situation where central bank reserves in the monetary system exceed the required level of reserves. Under most monetary regimes financial institutions are required by law to hold a certain fraction of their deposit base in their central bank account. The required amount varies from system to system and it is notable that the level is of little significance to monetary policy despite some arguments concerned with the increase in volatility of short-term rates in frameworks with a small RR[10]. Historically the levels of excess liquidity have been miniscule until the start of the current financial crisis. This point will be illustrated later.

In the case of the ECB the amount of excess liquidity (deviation from neutral liquidity conditions) can be calculated in two different ways. Firstly, it can be viewed as the sum of all outstanding euro-denominated market operations minus autonomous liquidity factors (AF) and the reserve requirement (RR) of the financial institutions based in the euro area. A second route, which leads

[10] This concerns the Federal Reserve and the use of sweep accounts to avoid reserve requirements (Demiralp & Farley, 2003, p. 5).

to the same amount, is to add the current account holdings (CA) together with the use of DF and subtract the RR plus the use of the MLF from this figure. Formulas are

$$excess = OMO - AF - RR \qquad [1]$$

or,

$$excess = CA + DF - RR - MLF\,. \qquad [2]$$

2.2.4.1 Reasoning why excess liquidity is not inflationary

As the amount of excess liquidity soared to unforeseen levels, many analysts and even economists were worried about the inflationary aspect of the rapid expansion in the monetary base. Many argued that this would happen through the money multiplier as banks holding excess liquidity would seek to lend it to the public. These loans would then turn into deposits, because money lent from a bank returns to a bank. Each new deposit would increase the RR lowering the amount of excess liquidity. The smaller amount of excess liquidity would still however exist and this loop would continue until the level of reserves would precisely match that of required reserves. As a result of the process, banking sector money creation should be sizable and cause inflation. (Keister & McAndrews, 2009, p. 5) Therefore we now take a look at the current situation and show how excess liquidity need not be inflationary.

As long as there is a gap between market interest rates and interest paid on reserves, the example above should reflect reality relatively well. A further assumption required would be to have no lag in the determination of the RR from the deposit base. The first assumption held in the US previously as the Federal Reserve was not authorized to pay interest on excess liquidity (forcing it to sterilize its interventions with treasury sales to maintain control of the fed funds rate) and the ECB maintained market interest rates well above the interest rate paid on the use of the deposit facility (DF). However during the crisis the Fed was authorized to pay interest on excess reserves in October 2008 and the ECB supplied its counterparties with all the liquidity they wanted. Especially the Eurosystem is a fine example of how market interest rates behave under excess liquidity and how powerful tool for monetary policy the interest rate corridor formed by the standing facilities (DF and MLF) can be.

The whole idea of excess liquidity not being inflationary is based on opportunity costs which banks face. Take Bank A in our example. As long as market interest rates are above the interest rate on excess liquidity, it seeks to lend out all of its excess reserves - 5€ in our case (see table 3). But as it lends these funds out it brings down market interest rates as supply does not meet demand at the prevailing interest rate. Each expansion of its loan book increases the RR as it translates into a new deposit somewhere in the banking system. But since this increase in the RR is fairly small, the loop quickly reaches the point where market interest rates are near the rate of the DF in the ECB's case. At this point the opportunity costs, or the spread between the two rates, disappear. In a world with no interest paid on excess liquidity the loop, or money multiplier, would continue to work as long as the market interest rate stays positive or all of the excess reserves are transformed into required reserves. (Keister & McAndrews, 2009, p. 8)

This effect was clearly observable when central banks increased their supply of liquidity. Overnight rates plummeted down towards the interest rate paid on reserves. The amount of reserves in the banking system corresponds to the central banks actions almost entirely as it is the sole supplier of the monetary base, whereas the money multiplier is in the hands of the public as they determine the demand for loans. The lending behaviour of banks should not change, when there exists no spread between the market rate and the interest on excess reserves. They merely hold the funds in their interest earning reserve accounts (or DF) as a backstop to market shocks. The point in increasing reserves by central banks was not to promote bank lending dramatically, since it only does this as long as the money multiplier works, but to encourage banks to sustain their lending policies instead of decreasing their balance sheets substantially. In the ECB's case the market interest rates did fall well below the main policy rate prompting some analysts to refer to the increase in reserves as loosening by stealth.

The fact that the interest on excess liquidity provides a floor to market interest rates is a useful concept from a monetary policy point of view as it provides a tool to adjust interest rates according to the macro economic situation even in the case of severe disruptions in the money markets. If market rates were to fall too low for too long banks would be inclined to provide the economy with too many loans given the economic situation. These loans would then later turn into the seed of a new wave of loan losses. The ability to separate these two functions has prompted for example Goodfriend (2009) to propose a terminology, where monetary policy would cover the decisions over the monetary base (reserves and currency in circulation) and interest rate policy would refer to the decision over appropriate level of interest rates in the economy.

As the economy is currently showing signs of recovery and companies and individuals increase their demand for loans to fund investments and banks see more profitable lending opportunities, the central bank can prevent the overheating of the economy by increasing interest rates without having to worry about the excess liquidity floating in the monetary system. The interest on excess liquidity (or the rate on the deposit facility) has de facto become the main policy rate. Raising it will translate into an increase in rates of importance for the real economy. To use the floor of the corridor as an effective policy tool the central bank must maintain the level of excess liquidity high enough in the system. If it fails, the market interest rates would tend to rise back above the interest paid on excess liquidity and towards the previous policy rate. There might even be a period with a loss of control of the interest rate if it would float without a clear guidance between the two rates. A prolonged period might impose increased volatility further along the yield curve as expected future short-term rate expectations would become partially undetermined or extremely volatile. The narrowing of the corridor could be used to limit the loss of control. However, a possible drawback would be the crowding out of the interbank market as it would decrease the opportunity cost of using the central banks facilities instead of market mechanisms.

2.2.4.2 Draining excess liquidity

When the extraordinary policy measures leading to the dramatic increase in excess liquidity were taken up, the ECB elaborated that the measures taken would and could be unwound as it saw fit. This was paramount to convincing financial markets of the robustness of the framework and to control inflationary pressures.

The measures taken will reverse themselves automatically once the full-allotment policy is cancelled and the normal framework adopted again. The supplementary refinancing operations would then reduce the amount of excess liquidity as they mature. But obviously there was a concern in the financial markets whether this process would be swift enough to reduce the amount of liquidity if inflationary pressures were to present themselves. But again one needs to differentiate between liquidity and interest rate policies.

The ECB has described in its general documentation on the implementation of monetary policy a very flexible operational tool - the fine-tuning operation (FTO). They are mainly used to counter liquidity imbalances on the last day of the MP, but can be used to collect fixed-term deposits also. In essence the operation type can be used to provide or absorb liquidity in the banking system. The maturity of the operation depends on the situation and is without an upper limit. (ECB, General Documentation 2008, p. 16)

Another standard tool at ECB´s disposal is the issuance of debt certificates if it deems necessary to adjust its structural position vis-á-vis the private banking sector. One such situation might be the undesired level of excess liquidity.[11] The certificates would be fully transferable and issued at a discount (zero-coupon). The maturity of the certificates is limited to 12 months and they are issued through standard tender procedures. The tender would be open to all monetary policy counterparties. (ECB, General Documentation 2008, p. 17) Liquidity deficit can also be adjusted by buying or selling assets from the investment portfolio to the market.

2.3 EONIA

Euro Overnight Index Average or EONIA is the very start of the yield curve and the shortest quoted interest rate. It is computed as a weighted average of all overnight unsecured lending transactions undertaken in the interbank market initiated within the euro area by the contributing banks which are the same as the panel banks for EURIBOR fixings. EONIA´s importance is accentuated as it is used in many derivative contracts as their underlying interest rate. (Euribor.org)

Traditionally EONIA has been viewed to be under the control of the ECB as the spread between it and the main policy rate applied to fixed tenders as such or to variable rate tenders as the minimum bid rate has been relatively small and stable. It has been perceived to be the operational target of the central bank and therefore have some signalling content about the alignment of the monetary policy stance. (Würtz, 2003, p. 7)

[11] Swiss National Bank started to issue money market bills after excess liquidity was increased as a result of their FX interventions.

3. EUROPEAN CENTRAL BANK AND THE FINANCIAL CRISIS

Central banks played a crucial role in countering the financial crisis. Drastic unconventional measures were eventually required to secure funding needs of banks. We begin with a brief look at how the situation escalated and then go through the measures the ECB in particular undertook between 2007 - 2009. We refrain ourselves from addressing unconventional measures taking place since then, namely the Securities Markets Programme (SMP)[12].

3.1 Collapse of the interbank market

The initial disappearance of market liquidity in Q4 2007 from the money market led to a significant increase in unsecured versus secured money market rates. These spreads proved to be prohibitive for trading, and as a result the trading volumes decreased and maturities shortened as frictions got worse and worse. The money market grinded to a virtual halt after the collapse of Lehman Brothers.

3.1.1 Liquidity disappears from the market

The current downturn originated as a financial market crisis, which subsequently spread to the real economy. In the heart of the problem was the maturity mismatch resulting from the structure of originate & distribute -banking, which relied heavily on short-term wholesale market funding. Banks originated loans, repackaged the cash-flows generated by these loans into Mortgage Backed Securities (MBSs) and Asset Backed Securities (ABS) and distributed these securities to investors. The selling was conducted mainly via Special Purpose Vehicles (SPVs) (conduits or Special Investments Vehicles, SIVs), in order to appear as off-balance sheet liabilities of the bank. The SPVs held the securities in their portfolios and funded the transaction with an issuance of (short-term) Asset-Backed Commercial Paper (ABCP) to fund potentially illiquid longer-term securities. Problems emerged as the credit quality of these securities declined especially in the US and UK and

[12] Within the SMP it conducts interventions in the euro area public and private debt markets to ensure depth and liquidity of the markets are sufficient enough not to hamper the monetary policy transmission mechanism. (ECB 2010)

inadequate capital buffers of SPVs were depleted. The subsequent rating downgrades and the realization that risk assessment and pricing methods for such complex instruments were inadequate increased uncertainty over the securities up to the point where the ABS markets dried-up and market liquidity evaporated (Borio, 2009, p. 9). The issuance volumes of Collateralised Debt Obligations (CDOs) dropped and translated to refusal by investors to roll-over their ABCPs holdings when they matured. The SPVs had to draw on their committed credit lines from their sponsoring banks to refinance their investments proving that the off-balance sheet liabilities came to haunt their parent banks and were not after all separated financially. (Nikolaou, 2009, p. 39-40)

The loss of trust in the wholesale interbank market due to exposures to mainly ABSs caused substantial funding problems to banks all over the globe (funding liquidity disappeared). The collapse of Bear & Stearns in spring 2008, fall of Lehman Brothers on the 15th of September 2008 accompanied by the bailout of American International Group, Citigroup, Fannie Mae, Freddie Mac and Hypo Real Estate, Dexia, Fortis and several German Landesbanks in Europe most notably, put further tightening pressure to the terms of interbank lending and highlighted the fragile nature of market based wholesale funding to loss of funding liquidity. To cut the vicious cycle of disappearing market liquidity → funding liquidity → increased credit risk → market liquidity etc. central banks had to step in (Borio, 2009, p. 18). This called for drastic and co-ordinated measures from central banks to provide the ailing financial sector with liquidity in order to keep the institutions up and running and prevent capitulation. As the interbank market collapsed and institutions lost their flexibility in financing, they required a large buffer of liquidity for themselves as an insurance to cope with unforeseen liquidity shocks stemming from their operations. On top of changes to liquidity provision the counterparty and collateral rules were relaxed by the ECB and a targeted program to improve the functioning of the covered bond market was initiated.

3.1.2 Unsecured and secured lending spreads widen dramatically

Previously banks were able to attain their unsecured short-term financing from the interbank market at low premiums compared to interest rates charged on secured transactions. The spread between the two exploded and the market dried up as a consequence leaving many financial institutions gasping for funds. Instead of portraying here the EURIBOR-Eurepo-spread, which would actually capture the precise spread between secured and unsecured financing we use a more commonly seen proxy for this. In figure 8 is the EURIBOR-OIS (overnight index swap)-spread that captures the effect in the euro money market. An overnight indexed swap is a contract in which one counterparty pays a fixed interest rate in exchange for receiving the average overnight rate. This is a good proxy since the credit and funding liquidity risk premia for overnight transactions remained negligible even during the crisis (ECB monthly bulletin July 2009, p. 77). Similar situations occurred in other money market segments as well. In figure 9 the credit default swap (CDS) spreads for few chosen European banks are presented. They point out the market perceived credit risks of the banking sector.

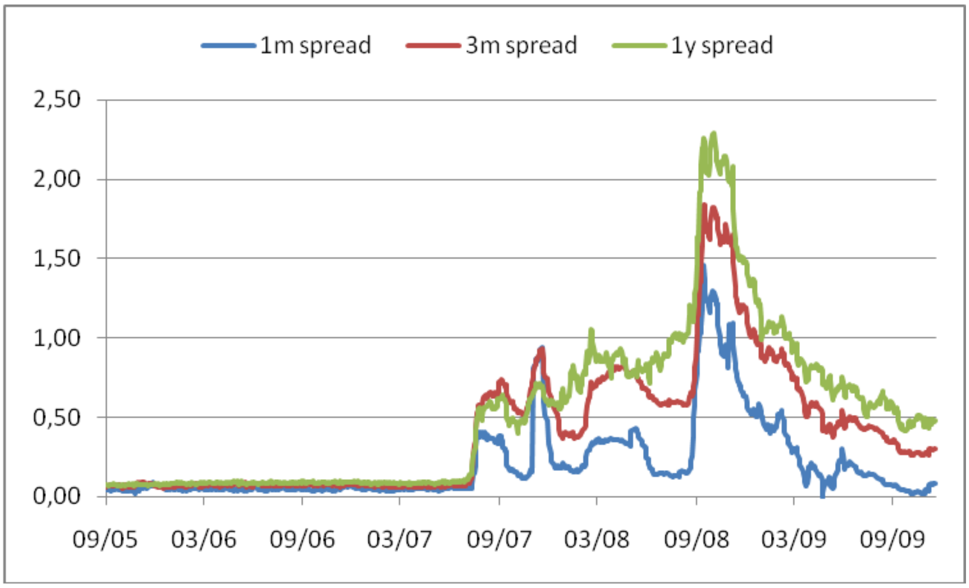


Figure 8. Euribor-OIS-spreads in percentage points in different maturities. (Source: Thomson Reuters)

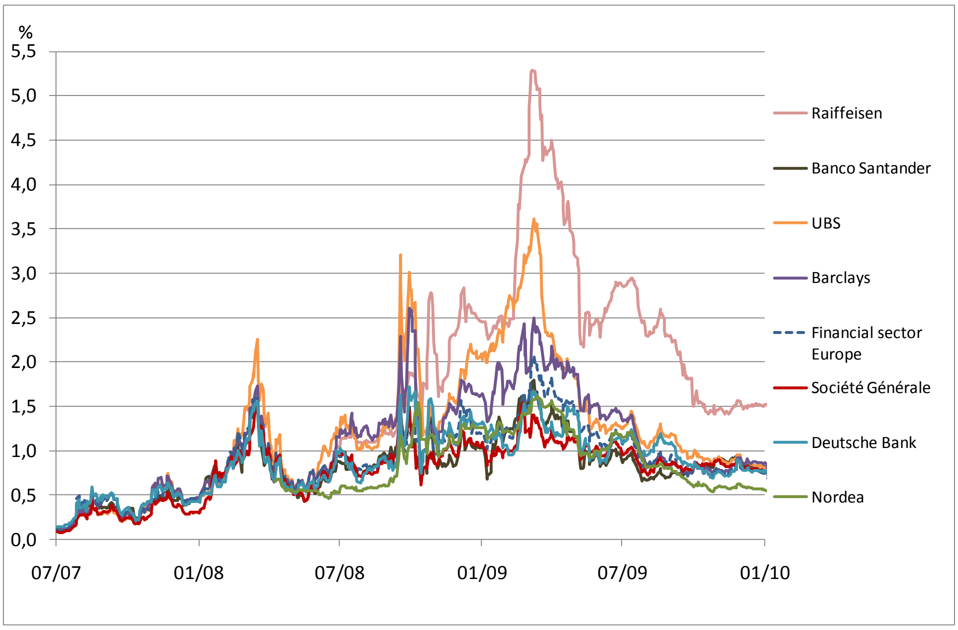


Figure 9. Selected major European bank CDS-quotes in percentage points. (Source: Bloomberg, Bank of Finland)

The tensions in money markets haven not fully receded in the three years since, and in particular the problems in term financing spreads seem to remain substantial. This may reflect the continued fear of banking sectors exposure to further credit losses and also a general re-pricing of liquidity risks. There are some hints that the crisis may have changed the structure of the money market. In the future, collateralized funding in longer maturities is likely to hold on to the market share grabbed as a result. (ECB monthly bulletin July 2009, p. 79). It is also likely that such narrow spreads will not be seen at least in the near-term future. It might even be that the narrow spreads leading up to the financial crisis, were indeed below their equilibrium levels.

3.1.3 Money market volumes drop especially in term markets

Figure 11 illustrates the drying up of the euro money market through a 30-day moving average of the EONIA volumes. As the money market volume went down banks were unable to distribute the reserves accordingly to each bank in order to meet their respective reserve requirements. The qualitative assessment in the September 2009 money market survey confirms this (see figure 10). Despite the relatively well functioning secured money market (ECB money market survey September 2009, p. 15) it became apparent that the central bank was required to step in and provide the liquidity to individual banks as requested. The role of the money market as a source for funds and a place to invest surplus reserves became ever smaller. The transmission mechanism had broken down.

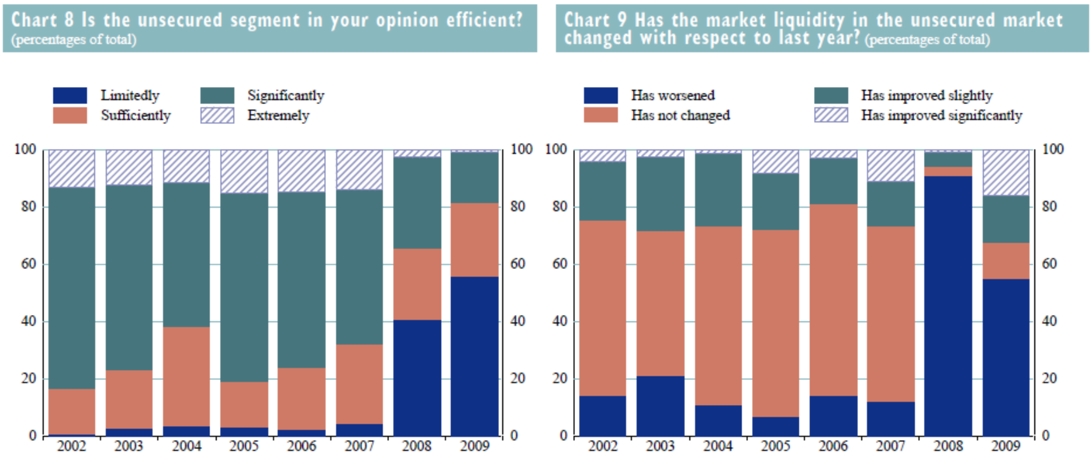


Figure 10. Qualitative assessment of the unsecured money market segment. (ECB money market survey September 2009, p. 9)

Under normal circumstances the ECB estimates the aggregate liquidity need of the banking system based on the autonomous factor forecasts of individual national central banks (NCBs) so that the banking system as a whole can meet its RR smoothly and as precisely as possible during the course of the maintenance period. Banks with excess reserves lend them to banks with cash shortages in the money market at market interest rates. Fecht et al. (2008, p. 41) have access to bank specific liquidity positions from early millennia and show that small banks are less short on liquidity than larger ones. They conclude that this fact focused the pressure especially on large banks under adverse liquidity conditions at the time despite relatively better access to the interbank markets.

As can be seen from figure 3 the allocation procedure worked extremely smoothly up until the start of the financial crisis in the fall of 2007 as the recourses to the standing facilities remained miniscule. From there on jitters can be seen in the curve as some banks failed to meet their RR without tapping the marginal lending facility for extra cash at higher interest rates. This was due to some banks´ reluctance to lend to others (credit rationing) as they were unsure about their own and counterparty´s exposure especially to the sub-prime mortgage market and other structured products (Nikolaou, 2009, p. 8). Instead they chose to hold large liquidity buffers in their current accounts with the central bank and took advantage of the overnight deposit facility (DF) to invest their excess holdings. (ECB monthly bulletin July 2009, p. 76)

Daily EONIA-volumes actually went up after August 2007 since pressure was first asserted mainly on the term funding market which grinded to a standstill. The volumes moved from longer maturities to the still relatively well functioning overnight market. All maturities of unsecured financing of over one week became practically non-existent as the spreads widened to astronomical levels (see figure 8). A transition from unsecured to the secured money market segment also resulted. (ECB monthly bulletin July 2009, p. 77, Heider et al., 2009, p. 27) The secured money market (including long maturities) and EONIA-futures markets remained to function relatively well. The first because of collateralization and the latter because of banks having to hedge the exposure to non-financial institutions´ willingness to borrow in the term unsecured market even at higher spreads as their access to overnight was restricted (Eisenschmidt & Tapking, 2009, p. 18).

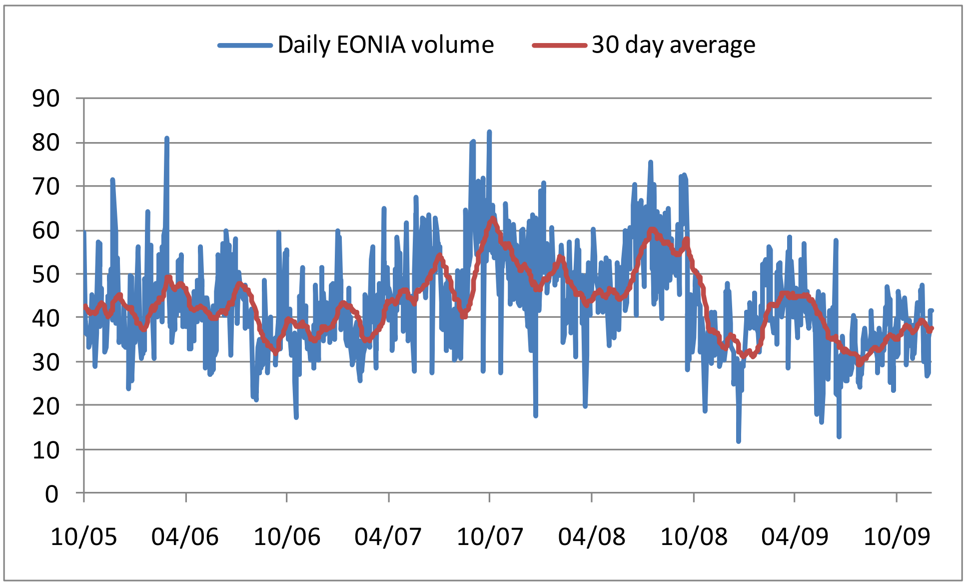


Figure 11. EONIA volumes in EUR billions. (Source: Bloomberg)

After the collapse of Lehman Brothers in September 2008 we see the volume in the overnight market nearly halving from an average of EUR 60 billion per day to just over EUR 30 billion (see figure 11). This was due to two reasons. Firstly the tensions even in the overnight market increased. Secondly and probably more importantly the ECB stepped in as an intermediary in the money market by fully accepting banks´ bids at a fixed interest rate. The banks did not need to trade with each other to the same extent anymore and as EONIA approached the rate on the DF, the opportunity cost between the market and the use of DF decreased inducing banks to use the DF instead of the market for excess cash as speculated already by Moschitz (2004, p. 18).

3.2 European Central Bank´s response to the financial crisis

The financial crisis put the resilience of the ECB´s operational framework to the test. The framework had previously been challenged by the over- and underbidding problems, but this time it was not just banks´ bidding behaviour that required adjustments. The redistribution mechanism of the interbank market was severely disrupted, term financing had ceased along with foreign currency funding and the price of liquidity in tender auctions had gone dramatically up. A particular problem in the Euro area was the cross-country disintegration of money markets as depicted here by the cross-country standard deviation of various key money market rates across euro area countries (see figure 12). This development obviously hampered the transmission mechanism of the single monetary policy. To address these issues the ECB used the considerable flexibility of its framework and changed dramatically the implementation of monetary policy.

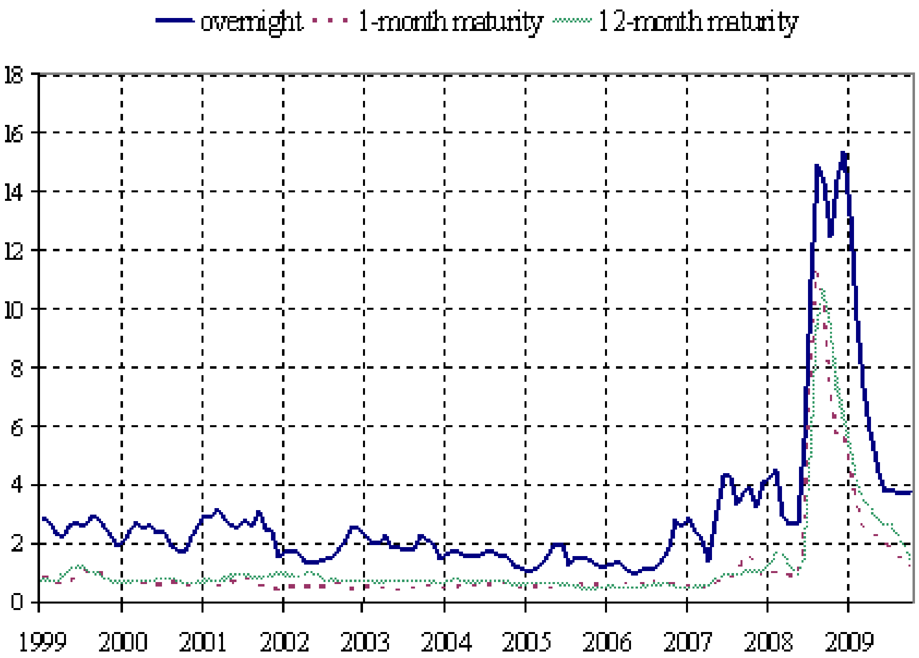


Figure 12. Cross-country standard deviation in basis points of the average unsecured interbank lending rates across euro area countries (moving average)

ECB´s main concern was that without a fully functioning money market the pass-through of policy interest rates to the real economy would become more volatile and less predictable since the first step in the monetary policy transmission mechanism is the formation of interest rates in the money market in tandem with the Governing Council´s decisions. The measures taken were also necessary to reduce the impact of market illiquidity on the operations of solvent financial institutions and preventing them from going bankrupt or decreasing their lending operations (Karas et al., 2008, p. 7). In essence the ECB assumed a more prominent role in the money market thus influencing the dynamics of interest rates in particular through changes to tender procedures and the interest rate corridor. (ECB monthly bulletin July 2009, p. 76) Therefore we shall now go through the key features of these measures.

3.2.1 Quantities supplied

After August 2007 the higher and more varying demand for reserves from the banking sector prompted the ECB to take the first steps in addressing emerging tensions in money markets. Within its framework it chose to change the balance of provision of liquidity within the maintenance period (MP). This “frontloading” meant that it provided funds above the benchmark allocation early in the MP and then reduced the supply gradually towards the end by adhering to the benchmark more closely. The aim was to relieve the stress banks face especially at the end of the period as they would have fulfilled more of their reserve requirement (RR) earlier on in the period (see figure 13). Heider et al. (2009, p. 25) identify this period as a regime of adverse selection in the interbank market. Frontloading succeeded in maintaining the EONIA close to the policy rate (on average +0,7 bps - a mean even lower than at normal times). However, the volatility of the rate doubled from the year before to 12 bps. (ECB monthly bulletin July 2009, p. 79-80)

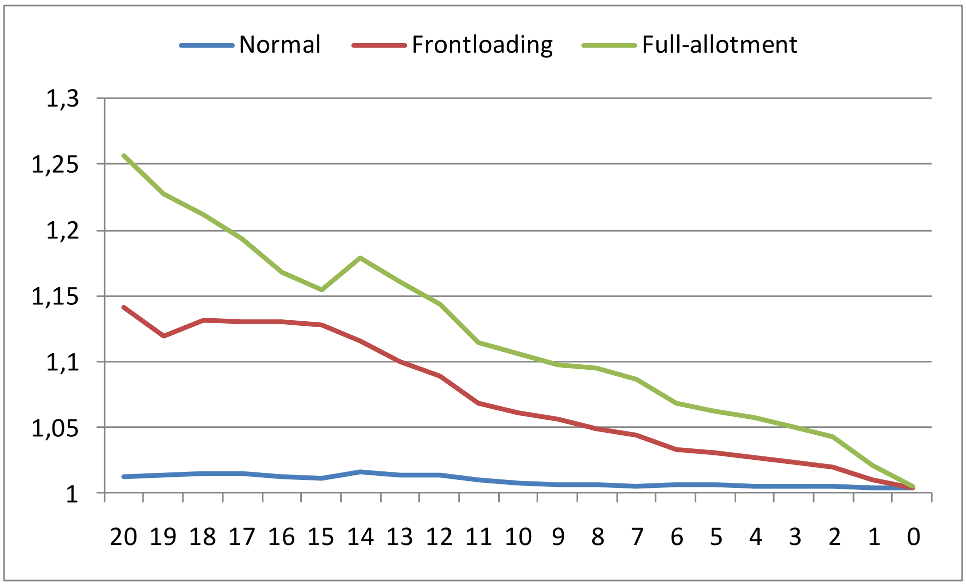


Figure 13. Accumulation of reserves (ratio between the cumulative average holdings and required reserves) within the MP during different regimes. The x-axis shows the day of the MP with 0 indicating the last. The MP between the 10th of September 2008 and the 7th of October 2008 is excluded as an outlier. (Source: Bank of Finland)

After Lehman Brothers had collapsed this measure was deemed insufficient as the problem did not lay only in the allocation but also in the aggregate amount of reserves requested by credit institutions (ECB monthly bulletin July 2009, p. 77). Allocation problem manifested itself also through the increase in the use of both of the standing facilities (SF) reflecting the liquidity hoarding by some (DF use) and desperation by others (MLF use). (Heider et al., 2009, p. 25) See appendix 1 for a breakdown of the use of SFs during a MP on average.

As tender spreads (marginal MRO rate and weighted average rate versus the MBR) increased substantially in September 2008, implying desperation of counterparties to have access to central bank financing, the ECB changed its tender procedure to fixed-rate full allotment in all euro-denominated tender operations starting from the MRO settled on the 15th of October 2008 (decision taken by the Governing Council on the 8th of October). Before September 2008 and especially before August 2007 the marginal rate was quite stable and predictable thus easing the bidding process for counterparties. Also the drawbacks of being unsuccessful in bidding increased substantially as borrowing from the market to make up for the lack of funds was difficult. (ECB monthly bulletin July 2009, p. 82)

Fixed-rate full allotment solved not only the allocation problem in the interbank market but also reduced the uncertainty of individual banks participating in operations over the liquidity allocated to them and the cost of these funds (see section 2.2.2 on tender procedures). (ECB monthly bulletin July 2009, p. 81) The intermediating role of the ECB was also apparent on the basis of the increase in the number of counterparties both participating and seeking eligibility to participate in operations (ECB monthly bulletin July 2009, p. 85). The measures taken with respect to the width of the corridor have been covered already in section 2.2.1.3.

As discussed by Bindseil et al. (2004, p. 6), the implementation of such liquidity policy needs to be signalled carefully. If not deemed to persist over some time the guidance on the future evolution of short-term rates is clouded, leading to destabilization of the yield curve and complicating inter-temporal economic decisions of economic agents. Therefore the ECB chose to set specific timelines for these operations and communicate well in advance about the changes in full allotment policies. For example, in the first press release (8^{th} of October 2008) of the new liquidity policy, it highlighted that measures would be: *"in place for as long as needed, and at least until the end of the first maintenance period of 2009"*. It then subsequently continued the measures with similar communication well in advance of reaching the previous timeframe. One must also consider the costs of replacing the money market with substantial central bank intermediation. The money market is after all very important from a welfare point of view as it aggregates information, discovers prices and enforces peer monitoring (Heider et al., 2009, p. 33).

Frontloading and full allotment were not the first time when the ECB deviated from its neutral liquidity allocation. During the underbidding episodes of 2001 it was not able to allocate desired amounts. In the old framework (before March 2004) the policy spread (EONIA-MBR) reflected interest rate expectations to some extent prompting the ECB to respond sometimes by promoting loose (tight) liquidity conditions when EONIA was well above (below) the policy rate. Cassola & Morana (2008, p. 7) explain the slight allotment above benchmark since 2005 as being a counter measure to the slightly increasing trend in the policy spread, which was caused by an increasing liquidity deficit. Deviations from neutral liquidity can be seen from figure 14.

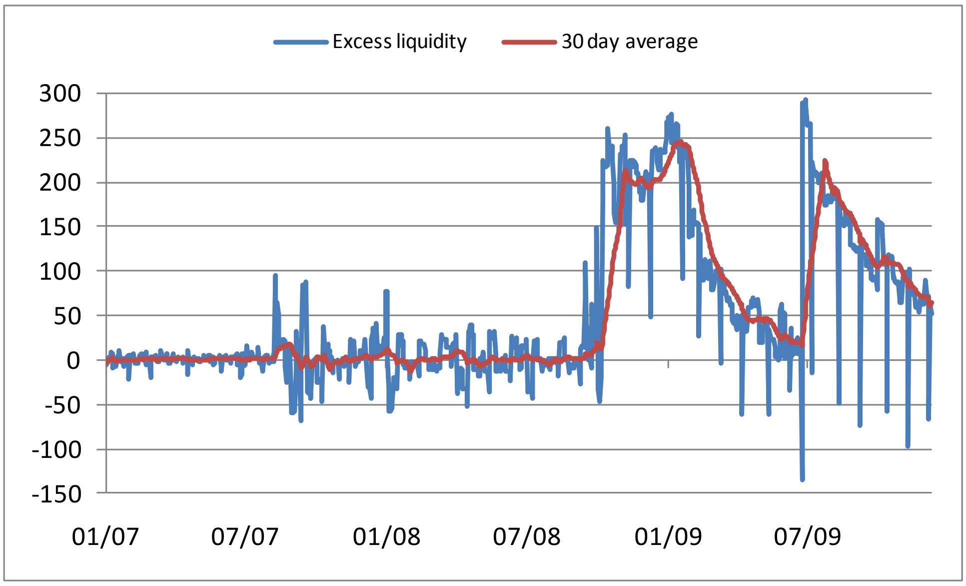


Figure 14. Excess liquidity of the Eurosystem in EUR billions. (Source: Bloomberg)

3.2.2 Lengthening of the maturity of central bank refinancing

During the early phase of the crisis in August 2007 an additional 3-month supplementary longer-term refinancing operation (SLTRO) was introduced. This SLTRO was renewed subsequently on a pre-announcement basis but never taken to the regular open market operation (OMO) -calendar. The amounts to be allotted were pre-announced and varied from EUR 40-75 billion. In April and July 2008, a 6-month SLTRO was conducted but with a limited volume of just EUR 25 billion.

After the collapse of Lehman Brothers the implementation of euro-denominated monetary policy was changed in a dramatic way starting with the special-term refinancing operation on the 29th of September 2008. EUR 141 billion worth of bids were received and of those EUR 120 billion allotted with a maturity of 38 days, which fully covered the remaining days of the then prevailing MP and the next (ECB monthly bulletin July 2009, p. 81). Subsequently, these operations with a maturity of one MP were then continued. The additional 3-month SLTRO and an additional 6-month SLTRO (one each per month starting from November 2008) were taken to the regular OMO-calendar on the 15th of October 2008. (ECB 2008a) Finally, three 12-month operations were announced on the 7th of May 2009 (settled on 25th of June, 1st of October and 17th of December 2009) (ECB 2009a). The one-year operations can be viewed as more interest rate then liquidity policy operations as they pressed the overnight rate firmly against the DF rate by creating an ample and persistent liquidity surplus to the money market. [13]

The longstanding principle of the ECB to have a broad counterparty list was further honoured, as starting from the 6th of October 2008 all institutions that were eligible to participate in Eurosystem standard OMOs and that fulfil additional operational criteria specified by the respective national central banks, could participate in quick tenders (fine-tuning operations or FTOs) as well (ECB 2008b). Quick tenders are carried out with an accelerated schedule as the announcement, allotment and settlement of the operation take place during the same business day. Absorbing FTOs were pushed later to the afternoon so that counterparties would have more time to observe their liquidity positions and prepare their bids.

[13] To preserve flexibility of the framework an option to introduce a spread to SLTROs was retained and indeed exercised in the last 12-month operation settled on the 17th of December 2009, where the interest rate was indexed to the average MBRs of the MROs over the life of the operation. (ECB 2009b)

Not only was the euro funding of banks in jeopardy, so was the funding in many other currencies of importance also to the euro area banks many of which were acting across borders and provided financing in various foreign currencies. To address this problem central banks across the globe took co-ordinated action and set up swap lines between each other. The most important one to euro area banks was the Federal Reserve´s Term Auction Facility (TAF) launched in December 2007. These were organized as auctions for Eurosystem counterparties against eligible collateral accepted in Eurosystem credit operations with a maturity of roughly one month. The US dollars were then provided by the Federal Reserve to the ECB through the established temporary reciprocal swap line. In July 2008 these were accompanied by a similar operation with a maturity of 84-days. In September overnight variable rate operations commenced. All TAF operations became fixed-rate tenders with full allotment on the 13th of October 2008. At the height of the crisis outstanding amounts in TAF operations were nearing USD 300 billion. Starting from October 2008 the ECB conducted in partnership with the Swiss National Bank EUR/CHF FX swap operations with a fixed price primarily in a maturity of one week. (ECB monthly bulletin July 2009, p. 80-81, 83-84) EUR/USD FX swap operations made an appearance briefly as well. These FX swap operations were euro-absorbing in nature as they provided Swiss francs and US dollars in exchange for euro cash (EUR/CHF and EUR/USD tender procedures).

3.2.3 Changes to collateral rules

As both liquidity providing OMOs and the use of marginal lending facility require adequate collateral the changes to the rules were very important to the marginal costs of counterparties´ financing. The ECB has always accepted a wide range of collateral in its operations so it only became a possible constraint to counterparties with the introduction of fixed-rate full allotment. Some of the loosening of collateral rules can also be attributed to the significant reduction in previously accepted collateral due to downgrades (Eisenschmidt & Tapking, 2009, p. 8). To protect itself against credit losses from its operations the ECB imposed sharper haircuts to these new classes of collateral. (ECB monthly bulletin July 2009, p. 83)

From the MRO settled on the 22[th] of October 2008 (decision taken by the Governing Council on the 15[th] of October 2008) the rating threshold for securities other than ABS (unchanged at A-) was lowered from A- to BBB-. Debt instruments issued by credit institutions themselves and traded on some of the non-regulated markets recognised by the ECB together with subordinated marketable debt instruments became also eligible. Starting from the 14[th] of November 2008 US dollar-, pounds sterling- and yen-denominated marketable debt instruments issued in the euro area by an issuer within the European Economic Area (EEA) became eligible. (ECB 2008a & ECB monthly bulletin July 2009, p. 83)

The brand new eligible asset classes accounted in 2009 only 3,8% of the collateral put forward to the ECB by counterparties. Another major development was the reduction in ABS put forward as opposed to the sharp increase in 2008. However, the drop reflects mainly the sharper haircuts and decreases in market values compared to 2008. (ECB Annual Report 2009, p. 104)

3.2.4 Purchase of covered bonds

On the 7[th] of May 2009 the Governing Council took the decision to initiate the covered bond purchase program (CBPP), which outlined the outright purchase of euro-denominated covered bonds issued in the euro area worth EUR 60 billion. The purchases took place both in the primary and secondary markets starting from early July 2009 and were completed at end of June 2010. The objective was to contribute to the decline in money market term rates and ease funding conditions of credit institutions for which the covered bond market had been a significant source of funding thus encouraging them to maintain and expand their lending to the public. Improving market liquidity and reducing spreads in this market was also deemed beneficial to the overall market sentiment. (ECB 2009c & ECB 2009d)

3.2.5 Increase in tender spreads and un-alignment of the minimum bid rate and EONIA

As the financial crisis caused trust to disappear from the interbank market, the market participants turned to the central bank for their financing as described earlier in section 3.1. As the ECB was still conducting auctions as before (fixed amount, variable rate) this pressure was reflected in the price of central bank funds. The marginal rate became significantly higher compared to the minimum bid rate (MBR). The reason was that as the amount was fixed banks became desperate to meet their liquidity deficits from the refinancing operations since they could not get funds from the interbank market. Therefore they tried to assure their success by raising their bid rates. As the troubles spread and worsened, the spread between the marginal rate and MBR widened significantly from the few basis points it was before the crisis towards the marginal lending facility rate (see figure 15). A similar pattern can be observed in the weighted average rate.

The sudden halt in the spread after October 2008 can be attributed to the change in operating procedures to fixed-rate full allotment from variable rate tenders, which meant that the ECB would satisfy all bids at the fixed rate prevailing (main policy rate) so no spread could develop.

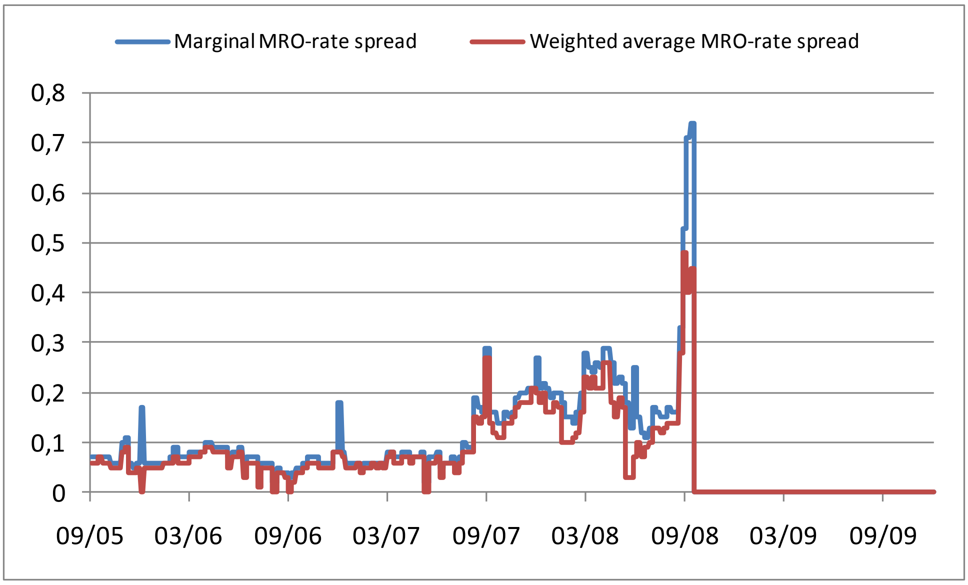


Figure 15. Tender spreads in percentage points in weekly MROs. (Source: Bank of Finland)

3.2.6 Duration of bank funding increased

Funds provided monthly in the long-term refinancing operation (LTRO) were initially EUR 25 billion in the new framework. The LTRO is not used as a policy signal but the ECB adjusted the operation slightly upward increasing the amount allotted to EUR 30 billion in January 2005, to EUR 40 billion in January 2006 and further to EUR 50 billion in February 2007 (Bank of Finland statistics) with the intention of stabilizing the allotments in MROs as the liquidity deficit of the Eurosystem trended higher - a method also proposed by Välimäki (2008, p. 34). See appendix 7.1 for the liquidity deficit. Since the start of the financial crisis the role of these operations changed as the additional operations and their increased volumes were utilized to relieve tensions in the money markets and particularly in the term market. Figure 16 shows how the volume-weighted average maturity of liquidity providing OMOs increased in August 2007 and then finally after the first 12-month operation in June 2009 rose to above 200 days. Trending higher it reached 300 days shortly after the second 12-month operation settled on the 1st of October of the same year.

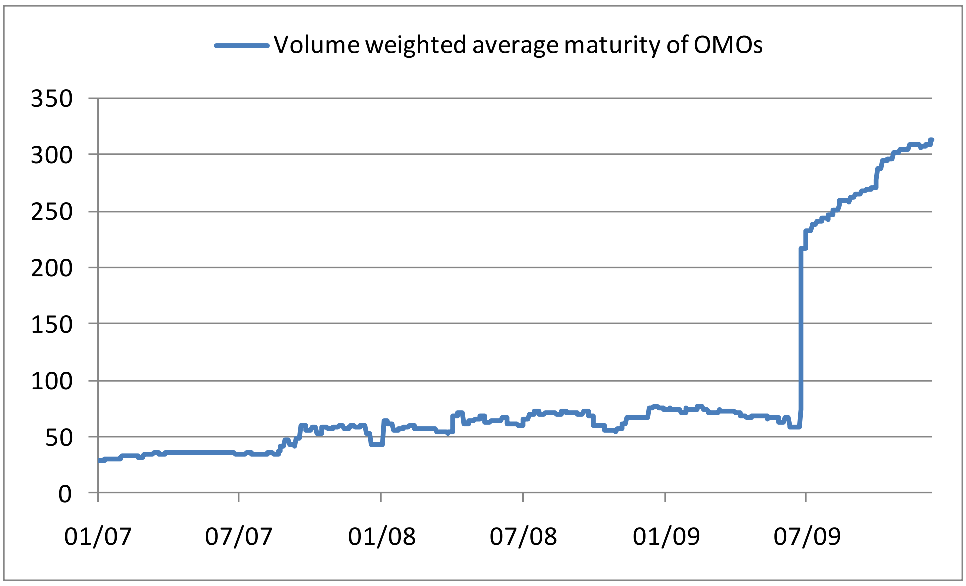


Figure 16. Volume weighted average maturity of outstanding OMOs in days. (Source: Bloomberg, Bank of Finland)

4. PREVIOUS RESEARCH ON OVERNIGHT INTEREST RATES

The research concerning overnight interest rates is plentiful and mainly focuses on the fed funds and EONIA rates. As the monetary policy framework of the Federal Reserve deviates from ECB´s in many respects[14] we must interpret the results of these papers carefully and concentrate more on the works of Würtz (2003), Välimäki (2008), Linzert & Schmidt (2007), Moschitz (2004), Cassola & Morana (2008), Gaspar et al. (2004), Benito et al. (2006), Nautz & Offermanns (2006), Kempa (2007), Cassola (2008) and Ejerskov et al. (2003), which deal directly with the euro money market although only few have developed explicit empirical models to the tune of our attempt for the rate itself or the spread. Clear similarities and most important characterizations of the fed funds rate will be mentioned. Some methodologies and approaches are adapted from fed funds modelling.

4.1 Liquidity effect

As Disyatat (2008, p. 18) notes, the existence of a liquidity effect is quite hard to detect and paradoxically easier to detect when the liquidity management of a central bank is inadequate. In longer timeframes the existence of it is actually even somewhat trivial as temporary effects do not travel along the yield curve. In the current situation the existence of a liquidity effect is however undoubtedly important even from a macroeconomic point of view. Recall that the effective interest rate EONIA is currently (the 25th of August 2010) some 60 bps below the minimum bid rate (MBR). Thus simply by merely absorbing the excess liquidity and not raising interest rates the ECB would accomplish a de facto interest rate hike, which would travel along the yield curve and into the real economy.

A study by Würtz (2003) in the old framework (prior to March 2004) concludes that the spread was affected by expected liquidity conditions but only on the last few days of the MP. Interestingly he found that a EUR 10 billion recourse to the marginal lending facility (deposit facility) increases

[14] The Fereral Reserve has daily market operations, carry-over provisions, no corridor system, shorter maintenance periods (MP) and lower reserve requirements (RR).

(decreases) the spread by about 40 bps.[15] The impact of forecast errors is recognized only indirectly through the daily liquidity conditions as measured by current accounts (CA) minus reserve requirements (RR). Despite this the previous research serves as a good basis for a comparison to the current situation where the recourse to the deposit facility (DF) has been enormous during the whole period. Moschitz (2004, p. 26, 31) estimates that a EUR 1 billion deviation above neutral liquidity (autonomous factors (AF) and net use of standing facilities) deemed to persist till the end of the period (after last MRO) reduces EONIA by 8 bps but only takes place on the last day of the MP confirming the theoretical demand curves in section 2.[16] The banks react rather sluggishly to supply shocks as also lagged values of liquidity conditions were found to be significant. Importantly Moschitz confirms that banks have the ability to react to the liquidity situation already during the trading day and before the announcement of the AFs by observing the flow of payments in their own reserve accounts. Whitesell (2003, p. 10) recognises this effect as well.

Gaspar et al. (2004, p. 30) who have access to bank specific panel data of EONIA trading, point out that the elasticity of the supply (not demand) of funds (i.e. how flexible banks are in providing funds to their counterparties) during the MP decreases significantly after the last MRO but also that market segmentation and heterogeneity contribute to the behaviour of market interest rates. Linzert & Schmidt (2007, p. 3, 5-6) use MROs as data frequency (i.e. weekly data) and conclude that the relationship between liquidity and interest rates only becomes significant during the last MRO of the MP. They divide liquidity shocks into a policy variable (allotment versus benchmark) and a shock factor where cumulative average AF-forecast errors are used. According to their results, an allotment above benchmark to the

[15] However, the main liquidity measure employed by Würtz (2003) has been subject to some critique as the ex post accumulated net recourse to SF is a figure not known to banks when they take their decisions.

[16] Note, that the curves require allotment equal to BM in the last MRO and banks trusting the AF forecast until the last day of the MP or an end of period FTO to neutralize the effect of those shocks.

extent of EUR 1 billion in the last MRO decreases the spread by 4 bps in the new framework after March 2004. As the authors compare the two frameworks they interestingly find out a stronger liquidity effect in general in the new framework, which is explained by banks having more flexibility in the old framework when MROs overlapped. Additionally the ECB is more transparent in its liquidity management nowadays. High cumulative average reserve fulfilment ratio seemed to relieve some of the pressure of fulfilling the RR towards the end of the MP thus exhibiting a negative coefficient of -0,144 in the new and -0,252 in the old. Both of them were statistically significant. This relates conveniently to the frontloading effect during the financial crisis. (Linzert & Schmidt 2007, p. 10-11)

Ejerskov et al. (2003, p. 29-31) find a liquidity effect on a weekly frequency (MRO frequency) but the coefficient on MROs before the last one is merely -0,02 translating to a 2 bps decrease in the spread if the allotment is EUR 1 billion above benchmark or the average AF-shock during the week amounts to that. However, on the last week of the MP this coefficient increases to -0,37. A large coefficient compared to other results is explained largely by their data frequency of MRO. They do not find any statistical difference with respect to the source of the shocks, that is, it does not matter whether the imbalance is caused by liquidity policy decisions or forecast errors. Rather counterintuitively, they find an asymmetric effect of liquidity shocks in the sense that loose conditions move the EONIA more than a squeeze in liquidity. The asymmetric reaction to liquidity shocks cannot be confirmed by Moschitz (2004, p. 30).

Allotment above benchmark in the front loading period is found to have a downward but also stabilizing effect on the spread (Cassola & Morana, 2008, p. 26). Välimäki (2008, p. 6, 29) points out that the systematic fine-tuning operations (FTO) on the last day of the MP have decreased the elasticity of demand for liquidity even in the last MRO. Related to this he estimates the average spread under benchmark liquidity to be 4 bps on the last day to which an increase (decrease) of EUR 1 billion decreased (increased) the spread by 6 bps.

The use of “wrong facility” can be associated with some structural demand for the DF as the use of it has been higher when the aggregate use of standing facilities (SF) was in MLF´s side, and vice versa, when the aggregate use was on the side of DF, the recourse to MLF was EUR 285 million smaller. This structural demand can lead to tight liquidity conditions despite neutral aggregate liquidity conditions as funds deposited in the DF do not count as reserve fulfilling. Reasons for this demand are largely the same as for excess reserves (see section 2.2.3). (Välimäki, 2008, p. 24)

Benito et al. (2006, p. 16) found that EONIA exhibits mean reversion properties and that the reversion from below is faster in their ARCH-Poisson-Gaussian jump process model, which does not include liquidity variables but takes into account the end of MP effect. Cassola & Morana (2008, p. 9) find mean reversion as well but also some persistency in the spread due to the long MP, rare OMOs and high RR. Nautz & Scheithauer (2008, p. 9) reach similar conclusions and speculate that well-functioning SFs of the ECB decrease persistency. Ayuso and Repullo (2003) show how an asymmetric loss function of the central bank will lead to an asymmetric reversion towards the policy rate.

Somewhat counterintuitively there is also theoretically a possibility that the liquidity effect is reversed. Tight (loose) liquidity conditions could cause EONIA to decrease (increase) under assumptions of heterogenic behaviour by banks and asymmetric information between them as sophisticated (active money market traders with superior resources devoted to liquidity management) banks take advantage of their strategic positions and time their fulfilment of RR more optimally whereas unsophisticated banks will trade away their liquidity imbalances on a daily basis. This division in behaviour will result in less correlation in day-to-day movements thus decreasing the spread but increasing its volatility. The authors move on to use this argument to make a case for not releasing aggregate liquidity information after the last MRO. (Ewerhart et al., 2004, p. 8, 10 and 15)

Some important results from the fed funds market research include the seminal work of Hamilton (1996), who found a liquidity effect only on the last day of the MP, which was later proven by Thornton (2001) to be related to only few significant outliers. Thornton (2008, p. 6) also questioned the liquidity shock variable as Hamilton used his own model to estimate the forecast misses on the Treasury´s account balance. The model may not be the same as the one the Federal Reserve uses. Thornton argues that even though he manages to find a statistically significant liquidity effect (with data prior to 1994) it does not mean the effect is "policy-relevant" anymore as lagged reserve accounting (a 2 MP lag introduced in July 1998) separates the demand for reserves and the demand for money (Thornton, 2008, p. 17). He found a liquidity effect on the last few days of the MP, which was linear and of equal size to both directions. After 1998 the liquidity effect was greatly reduced. (Thornton, 2008, p. 23-24, 27). Carpenter & Demiralp (2004, p. 4) use actual forecast errors of the Federal Reserve´s liquidity management and data from May 1989 to January 2004 to research the daily liquidity effect and find out that there exists a liquidity effect on some other days too if the forecast error is large. A higher aggregate amount of reserves is associated with lower liquidity effects during the period but with larger effects on the last few days of the period. A rough estimate of the magnitude is 3,5 bps per USD 1 billion on the last day and 1 bps per USD 1 billion on other days. Due to carry-over provisions in the Federal Reserve´s framework the liquidity effect on the last days of the MP is likely to be more muted than with the ECB (Carpenter & Demiralp, 2004, p. 17)

4.2 Calendar effects

There have also been calendar effects present since EONIA has spiked higher at end of months and more pronouncedly at end of semesters due to window dressing activities by banks which forces the demand for reserves to go up (Würtz, 2003, p. 28, Moschitz 2004, p. 7). But unlike Prati et al. (2002)

and Gaspar et al. (2001) Würtz did not find evidence of this effect spilling over to the previous and subsequent days as did not Moschitz either. Moschitz (2004, p. 33) determines the end of month effect to be +5 bps, second quarter +18 bps and end of year +31 bps. No weekday effects were found. Benito et al. (2006, p. 47) found on top of end of month effects also a slight effect during the meeting days of the Governing Council. Their data is however from the framework prior to March 2004 leading to suggest that this effect like the interest rate expectation effect is no longer visible. In the fed funds market where required reserves are significantly smaller, some of the calendar effects can also be explained by larger demand for reserves on these days due to increased payment flows requiring larger clearing balances to accommodate the transactions between banks themselves and their clients (Carpenter & Demiralp, 2004, p. 9).

4.3 Counterparty risk effect

After August 2007 banks paid higher premiums in MROs because adverse selection in the interbank market forced them to rely more on reserves acquired straight from the ECB thereby pushing the marginal rate higher. These credit risks increased volatility of overnight rates putting upward pressure on them. However, active liquidity policy (frontloading and supplementary long-term refinancing operations) was effective in countering this rise. (Cassola & Morana, 2008, p. 6, 9)

Related to counterparty risk to some extent, Linzert & Schmidt (2007, p. 7-8) use bid-to-cover ratio in MROs and liquidity uncertainty (conditional volatility of current account holdings) to capture the effect of banks leaving so-called safety bids at high rates to ensure at least a partial success in the tender. Banks bid more aggressively, when faced with liquidity uncertainty. This effect might be self-sustaining and increase the EONIA spread. High bid-to-cover and high liquidity uncertainty were found to be statistically significant and to increase the level of the spread more dominantly in the new framework after March 2004 (insignificant in the old). The coefficients for the two aforementioned variables were 0,037 and 0,101 respectively. (Linzert & Schmidt 2007, p. 10).

4.4 Bidding behaviour

Abassi & Nautz (2008, p. 7) investigate the effects of the outcome of MROs to the money market including EONIA and find that the emerging marginal rate is significant and contributes to the EONIA with a plus sign as one would expect. The marginal rate was the main contributor with a coefficient of 0,46 with EONIA from the auction day to the next being the dependent variable. The additional information entailed in the spread between weighted average and the marginal rate was only significant at the 10% level. They also had cover-to-bid ratio (inverse of our bid-to-cover ratio) in their model, which counterintuitively caused upward pressure in the spread. We would take the last result with a pinch of salt as their data set covered MROs between June 2000 and August 2006 entailing therefore several episodes of underbidding.[17]

In the follow-up paper of 2010 the authors conclude that the stabilizing effect of money market auction results vanished and safety bids even exacerbated the disconnection of money market rates from the policy-intended interest rate level. A vicious cycle of high marginal rates leading to a higher EONIA rate was apparent. As established before, this was indeed one of the reasons why the ECB chose to adapt the fixed-rate full allotment policy. They use the Quandt-Andrews structural breakpoint test to show the different response of money markets to tender outcomes after August 9. 2007. The most noticeable difference between the papers is in that the cover-to-bid ratio has different signs before and after March 2004 when the new framework was established. The coefficient sign turns negative as one would suspect after omitting the effects of underbidding episodes. (Abbassi & Nautz, 2010, p. 10, 20)

[17] Underbidding episodes were indeed omitted in their follow up paper of 2010.

4.5 Interest rate expectations effect

As evidenced by Würtz (2003) the expectations of rate hikes or cuts (the difference between the forward rate implied by the 1- and 2-month EONIA swap rates and the mid of the corridor) also affected the spread in the old framework where changes to interest rates did frequently take place during the MP. Especially under rate hike expectations the policy spread widened to +11 bps and in contrast under rate cut expectations the spread narrowed to -6 bps. This was explained by banks underbidding in MROs in a possible rate cut situation as they were hoping to acquire funds more cheaply from the ECB later. This underbidding offset some of the expectation effect as it had liquidity tightening implications which tend to raise EONIA explaining the milder response. (Würtz, 2003, p. 32) With the same expectation variable Linzert & Schmidt (2007, p. 3) find no statistical significance for the variable in the new framework whereas in the old expectations did play an important role. Moschitz (2004, p. 30) uses the next week's forward rate implied by the 1- and 2-week EONIA swap rates and found that the coefficient between the expectation and prevailing EONIA was 0,6. He notes that the rate expectations should diminish in importance as we move closer to the end of the MP as the rate in the next period should not affect the current one. However, the use of such a short measure of interest rate expectations is in our view prone to calendar effects or possible weekday effects having a strong distorting impact causing outliers.

Nautz & Offermanns (2006, p. 16-18) investigate whether the main policy rate is the only co-integrating variable to the EONIA and find out that the term spread (3-month EURIBOR versus EONIA) was statistically insignificant but the reaction of EONIA to deviations from the policy rate was -0,261 implying that roughly one quarter (26%) of the deviation is eliminated in one day. When they account for different dynamics after the last MRO they find that the integration to the policy spread weakens (from -0,37 to -0,16) but loses some of its statistical significance. The term spread actually becomes negative during the life of the last MRO reflecting that interest rate hike expectations actually decrease the policy spread. This counterintuitive result is reconciled with the over- and underbidding episodes in the old framework. Underbidding lowered the amount of reserves in the market under rate cut expectations thus actually raising EONIA whereas overbidding occurred during periods of rate hike expectations tempting the ECB to allot too many reserves for the market leading to a drop in EONIA through the liquidity effect. Both of these episodes contributed to the negative sign (Nautz & Offermanns, 2006, p. 17).

4.6 Conditional volatility

Conditional volatility is an important part of modelling overnight interest rates in a period averaging system as there is plenty of evidence, that the EONIA spread exhibits different volatility patterns during the period. Gaspar et al. (2004, p. 39) note that the volatility increases significantly and almost linearly during the last week from around 10 bps close to 50 bps. They attribute this change to the increasing importance of liquidity shocks at the end of the MP. The use of standing facilities and trading volume of EONIA go up for the same reason. Moschitz (2004, p. 32) found also a significant increase in volatility during the last MRO and also on end of months. His EGARCH specification allows him to estimate, that positive shocks to the spread increase the volatility by 9% compared to negative shocks, with the interpretation of banks being more worried about ending the MP with too few reserves. Carpenter & Demiralp (2004, p. 20) find a similar result for the fed funds market. One reason for frequent FTOs on the last day of the MP was to lower this volatility (ECB Monthly Bulletin February 2008, p. 8).

Benito et al. (2006, p. 10) model conditional volatility with a GARCH family specification suited for jump processes, whereas many other regression models incorporate EGARCH specifications. Also in the fed funds research EGARCH seems to be the favoured choice (Hamilton 1996, Carpenter & Demiralp, 2004, Thornton, 2008). Thornton (2008, p. 22) uses Students t-distribution to take into account the fat tails in the fed funds rate´s distribution. Other papers incorporating EGARCH in various markets include Quiros & Mendizabal (2005), Gaspar et al. (2004), Bartolini & Prati (2006) and

Moschitz (2004). One favoured approach seems to be to fit a mixture of two normal distributions. Both Würtz (2003) and Moschitz (2004) use this.

4.7 Natural spread

Previous studies point out to a natural spread between EONIA and the minimum bid rate (MBR). Ejerskov et al. (2003, p. 33) estimate it to be 6 bps whereas Würtz´s (2003) highly parameterized model finds a constant of 2,5 bps. (Cassola & Morana (2008, p. 26) identify the marginal bid rate - MBR to be the only long memory factor affecting money market spreads as it captures the effects of bidding behaviour and tender outcomes. Nautz & Scheithauer (2008, p. 15) find a significant increase in long memory of the spread after the new framework was introduced in March 2004 as the overlapping MROs were discontinued and refinancing volumes doubled. Prior to that the spread averaged 7 bps and can be attributed to the different maturities and collateral rules as discussed earlier (Nautz & Offermanns, 2006, p. 11) and also to interest rate expectations exerting upward pressure to the spread irrespective of rate hike or cut expectations (Välimäki, 2008, p. 8). Linzert & Schmidt (2007, p. 12, 14) measure these opportunity costs with the difference between 1-week EONIA swap rate and the MBR, contemplating that banks will accept higher prices at MROs when market rates are higher. As they use many interest rate based variables, the interpretation of their results is difficult because the variables are necessarily interlinked. To counter the increasing trend of the spread they propose reducing the liquidity deficit[18], increasing allotments in the last MRO and increasing transparency. Välimäki (2008, p. 33-34) adds to the list using purely fixed rate draining FTOs[19] on the last day at the policy rate to deter overbidding in prices or volumes and full allotment at policy rate, which would anchor the expectation of the marginal rate firmly and abolish uncertainty over the allotment.

[18] The ECB could increase outright holdings of assets or reduce reserve requirements.

[19] Despite slight allotments above benchmark 1/3 of FTOs were still liquidity providing.

Välimäki (2006, p. 6, 10), responding to the ex ante unexpected increase in the tender spread (a key driving factor of the policy spread) in the new framework, derived theoretically how expected bid volumes and the probability of bidding at rates above the marginal rate increases as a function of the individual targeted refinancing volume in the MRO. Bidding at rates above the marginal rate would stem from market frictions or from uncertainty over the outcome of the tender, i.e. how much is the individual bank going to get with risk aversion leading to higher bids. Another source of liquidity uncertainty is the maturity of the last MRO and the expectation of an FTO on the last day. However, he reminds that the stability of the policy spread did increase after the changes, which is more important than the level as it can always be taken into account when taking decisions about appropriate interest rates. (Välimäki, 2008, p. 8) Despite this, one needs to remember the co-integration of the tender spread and the policy spread. With the possibility of an increasing trend in the tender spread due to its adaptive and self-sustaining features the central bank should use active liquidity policy to stop the expectation of increasing spreads affecting longer maturities with economic relevance (Välimäki, 2008, p. 29). Linzert & Schmidt (2007, p. 8) try to capture the increasing need for refinancing effect by using the natural logarithm of the outstanding OMOs [20] as a proxy.

Using the Eurosystem´s framework, Välimäki (2003) established that an increasing trend in EONIA towards the end of the MP is possible if we consider banks facing a lock-in state, where they have fulfilled their RR but are required to keep a positive operating balance to clear payments encouraging them to pay extra in tenders.

4.8 Martingale hypothesis

When bank reserves are fully substitutable within an MP the EONIA should equal on any given day, according to the martingale theory, the interest rate expected to prevail on the last day of the MP, as otherwise banks could

[20] Amount of OMOs is basically the same as the liquidity deficit (see appendix 7.1).

exploit inter-temporal arbitrage by buying (selling) more reserves from the interbank market when the rate would be lower (higher). Välimäki (2003) formalized the original theory by Poole (1968) for the institutional specifics of the ECBs monetary policy framework.

Moreover, the expected overnight rate for the last day of the MP should be equal to the probability-weighted average of the rates of the two standing facilities (SF). The probability of having to use either SF (DF or MLF) must however remain low. If policy rates are not changed during the MP, the spread of the overnight interest rate against the minimum bid rate (MBR) can be expressed as follows:

$$EONIA_t - mbr = E_t(EONIA_T) - mbr = \left[l * P_t(ML_T)\right] + \left[d * P_t(DF_T)\right] - mbr \,, \quad [3]$$

where l is the MLF rate, d is the DF rate, $P_t(ML_T)$ denotes the probability of marginal lending and $P_t(DF_T)$ recourse to the deposit facility on the last day of the maintenance period T conditional on information available at time t. If the MP ends with a liquidity shortage, banks must borrow overnight from the MLF of the ECB at a penalty rate l. If the MP ends with a liquidity surplus, banks will transfer the surplus overnight to the DF of the ECB at a penalty rate d. When the interest rate corridor is symmetric like it has always been with the ECB and it targets zero recourse to SFs (allotment = benchmark) assuming unbiased forecasts of AFs the probabilities $P_t(ML_T)$ and $P_t(DF_T)$ should be equal and amount to 1. This should hold EONIA firmly at the MBR with perfect markets at least until the allotment of the last MRO after which the probabilities of recourse to the SFs are likely to change due to liquidity shocks that cannot be countered without additional fine-tuning operations (FTO). The announcement of the interest rate corridor and well-communicated neutral liquidity policy should alone be enough to keep EONIA equal to the MBR.

It can be shown, that with a symmetric corridor and unbiased liquidity forecasts the banks should also fulfil their respective reserve requirement (RR) linearly during the period (Cassola, 2008, p. 11-12). Cassola (2008, p. 5, 21) could not reject linear fulfilment path with data from March 2004 to February 2007. The reversion back to linear fulfilment seemed to be very high with 70% of the deviation corrected in one day and proves that the martingale hypothesis hinges on whether the probability of overdrafts and fulfilling the RR too early are low. His theory (confirmed by panel data) suggests only a 1% probability of a daily overdraft. However, a small natural spread exists in practice. (Cassola & Morana 2008, p. 10-11). Kempa (2007, p. 16) disagrees with linear fulfilment when considering individual bank fulfilment paths by showing a maximum deviation of roughly EUR 1,4 billion from neutral liquidity position peaking in the middle of the period and large banks being the main contributors. He also considers several factors questioning the risk neutrality assumption of the martingale hypothesis. He explores the implications of banks avoiding volatility in their costs and market frictions, such as avoiding large trades signalling distressed positions (Kempa, 2007, p. 22). Banks are likely to exhibit smaller propensity to maintain extra reserves when the available collateral pool is large. Another argument confirmed with the simulation of his theoretical model, is the indifference of allotments versus benchmarks or accumulated imbalances due to liquidity shocks as long as the central bank is committed to rectifying these imbalances with an FTO at end of the MP or adhering to the benchmark allocation in the last MRO[21]. (Kempa, 2007, p. 32, 35)

Several papers have tested the martingale hypothesis. The seminal paper of Hamilton (1996), who was the first to study empirically the liquidity effect in the fed funds market, found that the rate exhibited “near-martingale” behaviour as market frictions[22] prevented a perfect random walk.

[21] Assuming a perfect forecast of AFs and excess reserves and no structural demand for SFs.

[22] Resulting mainly from transaction costs and weekend accounting conventions.

Ejerskov et al. (2003, p. 32) confirm the martingale hypothesis in the euro money market as they show that only liquidity imbalances on the last week of the MP result in significant liquidity effects. This confirmed that market participants were indeed reassured of the ECBs commitment to counter any liquidity imbalances accumulated previously in the next MRO allotment. Gaspar et al. (2007) come to the same conclusion with data after the changes to the operational framework in March 2004. Würtz (2003) and Moschitz (2004) provide evidence backing the martingale hypothesis to some extent in the old framework. However, the well-documented existence of calendar effects can be regarded as violating the martingale hypothesis thus confirming Hamilton´s original idea of near-martingale like behaviour.

5. METHODOLOGY

The method to capturing the various determinants of the spread is a comprehensive regression analysis from an empirical perspective, with variables related to liquidity conditions, interest rate expectations, bidding behaviour, calendar effects, refinancing pressure, mean reversion and various dummy variables to capture extraordinary distortions in the overnight market. To correct for autocorrelation we employ autoregressive processes as required. Due to the periodic volatility behaviour of the spread an EGARCH-specification will accommodate the heteroskedasticity properties.

To capture the differences in the determination of EONIA under different market conditions the data is segregated into three different regimes. The first one corresponds to normal market conditions from the 12th of October 2005 to the 6th of August 2007. The second regime deals with the financial crisis from the 8th of August 2007 to the 30th of September 2008. Last regime is related to the full allotment procedures during the period from the 15th of October 2008 to the 4th of December 2009.

5.1 Liquidity related variables

A lot of attention was directed to modelling the liquidity conditions as they were critical determinants of the EONIA during the crisis and intentionally targeted by many of the ECB´s unconventional measures. The liquidity situation was modelled through three variables. Firstly we aim to capture the effects of liquidity policy, that is, supply side deviations from neutral liquidity. This liquidity policy variable is calculated as the cumulative average accumulating from the settlement day of the outstanding MRO up until its maturity of the allotment above benchmark (BM) plus (minus) similarly cumulating average of liquidity providing (absorbing) FTOs, which take place prior to the last day of the MP. Formula is as follows:

$$pol_{st} = \sum_{i=i}^{t} \frac{(bm_i + fto_i)}{t}, \qquad [4]$$

where bm_i is the deviation from BM allotment and fto_i the conducted FTO. The symbol s indexes the MROs (i.e. first MRO of an MP is –4, then -3 etc.) and t refers to the day within an MRO typically running from 1 to 7. If a MP had more than 5 MROs, then the first ones were categorized as –4 as well instead of a new variable with an index of –5. Similarly MPs with for example 4 MROs start the indexing from –3.

Equivalently we model the demand side deviations from neutral liquidity with a variable involving again the cumulative average accumulating from the settlement day of the outstanding MRO up until its maturity. However, this time the components are the deviation of the realized autonomous factors (AF) from forecasted so that a positive figure indicates loose conditions as the realized AF would be smaller than forecasted therefore decreasing their liquidity absorbing capacity. The second component is the accumulated net recourse to standing facilities (SF) calculated as marginal lending facility (MLF) minus deposit facility (DF).[23] Note how both of our liquidity variables assume implicitly the continuation of liquidity conditions as such till the settlement of the next MRO. This is a reasonable assumption as banks cannot know, whether the deviation in AFs on one day was forecasted or not as the ECB only publishes the average amount for the life of the operation. The results will later reveal whether or not banks react to the forecasting errors (and net SF) immediately or only towards the end of the last MRO of the MP. Shock variable is defined as:

$$shock_{st} = \sum_{i=1}^{t} \frac{(af_i + nsf_i)}{t} \qquad [5]$$

Here af_i is the autonomous factor forecast error and nsf_i the net recourse to standing facilities. For any given day (except for the last day of an MP) we have therefore two liquidity variables, which are distributed with dummy

[23] Remember, that reserves deposited at the central bank cannot be used to fulfil the RR and so the DF acts as an absorbing facility.

variables into categories related to corresponding MROs. The last MRO of the period is further split into separate days to study more meticulously the behaviour during the last days where supposedly the relationship between EONIA and liquidity is more elastic.

For the last day the most precise measure of the liquidity situation is simply the net recourse to SF. Deposit facility minus marginal lending facility in this case as a positive figure is related to loose liquidity conditions.[24] The possible miss in forecasting excess reserves is behind the reasoning to use the net recourse to SF on the last day instead of supply and demand side variables. The bulk of excess reserves are accumulated on the last few days of the period. All liquidity related variables are thus constructed to deliver an expected negative sign in the results because of the inverse relationship between liquidity and interest rates.

5.2 Interest rate expectations

Interest rate expectations are proxied with the average 1-month EONIA rate in one month´s time calculated from the 1- and 2-month EONIA swap quotes as:

$$fw_t = 2r_t^{2m} - r_t^{1m} - mbr \qquad [6]$$

Here r_t^{2m} is the rate for the 2-month and r_t^{1m} similarly for the 1-month EONIA swap. The minimum bid rate mbr is used to scale the level of the expectation as the forward implied rate is compared now to the middle of the corridor at all times. The variable is then segregated in a similar fashion as the liquidity variables above into corresponding MROs with dummies with the exception that this time the last MRO is not further separated.

[24] Compare to the calculation of the demand side liquidity variable, where sign is the opposite.

5.3 Bidding behaviour and refinancing pressure variables

Marginal spread and bid-to-cover serve many purposes in our model. One is to proxy for the tensions and frictions in the money market and another to measure the uncertainty over the outcome of the operation and bidding behaviour of banks. The variable is constructed as follows:

$$Btcmarg_t = btc_t \, marg_t \, , \qquad [7]$$

where btc_t refers to the bid-to-cover ratio of the outstanding MRO and $marg_t$ to the marginal spread of the operation. The main reason to combine the two is to reduce multicollinearity properties[25]. As discussed in the previous research section the marginal rate is an important long memory factor of the policy spread. The combination is also justified against the backdrop, that in various occasions the bid-to-cover might take into account some patterns in the bidding behaviour not present in the marginal rate, which was fairly stable before the crisis began in 2007.

Outstanding daily LTRO amount (the sum of all, including SLTROs) reflects the refinancing pressures of banks as they have to roll over the amounts in weekly MROs in the new framework, when overlapping was discontinued. The 3-month Libor-OIS is another market tension based parameter to capture the tensions and is measured daily in percentage points.

The combined bidding behaviour variable changes value on the settlement day of an MRO, and stays constant till the next operation. Its rise is expected to impose upward pressure on the spread, whereas increased LTRO amounts reduce the refinancing need in MROs and are expected to push down the spread. Libor-OIS spread is obviously expected to increase the spread.

[25] Correlation in regime 1 is 0,47 and in regime 2 0,36.

5.4 Dummy variables

To capture the well established calendar effects we employ dummy variables for the last day of each month Dm except for months coinciding with the end of a quarter. A dedicated dummy Dq for quarter ends is imposed. Days before holidays of the TARGET2-system are dummied as $Dtarget$ as during these days banks might face increased uncertainty over payment flows.

During the financial crisis exceptional situations and ad-hoc liquidity policy would exert unwanted anomalies into our model if not dummied out. Dummies related to bank failures are added on top of the standard model, whereas dummies for entire MROs displace the liquidity and interest rate expectation variables to ensure their "purity". The entire period between the 1st of October 2008 and the 14th of October 2008 is excluded due to severe distortions in the overnight market. The period in question also houses the only mid-period change to interest rates as the ECB co-ordinated with other major central banks in a joint effort to lower interest rates by half a percentage point (ECB 2008c). Table 6 lists the dummy variables with appropriate explanations.

Variable	Period
Outlier1 [1]	21st of November 2005
Outlier2 [1]	2nd of December 2005
Outlier3 [1]	13th of January 2006
BNP [2]	9th - 10th of August 2007
Crisislast [3]	29th of August - 5th of September 2007
SLTRO3m [4]	13th - 18th of September 2007
Lehman [5]	15th of September 2008
MRObef [6]	2nd - 8th of April 2008 and 9th - 15th of July 2008

Explanations

[1] Extreme outlier

[2] Tensions related to BNP Paribas
halting redemptions on three investment funds

[3] The ECB provides funds too scarcily in the second to last
MRO of the first maintenance period of the financial crisis

[4] The second supplementary longer-term refinancing operation conducted ad-hoc and not taken into account in the benchmark allocation of the outstanding MRO

[5] Tensions related to the bankruptcy of Lehman Brothers

[6] MROs during the life of which a 6-month SLTRO was conduncted

Table 6. List of dummy variables.

5.5 Mean reversion

We calculate the deviation $devmean_t$ of the EONIA spread of the previous trading day i_{t-1} from the regime average mean i_{avg} as such:

$$devmean_t = i_{t-1} - i_{avg} \qquad [8]$$

Thus if the coefficient is above zero and below one the spread is persistent as the deviation from mean the day before still has a positive effect on the spread today. The closer to one it is the stronger the persistency (a numerical value above one would suggest an explosive process). A negative value would result in true mean reversion as opposed to gradual phasing-out type of effect. We use the ex post realized average as a reference point and set the variable to zero for the first day of each MP to avoid the spill over from the previous MP´s last day when EONIA often deviated from the average.

5.6 Autoregressive-structure

After an initial OLS-estimation autocorrelation in the residuals was evident according to the Breusch-Godfrey serial correlation Lagrange multiplier test (null hypothesis H0 = no serial correlation). Let us begin with the functional form of our regression. Both of our initial models pass the Ramsey RESET test for functional form, i.e. no non-linear terms are necessary in the first two cases since the null hypothesis cannot be rejected (see probability values in table 7).

Ramsey RESET Test with one fitted term:			
Regime 1			
F-statistic	0,7229	Prob. F(1,415)	0,3957
Log likelihood ratio	0,771	Prob. Chi-Square(1)	0,3799
Regime 2			
F-statistic	2,2806	Prob. F(1,251)	0,1323
Log likelihood ratio	2,5417	Prob. Chi-Square(1)	0,1109

Table 7. The Ramsey RESET test for correct functional form.

Generally speaking an augmented regression for the RESET test is developed with matrix Z resulting in:

$$y = XB + Z\gamma + \varepsilon \qquad [9]$$

The restriction $\gamma = 0$ is evaluated. The tricky part is to figure out what variables the matrix Z should contain. Note, that one can easily construct the omitted variables test from this by including the tested variables in matrix Z.[26] For a functional form test Ramsey (1969) suggested that powers of the predicted or fitted values of y labelled here as $\hat{y}$ should be added to the estimated regression. In the case of two fitted terms this would yield the regression:

$$y = XB + x_1\hat{y}^2 + x_2\hat{y}^3 \qquad [10]$$

[26] Omitted variables test is used later to determine whether interest rate expectations could be omitted from the estimation.

$\hat{y}^1$ is obviously not included as it would be perfectly collinear with the X-matrix. If both x_1 and x_2 are jointly zero the original regression can be deemed to be correctly specified. Under the null hypothesis H0 the restriction $\gamma = 0$ holds. (Ramsey, 1969, p. 13-14) In case of linear functions this can be tested with a simple F-test:

$$F - test = \frac{RRSS - URSS}{URSS} x \frac{T-k}{m}, \qquad [11]$$

where $RRSS$ is the sum of squared residuals from the restricted regression and $URSS$ correspondingly the sum of squared residuals from the unrestricted regression. The test statistic is then distributed according to the F-distribution with m (number of restrictions) and $T-k$ (number of observations minus number of regressors in the unrestricted version) degrees of freedom. The F-test applies here for the omitted variable test and the Ramsey RESET test as the examined regressions are linear.[27] (Brooks, 2002, p. 102-104)

The difference between the F- and Chi-square (X^2) distributions is subtle and they are equal for infinite sample sizes since the following relationship applies:

$$\frac{X^2(m)}{m} \rightarrow F(m, T-k), \text{ as } T \rightarrow \infty \qquad [12]$$

The F-statistic is often preferred as it is sensitive to the sample size. (Brooks, 2002, p. 146) We now move on to the Breusch-Godfrey test.

[27] If they were not linear, a likelihood ratio test should be calculated instead. See p. 97 for such a case in the Wald-test.

Breusch-Godfrey Serial Correlation LM Test (2 lags):			
Regime 1			
F-statistic	26,66	Prob, F (2,414)	0.000
Obs*R²	50,55	Prob, Chi-Square (2)	0.000
Regime 2			
F-statistic	10,19	Prob, F (2,250)	0.000
Obs*R²	21,19	Prob, Chi-Square (2)	0.000

Table 8. Serial correlation of residuals after an initial OLS-estimation.

The Breusch-Godfrey test is a more general test for autocorrelation[28] than the standard Durbin-Watson. It can be constructed up to the order r. The initial regression to be carried out for the error terms u is:

$$u_t = p_1 u_{t-1} + p_2 u_{t-2} + ... + p_r u_{t-r} + v_t \qquad [13]$$

$$v_t \sim N(0, \sigma_v^2)$$

The residuals $\hat{u}_t$ obtained are then regressed on the initial OLS plus $\hat{u}_{t-1}$, $\hat{u}_{t-2}$ and so on. Get coefficient of determination R^2 and the test statistic is then given by:

$$(T-r)R^2 \sim X_r^2, \qquad [14]$$

where T is the number of observations, r the number of lags and X_r^2 shows that the statistic follows the Chi-square distribution with r degrees of freedom. The null hypothesis is H0: $p_1 = 0$, $p_2 = 0$ etc. (Brooks, 2002, p. 165)

To remove autocorrelation a single autoregressive process of the first order in the residuals was deemed adequate. This procedure known as the Cochrane-Orcutt method is widely used and is in fact an application of Generalized Least Squares (GLS). As can be seen from the correlograms in

[28] In this case the correlation between the initial value and lag k. Partial autocorrelation is then the residual autocorrelation remaining at lag k and not accounted for by the lags up to the order $k-1$.

figures 17 and 18, the AR(1)-process is able to accommodate very satisfactorily both autocorrelation and partial autocorrelation in both regimes.[29] Our mean equation specification is thus:

$$y = c + \beta X + u \text{ ,} \tag{15}$$

where $y = i - i^*$ (i being the EONIA rate and i^* the MBR) and is a vector of dimension $Tx1$. β is a $kx1$ vector of coefficients and X a Txk vector of independent variable values. The term c corresponds to the constant and is therefore a $Tx1$ vector. The term u is the error term with a $Tx1$ dimensions and follows an AR(p)-process:

$$u_t = \sum_{i=1}^{p} \phi u_{t-i} + \varepsilon_t \tag{16}$$

(Brooks, 2002, p. 239)

The remaining error term is distributed as:

$$\varepsilon_t \sim N(0, \sigma^2) \text{ ,} \tag{17}$$

where σ^2 is the unconditional variance of ε_t at this point (modelled further in section 5.7). Here it is still constant over time and therefore has no time subscript attached.

We are telling the statistical program EViews to estimate our model in a GLS-form by transforming the estimated equation. A simple illustration of the Cochrane-Orcutt procedure with one independent variable now follows. Take the one period lagged regression model:

$$y_{t-1} = c + \beta_1 x_{1t-1} + u_{t-1} \tag{18}$$

[29] The fact, that partial autocorrelation drops practically to zero after one lag is indicative of the sufficiency of one autoregressive term.

and multiply with ϕ to yield:

$$\phi y_{t-1} = \phi c + \phi\beta_1 x_{1t-1} + \phi u_{t-1} \qquad [19]$$

Subtracting [19] from [15] will give:

$$y_t - \phi y_{t-1} = c - \phi c + \beta_1 x_{1t} - \phi\beta_1 x_{1t-1} + u_t - \phi u_{t-1} \qquad [20]$$

Factorizing and plugging in $\varepsilon_t = u_t - \phi u_{t-1}$ gives us:

$$y_t - \phi y_{t-1} = (1-\phi)c + \beta_1(x_{1t} - \phi x_{1t-1}) + \varepsilon_t \qquad [21]$$

Substituting $y_t^* = y_t - \phi y_{t-1}$, $c^* = c - \phi c$ and $x_{1t}^* = x_{1t} - \phi x_{1t-1}$ will give us an equation with an error term ε_t being free from autocorrelation:

$$y_t^* = c^* + \beta_1 x_{1t}^* + \varepsilon_t \qquad [22]$$

Notice how we can still estimate the value of the coefficients straight from this equation but need to take into consideration that the estimated constant is c^* and $c^* \neq c$. For the estimation we need to know the value of ϕ. Cochrane and Orcutt (1949) suggest the value should be estimated from an auxiliary regression:

$$u_t = \phi u_{t-1} + \varepsilon_t\,, \qquad [23]$$

where u_t is the residual obtained from the regression with autocorrelation, and ϕ can now be used to perform the transformation of [18] into a GLS estimation problem. EViews then applies a Marquardt nonlinear least squares algorithm producing estimates, which are asymptotically equivalent to maximum likelihood estimates and asymptotically efficient (EViews 6 User Guide, 2007, p. 71-73).

For stationarity of the autoregressive process we require that the root of it must lie outside the unit circle (inverted root must lie within) so as to have a declining effect on the current value of u_t as time progresses. The characteristic equation for an AR(p) model is:

$$1-\phi_1 z-\phi_2 z^2-...-\phi_p z^p=0, \qquad [24]$$

which obviously collapses to:

$$1-\phi z=0 \qquad [25]$$

in an AR(1)-model such as ours. Here ϕ is the inverted root and z the root. (Brooks, 2002, p. 167-168, 240). See figures 17 and 18 for the autocorrelation and partial autocorrelation functions.

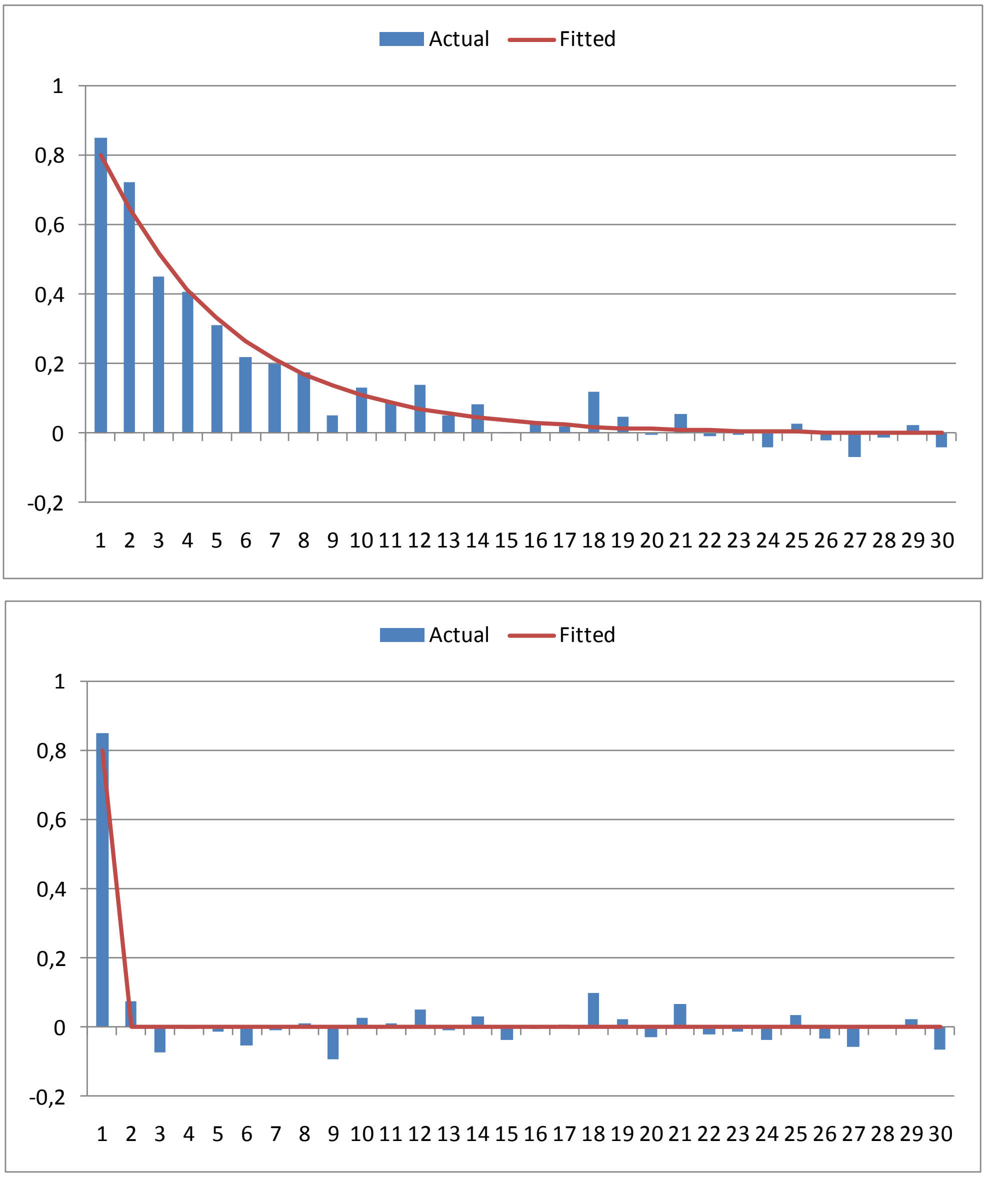
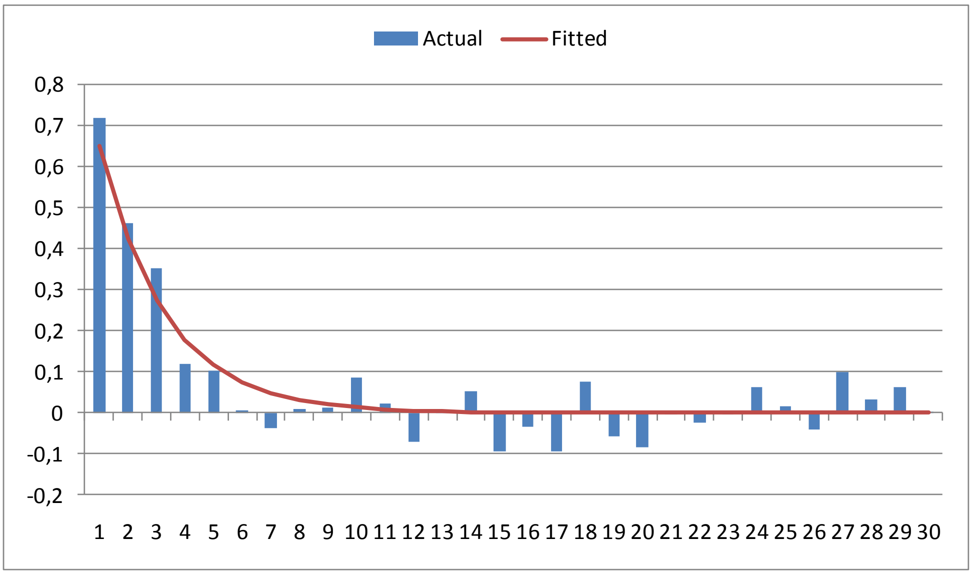


Figure 17. Autocorrelation (above figure) and partial autocorrelation functions together with the fitted AR-structures for regime 1.



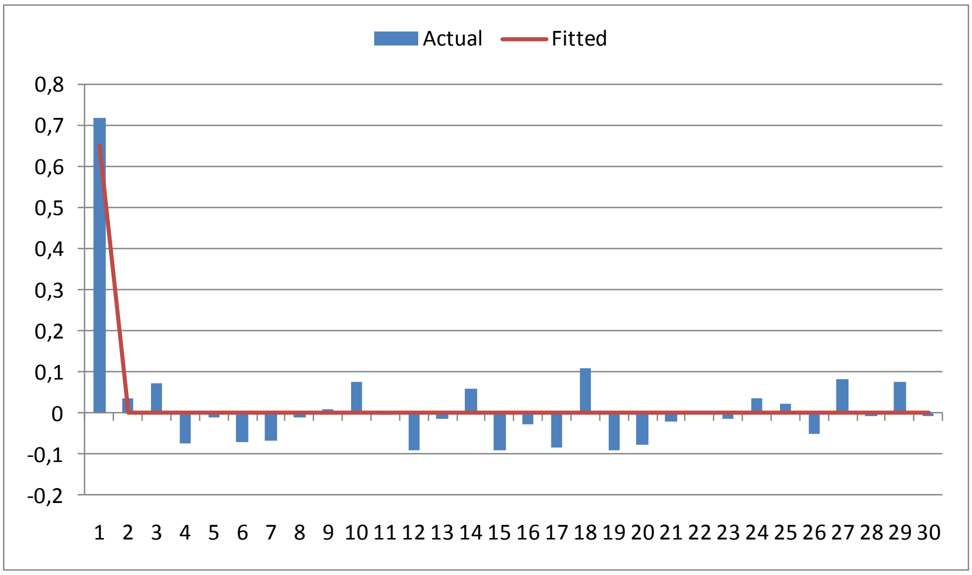


Figure 18. Autocorrelation (above figure) and partial autocorrelation functions together with the fitted AR-structures for regime 2.

The remaining modest autocorrelation at random intervals should not be a major concern. The Q-statistics in appendix 10 show no significant (95% confidence level) autocorrelation at any of the lags in neither of the models. No moving average (MA) terms were necessary.

5.7 EGARCH-specification

After completing the mean equation we turn our attention to the properties of the unconditional variance σ^2. Unsurprisingly we have strong heteroskedasticity left in the residuals (i.e. their variance is not constant over time) according to an ARCH test (H0 = no heteroskedasticity). The EONIA spread is clearly characterized by volatility clustering.

Heteroskedasticity Test: ARCH (2 lags)			
Regime 1			
F-statistic	10,3725	Prob, F (2,437)	0.0000
Obs*R²	19,9408	Prob, Chi-Square (2)	0.0000
Regime 2			
F-statistic	19,1904	Prob, F (2,276)	0.0000
Obs*R²	34,0614	Prob, Chi-Square (2)	0.0000
Regime 3			
F-statistic	74,8923	Prob, F(2,274)	0.0000
Obs*R²	97,9043	Prob, Chi-Square (2)	0.0000

Table 9. Heteroskedasticity test of residuals.

The test for ARCH-effects is carried out by obtaining squared residuals from the regression $\hat{u}_t^2$ and regressing them on q own lags. Again coefficient of determination R^2 is obtained to yield a test statistic:

$$TR^2 \sim X_q^2 \qquad [26]$$

Here T is the number of observations, q the number of lags and X_q^2 shows that the statistic follows the Chi-square distribution with q degrees of freedom. The null hypothesis is H0: $y_1 = 0$, $y_2 = 0$ etc. with y_q referring to the coefficient on the q lag. Due to non-linearity we must concentrate on the Chi-square test statistic. (Brooks, 2002, p. 448-449)

Traditionally this type of ”autocorrelation in volatility” is accounted for by introducing a GARCH-specification to allow the unconditional variance of the error term to be dependent upon previous errors squared – the q dimension (volatility during the previous period) and previous lags of itself – p dimension (fitted variance from the model during the previous period) thus becoming in essence conditional. The standard Generalized ARCH(p,q) takes the form of:

$$\sigma_t^2 = \alpha_0 + \sum_{j=1}^{p}(\beta_j \sigma_{t-j}^2) + \sum_{i=1}^{q}(\alpha_i u_{t-i}^2) \qquad [27]$$

(Brooks, 2002, p. 452-454)

The standard GARCH(1,1) would be sufficient to model the volatility clustering but the drawbacks of it are the inability to account for the leptokurtosis and leverage effects possibly looming in our data. We thus incorporate an EGARCH-specification with Generalized error distribution (GED) parameter fixed at 1 allowing for fatter tails in the distribution (a GED-parameter of 2 would yield the normal distribution). EGARCH is well suited as it allows for differentiation between positive and negative shocks to variance (leverage) and fat tails of the error term (leptokurtosis). Another option would be to use the Bollerslev-Woolbridge variance-covariance matrix estimator (also known as quasi-maximum likelihood or QML) to account for the non-normality properties. But as EViews allows for different error distributions the GED is chosen for its more specific nature. (Brooks, 2002, p. 461, 470-471)

The GED is used with a fixed parameter of 1, which is conveniently equal to the Laplace distribution. It has the desired property of accommodating leptokurtosis and the fixed nature of our error distribution reduces the probability of outliers influencing the fit of the model. Maximizing the log-likelihood function with freely adjusting error distribution would give too much influence to outliers in the optimization process. See below the comparison between the normal and Laplace probability distribution functions, which are respectively:

$$pdf_{Normal} : \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad [28]$$

and

$$pdf_{Laplace}:\frac{1}{2b}e^{\frac{|x-\mu|}{\sigma}}, \qquad [29]$$

where μ is the mean, σ^2 variance and $b=\sqrt{\frac{\sigma^2}{2}}$.

Both of these can be derived from the following probability density function of the GED - the normal distribution with the scale parameter $y=2$ and the Laplace with $y=1$. Γ is the gamma function $\Gamma(n)=(n-1)!$.[30] Function being:

$$pdf_{GED}=\frac{y\exp\left(-\frac{1}{2}\left|\frac{x}{\tau}\right|^{y}\right)}{\tau 2^{1+\frac{1}{y}}\Gamma\left(\frac{1}{y}\right)}, \qquad [30]$$

with

$$\tau=\sqrt{\frac{2^{-\frac{2}{y}}\Gamma\left(\frac{1}{y}\right)}{\Gamma\left(\frac{3}{y}\right)}} \qquad [31]$$

(Diop & Guegan, 2003, p. 3-4)

---

[30] Note that the gamma function outcomes for fractions required are: $\Gamma\left(\frac{1}{2}\right)=\sqrt{\pi}$ and $\Gamma\left(\frac{3}{2}\right)=\frac{1}{2}\sqrt{\pi}$.

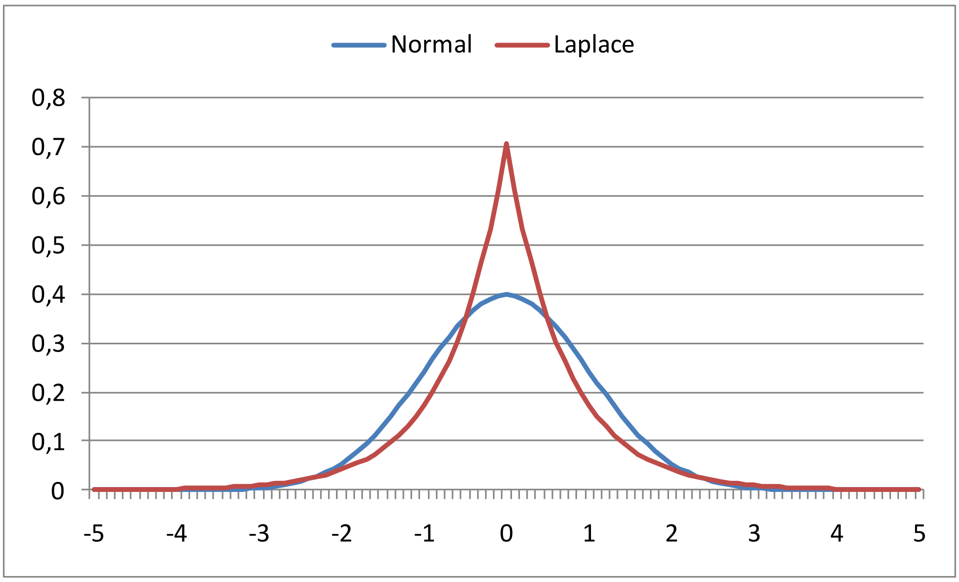


Figure 19. A comparison of the normal and Laplace distributions. Drawn with a mean of 0 and variance 1. $\mu = 0$, $\sigma^2 = 1$.

The exponential GARCH-specification (EGARCH) proposed by Nelson (1991) is a special member of the GARCH family notably as it models the natural logarithm of variance as opposed to variance itself:

$$\ln(\sigma_t^2) = \omega + \sum_{j=1}^{p} \beta_j \ln(\sigma_{t-j}^2) + \sum_{i=1}^{q} \left(\alpha_i \left(\left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| - E\left(\left| \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right| \right) \right) + \gamma_i \frac{\varepsilon_{t-i}}{\sigma_{t-i}} \right) + v_t D_{it} \qquad [32]$$

(Brooks, 2002, p. 470 & Schmitt, 1996, p. 6)

We use the EGARCH(1,1) specification. To further improve the responsiveness to the well documented changes in variance within the MP we use variance regressors D_{it} for the last of month, last of quarter and days preceding a TARGET2 holiday. Furthermore, the bidding behaviour variable $btcmarg$ is added to explain market tension based variance and last MRO dummy $Dlastmro$ to explain the rise in volatility towards the end of an MP. $\omega, \beta_j, \alpha_i, \gamma_i$ and v_t are the estimated parameters.

The news impact curve (NIC) can be calculated then by plugging into the equation different values of lagged standardized errors z_{t-1}, which represent news to evaluate the possibly asymmetric response of σ_t^2 to them. The exogenous variables in our models can be excluded as they are not functions of z. σ_{t-1}^2 is required and standard procedure is to use the median of the GARCH-series (for each regime) values of σ_t^2. See appendix 2 for graphs of the news impact curves. (Brooks, 2002, p. 479)

In table 10 we have similar ARCH-tests computed after the introduction of this specific variance equation. No significant ARCH effects were found.

Heteroskedasticity Test: ARCH (2 lags)			
Regime 1			
F-statistic	0,0143	Prob, F (2,437)	0,9858
Obs*R²	0,0287	Prob, Chi-Square (2)	0,9857
Regime 2			
F-statistic	0,5129	Prob, F (2,276)	0,5993
Obs*R²	1,0333	Prob, Chi-Square (2)	0,5965
Regime 3			
F-statistic	0,2498	Prob, F(2,274)	0,7791
Obs*R²	0,5042	Prob, Chi-Square (2)	0,7772

Table 10. Heteroskedasticity test of residuals after EGARCH.

5.8 Capturing non-linearity of the full allotment period

In the first two sub-samples it is reasonable to assume, that the response to liquidity is linear. However as we approach deviations of tens of billions from neutral liquidity, the linear response becomes increasingly inaccurate. To correct for this we use a filter proposed by Würtz (2003, p. 12), through which we estimate the relationship between liquidity (net recourse to standing facilities, DF-MLF, on the given day) and EONIA. The model for regime 3 thus deviates fairly substantially from the one used in earlier sub-samples. The difference is however fairly straightforward and is therefore not further elaborated. The EAGRCH-specification remains unchanged. The liquidity variable changes and the bidding behaviour variable is omitted as the fixed-rate full allotment policy rendered this variable obsolete. The formula for the non-linear response to liquidity conditions is as follows:

$$f(x_t, \alpha_t, \beta) = \alpha_t \left(\frac{2}{1 + e^{-2\beta x_t}} - 1 \right) \quad [33]$$

Here α_t is the interest rate corridor parameter, which is time dependent (hence the subscript). The symbol x_t is the value of the liquidity variable and β the associated coefficient. Notice how as $-2\beta x_t$ increases the term in brackets approaches -1 and vice versa, as $-2\beta x_t$ decreases the term approaches 1. The filter thus forces the linear response to stay within the prevailing corridor. The reason why only liquidity variable is estimated through the filter opposed to Würtz (2003), who estimates the response of all variables through such a specification, is simple. During full allotment the liquidity variable would overpower all other variables thus pressing the estimate of EONIA firmly to the bottom of the corridor, which would fit the data poorly. Other variables then contribute decisively to the spread between the bottom of the corridor and actual EONIA. The Cochrane-Orcutt-procedure is left out.

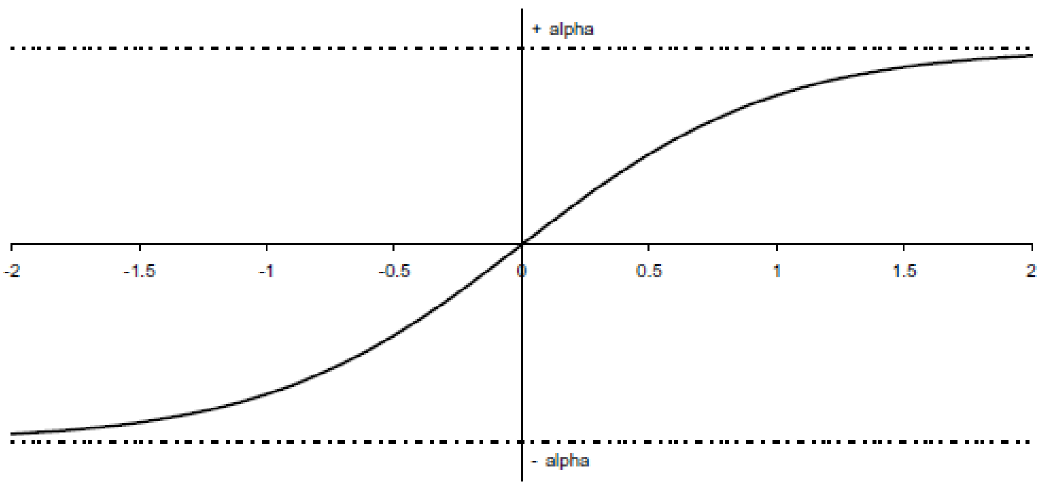


Figure 20. The relationship between the linear impact (x-axis) and the corridor. (Würtz, 2003, p. 12)

6. DATA

The data for this research was gathered from various sources. Interest rate related data, such as EONIA, policy rates and EONIA swap quotes, were extracted from Reuters XTRA 3000.[31] Below are the graphic descriptions of our dependent variable divided into sub-samples and descriptive statistics of these periods as stated by EViews.

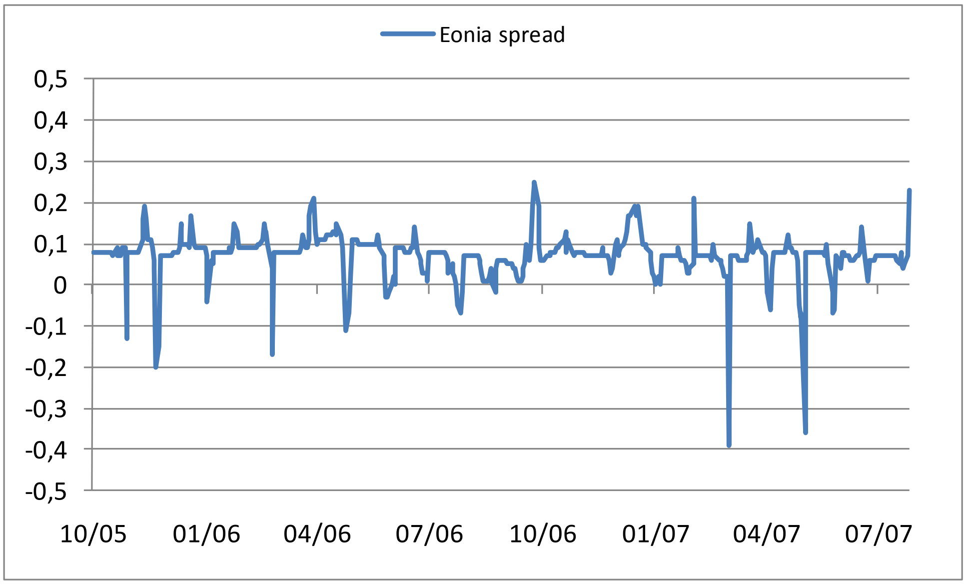


Figure 21. The EONIA-main policy spread in percentage points in regime 1. (Source: Thomson Reuters)

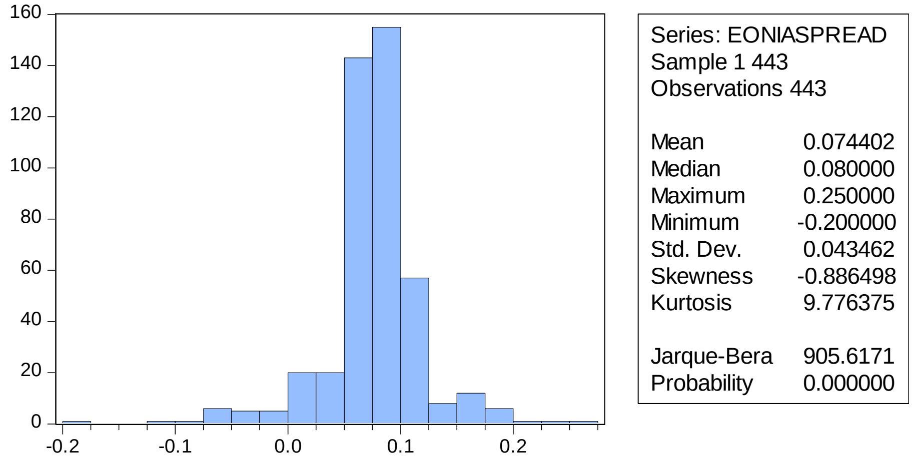


Figure 23. Corresponding descriptive statistics without the last days of MPs.

[31] Some modifications were required as the Reuters data series for the MBR changes somewhat incorrectly for our purposes on the allotment day of the MRO following the Governing Council´s rate change decision. The actual de facto rate change comes into effect starting from the settlement day of the MRO (and consequently the start of the MP).

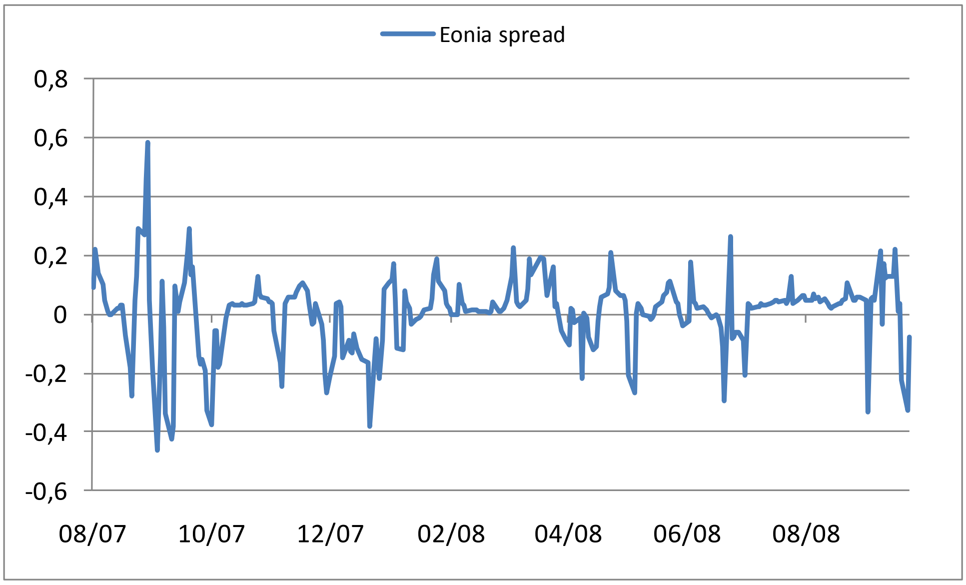


Figure 23. The EONIA-main policy spread in percentage points in regime 2. (Source: Thomson Reuters)

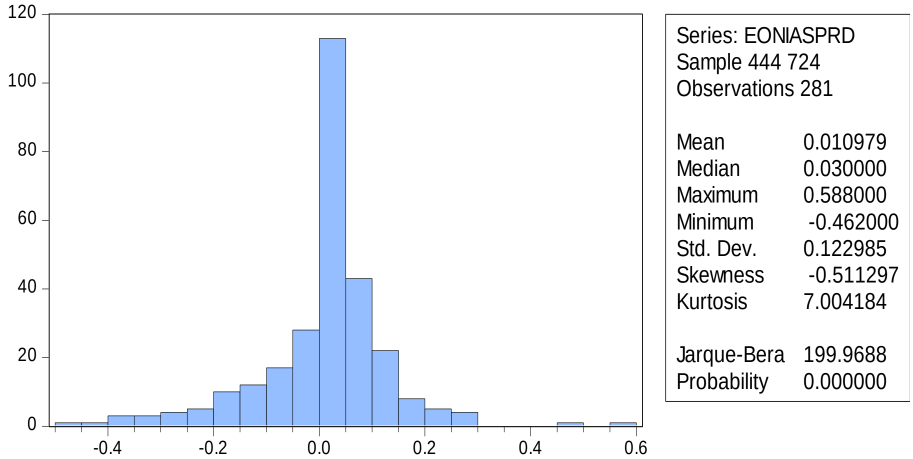


Figure 24. Corresponding descriptive statistics without the last days of MPs.

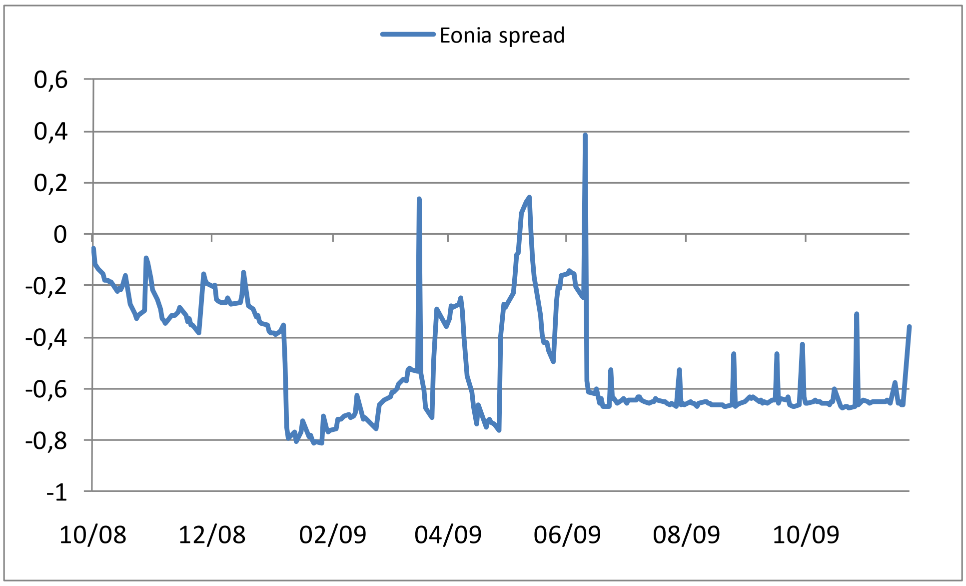


Figure 25. The EONIA-main policy spread in percentage points in regime 3. (Source: Thomson Reuters)

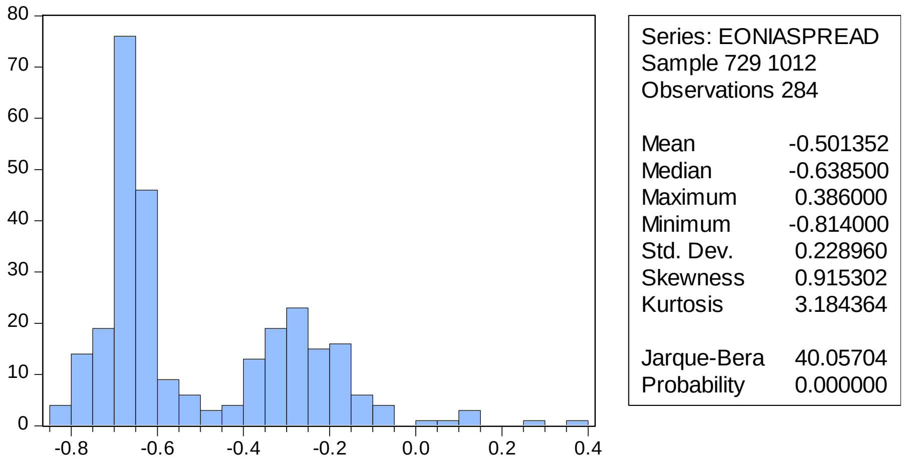


Figure 26. Corresponding descriptive statistics without the last days of MPs.

Evident from above is, that the spread is not normally distributed (Jarque-Bera test) and, that the standard deviation increases significantly as we move from sub-sample to another with respect to time, whereas the mean and median decrease as a result of the liquidity policy. The skewness trends higher (distribution moves left) and kurtosis lower (more kurtosis means fatter tails) as a function of time. The two clusters apparent in the last sub-sample are accommodated by the notion of excess liquidity pressing the interest rate towards the bottom of the corridor, which was not however constant during the sample range as discussed in section 2.2.1.3.

Jarque-Bera tests whether the coefficients of skewness and kurtosis (excess kurtosis as for normality a coefficient of 3 is required) are jointly zero. The coefficients are respectively given by:

$$b_1 = \frac{E(u^3)}{\left(\sigma^2\right)^{3/2}} \text{ and } b_2 = \frac{E(u^4)}{\left(\sigma^2\right)^2} \qquad [34]$$

The test statistic is then given by:

$$W = T\left(\frac{b_1^2}{6} + \frac{\left(b_2 - 3\right)^2}{24}\right) \qquad [35]$$

Here T is the sample size, u the error and σ the standard deviation. The test statistic follows the X^2-distribution with two degrees of freedom and null hypothesis of distribution being normally distributed i.e. symmetric and mesokurtic. (Brooks, 2002, p. 180)

An important prerequisite for the model is the stationarity of the dependent variable. This was confirmed with the augmented Dickey-Fuller unit root test, which requires the following auxiliary regression as we test with a constant c_1 and a linear trend $c_2 t$:

$$\Delta y_t = c_1 + \omega y_{t-1} + c_2 t + \sum_{i=1}^{p} d_i \Delta y_{t-i} + v_t \qquad [36]$$

Optimal number of lags p, which capture the dynamic structure of the dependent variable, are determined by minimizing the Schwarz information criterion (SIC). The test statistic does not follow any standard distributions so the explanation is omitted for brevity. Test values and corresponding critical values are shown in table 11. The null hypothesis of a unit root $\omega = 0$ is rejected in all samples. (Sinha, 1998, p 5 & Brooks, 2002, p. 378-380)

The test output shows clearly the rejection of H0 = the variable has a unit root. The spread is therefore stationary and integrated of order 0, $I(0)$. This outcome holds both for the entire sample as well for each individual sub-sample. We can therefore model the spread itself instead of the first difference or outcomes from other de-trending techniques.

Augmented Dickey-Fuller test

		Full sample	
		t-Statistic	Prob.*
	Test statistic	-6,2618	0,0000
Test critical values:	1% level	-3,9672	
	5% level	-3,4143	
	10% level	-3,1293	
		Regime 1	
		t-Statistic	Prob.*
	Test statistic	-9,2211	0,0000
	1% level	-3,9790	
	5% level	-3,4200	
	10% level	-3,1327	
		Regime 2	
		t-Statistic	Prob,*
	Test statistic	-8,2697	0,0000
	1% level	-3,9911	
	5% level	-3,4259	
	10% level	-3,1361	
		Regime 3	
		t-Statistic	Prob,*
	Test statistic	-4,3008	0,0007
	1% level	-3,9907	
	5% level	-3,4257	
	10% level	-3,1360	

*MacKinnon (1996) one-sided p-values.
Null Hypothesis: EONIA-MBR spread has a unit root
Exogenous: Constant, Linear Trend
Automatic lag length based on Schwarz information criterion

Table 11. Unit root test for the EONIA-spread.

The data related to liquidity management and monetary policy operations was extracted from various sources for convenience and cross-checking purposes. Bloomberg, the ECB´s Statistical Data Warehouse (http://sdw.ecb.europa.eu/) and Bank of Finland´s provided material were used. As we acquired data from various sources and with different day count conventions, meticulous care was appointed to matching the data with each other. The accumulating feature of liquidity variables (for example current account holdings over the weekend count towards fulfilling the reserve requirement) meant, that all calculations (cumulating averages etc.) had to be completed first with data for every day (including weekends and TARGET holidays) before pairing these up with corresponding day´s interest rate variables. As a result we have data for all 1 062 trading days between the 12th of October 2005 and 5th of December 2009 thus covering a total of 50 full maintenance periods. The sample used in the estimations has thus 1 012 observations. The 50 last days of MPs are subject to a separate analysis in section 7.4.

7. RESULTS

The section will be separated to each individual sub-sample accordingly followed by a separate analysis of the last day of the MP effects. The following discussion relies on the average behaviour of the EONIA-MBR spread and is therefore only characterizing in nature. However due to the division of data into sub-samples and the clear distinction between the behaviour in respective sub-samples the results offer some interesting patterns and insight to the market mechanisms at play. Additional tables and graphs for fits, residuals and omitted variables can be found in appendices 3 to 5.

7.1 Normal market conditions (12th of October 2005 – 6th of August 2007)

Our main finding is that the liquidity situation has a significant impact on the spread together with bidding behaviour, calendar effects and mean reversion as indicated by the results in table 12. A clear distinction can also be drawn between the effects of policy-related and shock-related liquidity conditions and the timing of these within the maintenance period (MP). Until the second to last main refinancing operation (MRO) the effect from either of the sources is not statistically significant as one would expect because of the countering of these shocks with the benchmark (BM) allotment in the last MRO. However, an allocation above BM in the second to last MRO already decreases EONIA slightly, whereas the demand side shocks are still non-differentiable from zero. Intriguingly the last MRO offers us interesting insights to the functioning and interplay of the monetary policy implementation framework and the money markets.

Dependent Variable: EONIA-MBR spread
Sample: 12th of October 2005 – 6th of August 2007
Included observations: 442
GED parameter fixed at 1 (Laplace distribution)

Mean equation	Coefficient	Std. Error	z-Statistic	Prob.
c	0,07633	0,00473	16,14062	0,000
Shock(T-1)	-0,00496	0,00096	-5,16989	0,000
Policy(T-1)	-0,01529	0,00247	-6,19571	0,000
Shock(T-2)	-0,00221	0,00215	-1,03118	0,303
Policy(T-2)	-0,02138	0,00406	-5,26036	0,000
Shock(T-3)	-0,00174	0,00062	-2,82579	0,005
Policy(T-3)	-0,01556	0,00379	-4,10225	0,000
Shock(T-4)	-0,00019	0,00040	-0,46769	0,640
Policy(T-4)	-0,01058	0,00264	-4,00547	0,000
Shock(MRO-1)	-0,00008	0,00010	-0,76884	0,442
Policy(MRO-1)	-0,00216	0,00100	-2,16579	0,030
Shock(MRO-2)	0,00003	0,00008	0,33135	0,740
Policy(MRO-2)	-0,00034	0,00085	-0,40410	0,686
Shock(MRO-3)	0,00021	0,00026	0,81102	0,417
Policy(MRO-3)	-0,00030	0,00088	-0,33737	0,736
Shock(MRO-4)	0,00025	0,00015	1,67943	0,093
Policy(MRO-4)	0,00082	0,00107	0,76800	0,443
Dm	0,02599	0,00169	15,33872	0,000
Dq	0,08487	0,00579	14,65152	0,000
Dtarget	0,01444	0,00307	4,70211	0,000
Btcmarg	0,11218	0,03167	3,54242	0,000
LTRO	-0,00008	0,00003	-2,22774	0,026
Libois	-0,00265	0,02987	-0,08853	0,930
Devmean	0,52069	0,03043	17,10859	0,000
Outlier1	-0,22425	0,01341	-16,72729	0,000
Outlier2	-0,09904	0,02501	-3,95994	0,000
Outlier3	0,01909	0,00150	12,71917	0,000
AR(1)	0,80188	0,03409	23,51934	0,000

Variance Equation	Coefficient	Std. Error	z-Statistic	Prob.
ω	-4,57013	0,45922	-9,95186	0,000
α	1,01040	0,09924	10,18113	0,000
γ	-0,06930	0,08046	-0,86127	0,389
β	0,61732	0,03699	16,68982	0,000
Btcmarg	-1,61493	2,77410	-0,58215	0,561
Dm	1,13504	0,46627	2,43428	0,015
Dq	3,88822	1,26565	3,07213	0,002
Dtarget	0,92062	0,98282	0,93671	0,349
Dlastmro	1,45313	0,23594	6,15901	0,000

R-squared	0,81	Mean dependent	0,07
Adjusted R-squared	0,80	S.D. dependent	0,04
S.E. of regression	0,02	Akaike info criterion	-6,51
Sum squared resid	0,15	Schwarz criterion	-6,16
Log likelihood	1475		
F-statistic	50,55		
Prob(F-statistic)	0,00		
Inverted AR Roots	0,8		

Table 12. Results for regime 1.

Recall, that the supply side does not change anymore after the last allotment[32] and provided an unbiased forecast of autonomous factors (AF) and excess reserves and non-structural recourse to the deposit facility (DF) an allotment above BM should result in a loose liquidity situation of the magnitude 7 times the allotment deviation as the duration of the operation is one week. This explains why the policy related variable becomes significantly negative immediately after the allotment, that is, on $mpday_{T-4}$. An allotment of EUR 1 billion above BM is sufficient to decrease EONIA by roughly 1 bps. If the martingale hypothesis holds, the coefficient on all of the days after the settlement of the last MRO should be increasing towards the end of the MP as the uncertainty regarding the possible shock from the AF forecast fades thus increasing the slope of the demand curve. For example a EUR 1 billion deviation above BM should therefore have a stronger downward impact on EONIA as a function of time (see figure 1).

[32] There were no FTOs during this period except for the last day of MP but this is excluded from our sample.

We test this with a Wald-test of all the liquidity policy coefficients being equal to each other. As the underlying regressions are non-linear one needs to focus on the Chi-square test statistic. Were our regressions to be linear, [33] we could use a similar F-test technique as already described with the omitted variables and Ramsey RESET tests. The test statistic appropriate for non-linear functions follows the X^2-distribution and is calculated as a likelihood ratio statistic:

$$LR - test = -2(l_r - l_u), \qquad [37]$$

where l_r and l_u are the values of the maximized log likelihood function of the restricted and unrestricted regressions respectively. Under H0 = the restrictions hold true, the X^2-distribution has degrees of freedom equal to the number of restrictions.

[33] They are now not as non-linearity is imposed through the AR(1) term.

Wald Test:

Equation: Regime 1

Test Statistic	Value	df	Prob.
F-statistic	2,09	(3, 405)	0,1006
Chi-square	6,28	3	0,0989

Null Hypothesis Summary:

Normalized Restriction (= 0)	Value	Std. Err.
C(3) - C(5)	0,0061	0,00377
C(5) - C(7)	-0,0058	0,00364
C(7) - C(9)	-0,0050	0,00352

Restrictions are linear in coefficients.

Table 13. Wald test for equivalent coefficients of liquidity policy variables during the last MRO in sub-sample 1. Coefficients C3, C5, C7 and C9 refer to the liquidity policy variables.

The effects seem to have a slightly increasing trend as we approach T. First -0,011, then on $mpday_{T-3}$ the coefficient is -0,016, then -0,021 and on the second to last day -0,015. Possible reasons for this are market inefficiencies as not all banks have the capacity or will (due to transaction costs) to take advantage of this pricing anomaly. Many might also prefer to fulfil their reserve requirement strictly linearly despite the liquidity situation in the market. According to previous research especially small banks are inclined to do so. The most plausible explanation is however that the overall liquidity situation is clarified only slowly as we approach T, and as we reject the null hypothesis of the coefficients being equal at the 10% significance level, the rate seems to present martingale properties as the coefficients increase in their negativity in line with the martingale theory. The reaction on the last day to the clarified liquidity situation is analyzed in more detail in section 7.4, but for now it suffices to say that the reaction is a lot sharper. One reason for this is that the last day fine-tuning operation (FTO) is designed to counter the liquidity imbalances accumulated through the MP and so the reaction before the settlement of the FTO is fairly muted. The FTOs are the likely cause why the slope of our demand curve during the last MRO is not as steep as the one estimated by Moschitz (2204) and Würtz (2003) in the old framework as put forth by Välimäki (2008, p. 6, 29).

The demand side shocks from AF forecast errors and net recourse to standing facilities (SF) only reveal their effects on the liquidity situation as time progresses. A similar Wald test for the equality of the coefficients is situated in appendix 9. The coefficients are clearly not the same either but portray an increasingly negative trend. Banks might be careful in taking advantage of seemingly loose conditions as the effects from demand side to the liquidity situation on the last day are not yet known. Considering that the ECB took de facto FTO on the last day to its framework, the liquidity effect seems irrational at first as the expected liquidity situation on the last day should be close to neutral after a providing or in most cases absorbing FTO. We must note however, that the rate at which the liquidity situation is rebalanced is not symmetric as the providing operations were conducted as variable rate tenders resulting typically in rates above the MBR and absorbing operations as fixed rate tenders with the MBR. This asymmetry can be determined to explain largely the liquidity effect. Another reason why the FTOs fail to remove the liquidity effect is the possibility of underbidding in the operations. If an FTO is underbid the remaining liquidity is left to the SFs (DF in loose conditions and MLF in tight conditions). The ECB has not also explicitly expressed its commitment to an FTO and in some cases the FTOs were insufficient in size to accommodate the imbalances.

The demand side shocks become statistically significant on $mpday_{T-3}$ (except for the T-2 coefficient) but the coefficients remain smaller than for policy induced shocks despite slightly increasing in magnitude towards the end of the MP. The fact that the perceived accumulated shocks according to our shock variable have so little impact on the rate is a manifestation of the market participants´ trust in the ECB in forecasting correctly the AFs. If they would not have faith in the ECB´s ability to forecast these factors the coefficients should be the same as for the policy related liquidity variables since the market should not make a separation between the origin of the liquidity shock. It is the overall perceived liquidity situation that matters. The drastic difference in the coefficients justifies our separation of the demand and supply shocks. Added together they would have become muddled, because determining the market expected shock from the forecast error is tricky. Our results however clearly show that banks do not react to AF shocks as they experience them (mostly) as random variations around the ECBs forecast, which to recap is only published as an average for the whole duration of the operation. Another advantage in our model construction is that the separation between the variables allows us to determine the true slope of the demand curve more precisely than with a single muddled total liquidity condition variable. We can determine the slope from the policy variable coefficients as the hard-to-estimate shock variable´s impact can be viewed to be zero. Recall, that the source of deviation from neutral liquidity should not matter.

Calendar effects were found to be statistically significant in all tested cases. For the last of month the increase is 2,6 bps, for last of quarter 8,5 bps and for a day prior to a holiday of the TARGET2-system 1,4 bps. All of these days are likely to be high payment flow days thus increasing the demand for reserves. Window dressing exercises are likely another reason especially at ends of quarters. Judging by the raw data the effect did not seem to spill over to the following days nor did it cause increases towards the quarter end excluding the year end of 2006, when the spread was elevated for roughly a week prior to the end of year. The last of month and the TARGET2-holiday seem to be individual spikes too not spilling either way although we did not specifically test for this statistically. Interest rate expectation variables were handled with an omitted variable Lagrange Multiplier-test, the result of which can be found from appendix 8. The interest rate expectation variables were not found statistically significant as one would suspect after the interest rate changes were synced with the change of an MP in 2004.

Bidding behaviour had an expected effect on EONIA. Larger marginal spreads due to more competitive bidding or large demand for central bank financing in the form of high bid-to-cover ratios translated into a higher spread during the week. The average bid-to-cover ratio was 1,25 and the average marginal spread 0,056 or 5,6 bps. Though the average effect taking into account the coefficient was therefore a mere 0,8 bps, the marginal spread (from 0 to 0,09) and bid-to-cover (from 1,00 to 1,44) did vary to some extent hence driving the spread. We suspect that the constant has absorbed already some elements of the natural spread leading to a relatively low effect from bidding behaviour. The constant of the estimation is actually very close to the average of the spread.

Unsurprisingly, the 3-month LIBOR-OIS-spread did not have a significant effect on the spread as the spread was both low and stable during the period. The amount of outstanding LTROs decreased the EONIA-MBR spread although the coefficient remained small. The EUR 60 billion increase lowered by itself the spread by only about 0,5 bps. The amount was raised from EUR 90 billion to EUR 150 billion during the period in order to keep the MRO amounts to be rolled over in check as the liquidity deficit steadily increased (see appendix 7). Lastly we note the mean reversion parameter being statistically significant and roughly 0,52 indicating fairly sizable “stickiness” in the spread.

Turning our attention to the variance equation we can see the absence of leverage γ at statistically significant levels, i.e. negative and positive shocks have the same effect on the conditional volatility (see however the news impact curve in appendix 2.1). The result can be viewed as confirmation of the ECB having a symmetric loss function, when it makes liquidity policy decisions, i.e. no noticeable bias, which could cause the rate to be more volatile on either side of its mean. The second reason is again the FTO-policy on the last day as banks could during the period be fairly safe, that the ECB will not let them end up short of liquidity, at least on an aggregate basis. The fourth parameter β measures the persistence of shocks, which in this case are actually fairly small (0,62) considering typical financial time series, where this parameter is often close to one. Market tensions measured by *Btcmarg* did not increase volatility whereas last of month (*Dm*), end of quarter (*Dq*) and days during the last MRO (*Dlastmro*) did. Like Gaspar et al. (2004, p. 39) we attach this effect to the liquidity effect and the steepening yield curve during the last MRO.

7.2 Financial crisis (8th of August 2007 – 30th of September 2008)

Intriguing differences were noticed in the response of the spread to the same variables we had in the model of the first sub-sample. Most notably the active liquidity policy by the ECB proved effective and adequate to keep the EONIA actually even closer to the policy rate on average despite the increased volatility and sources of upward pressure. Secondly, the importance and magnitude of many variables changed dramatically as a result of the tensions in the money market.

Dependent Variable: EONIA-MBR spread
Sample: 8th of August 2007 – 30th of September 2008
Included observations: 281
GED parameter fixed at 1 (Laplace distribution)

Mean equation	Coefficient	Std. Error	z-Statistic	Prob.
c	0,03646	0,02999	1,21573	0,224
Shock(T-1)	-0,01998	0,00468	-4,26727	0,000
Policy(T-1)	-0,02692	0,00307	-8,76460	0,000
Shock(T-2)	-0,01072	0,00360	-2,97940	0,003
Policy(T-2)	-0,02307	0,00298	-7,73110	0,000
Shock(T-3)	-0,00487	0,00276	-1,76736	0,077
Policy(T-3)	-0,01470	0,00229	-6,43247	0,000
Shock(T-4)	-0,00238	0,00267	-0,88871	0,374
Policy(T-4)	-0,01042	0,00242	-4,31255	0,000
Shock(MRO-1)	-0,00130	0,00063	-2,07925	0,038
Policy(MRO-1)	-0,00275	0,00021	-13,12407	0,000
Shock(MRO-2)	0,00019	0,00027	0,70709	0,480
Policy(MRO-2)	-0,00197	0,00026	-7,48509	0,000
Shock(MRO-3)	-0,00106	0,00113	-0,94065	0,347
Policy(MRO-3)	-0,00153	0,00025	-6,01550	0,000
Shock(MRO-4)	-0,00700	0,00374	-1,86894	0,062
Policy(MRO-4)	-0,00210	0,00057	-3,66042	0,000
Dm	0,05750	0,00621	9,26115	0,000
Dq	0,16459	0,02686	6,12668	0,000
Dtarget	-0,03256	0,03331	-0,97746	0,328
MRObef	-0,02187	0,00947	-2,30848	0,021
Btcmarg	0,17504	0,03774	4,63805	0,000
LTRO	-0,00014	0,00011	-1,23970	0,215
Libois	0,05265	0,02062	2,55304	0,011
Devmean	0,27519	0,03962	6,94521	0,000
Crisislast	0,20522	0,04494	4,56710	0,000
SLTRO3m	-0,41501	0,04718	-8,79654	0,000
BNP	0,19763	0,03408	5,79933	0,000
Lehman	0,20570	0,00719	28,62024	0,000
AR(1)	0,65012	0,04289	15,15868	0,000

Variance Equation	Coefficient	Std. Error	z-Statistic	Prob.
ω	-2,67737	0,46596	-5,74596	0,000
α	1,16478	0,19292	6,03753	0,000
γ	-0,07047	0,12415	-0,56759	0,570
β	0,80707	0,04966	16,25106	0,000
Btcmarg	1,78328	0,66345	2,68788	0,007
Dm	2,10107	0,71194	2,95120	0,003
Dq	0,50086	0,97506	0,51367	0,608
Dtarget	0,80129	1,42086	0,56395	0,573
Dlastmro	0,55293	0,24235	2,28149	0,023

R-squared	0,69	Mean dependent	0,01
Adjusted R-squared	0,66	S.D. dependent	0,12
S.E. of regression	0,07	Akaike info criterion	-3,47
Sum squared resid	1,30	Schwarz criterion	-2,97
Log likelihood	527		
F-statistic	14,83		
Prob(F-statistic)	0,00		
Inverted AR Roots	0,65		

Table 14. Results for regime 2.

One can arguably interpret the coefficients of our liquidity variables as the slope of the demand curve. The results show how the ECBs active liquidity policy of frontloading liquidity early in the MP and still aiming towards neutral liquidity at the end of the period was successful in depressing EONIA significantly. This means the demand curve is not flat until the last day of the MP (at least in crisis times) as one would expect according to the martingale hypothesis. The small (but highly significant) coefficients on liquidity policy variables for MROs early in the MP are not irrelevant. Take for example the second MRO of each MP, which averaged some EUR 35 billion above BM as opposed to deviations of EUR 1 to 3 billion from neutral liquidity under normal market conditions. With a coefficient of -0,0015 the effect on EONIA would account to a decrease of 5 bps. The coefficients for all MROs are negative and significant. The result is in line with the findings of Linzert & Schmidt (2007, p. 10) and Cassola & Morana (2008, p. 26) as they also showed how the early fulfilment of the RR relieved stress in the money market. Here the allotment above BM measures the same phenomenon as the recourse to standing facilities (SF) was rather negligible even during the crisis before the very last day of the period. The coefficients for demand side shocks are indifferentiable from zero except for the small negative coefficient for shocks during the second to last MRO. Overall the results establish that the frontloading policy was very successful and highlights how the liquidity demand for banks as a function of time is decreasing within the MP during a crisis.

During the last MRO the liquidity policy continues to be the main driver of the spread with coefficients roughly the same size as under normal market conditions. The only clear difference is the steeper slope on the second to last day. The same Wald test for coefficient equality reveals in table 15 that they are not equal to each other and therefore the rate presents again martingale properties as the same deviation from neutrality (in theory the expected recourse to SF) would cause different reactions to the spread and result in different EONIA rates as the overall liquidity situation slowly clarifies as the kurtosis of the shock distribution increases. One additional explanation during this period compared to regime 1 might be the commitment by the ECB to preserve orderly conditions in the money market. One interpretation could be that an FTO during the last MRO (that is other than the one on the last day) as part of the active liquidity management policy might change liquidity conditions further thereby conveying different expected liquidity conditions from the supply side opposed to the indications of allotment versus BM. In practice, only one providing (6th of September 2007) and two absorbing (7th & 10th of December 2007) FTOs took place during the last MRO in regime 2. But the mere possibility of these is likely to have sharpened the increasing trend in the coefficients.

Wald Test:

Equation: Regime 2

Test Statistic	Value	df	Prob.
F-statistic	8,21	(3, 242)	0,0000
Chi-square	24,63	3	0,0000

Null Hypothesis Summary:

Normalized Restriction (= 0)	Value	Std. Err.
C(3) - C(5)	-0,0038	0,00318
C(3) - C(7)	-0,0122	0,00339
C(3) - C(9)	-0,0165	0,00357

Restrictions are linear in coefficients.

Table 15. Wald test for equivalent coefficients of liquidity policy variables during the last MRO in sub-sample 2. Coefficients C3, C5, C7 and C9 refer to the liquidity policy variables.

The reaction to demand side shocks is a lot more pronounced here starting from $mpday_{T-3}$. This difference could be related to the comparably tenser market situation than in regime 1. The liquidity policy situation in both regimes during the last MRO was more or less the same as the ECB adhered to the BM allocation in the last MRO fairly strictly (the average deviation being EUR 4,6 billion). This steeper response to shocks can be viewed as evidence of the increased frictions in the money market. If a bank seemed to be falling short of its RR it was harder for it to make up the difference from the market. A same size forecast error would put much more pressure on money markets for this reason under these stressful conditions.

The result cannot be reconciled with the theory that a narrower probability distribution (higher kurtosis) in forecast errors by the ECB would result in a steeper demand curve. During the crisis the ECB liquidity management´s forecast error was on a daily basis on average EUR 0,82 billion below realized with a standard deviation of EUR 5,3 billion as opposed to EUR 0,1 billion underestimation in the first sub-sample with a standard deviation of EUR 5,1 billion. The most likely explanation can therefore be found from increased market tensions and liquidity hoarding. Liquidity hoarding is evident from appendix 1.2, where it is depicted how the net recourse to SF was strongly on the side of the DF throughout the period and more pronouncedly during the last MRO.

The calendar effects intensified noticeably in the period as window dressing related to showing liquid assets on balance sheet increased the demand of reserves especially at quarter ends. At the end of a quarter the spread increased on average by about 16,5 bps and remarkably even on the end of year 2007 despite the ECB flooding the market with liquidity in the two MROs covering Christmas and New Year. The increase during the last of month amounted to 5,8 bps. Pinning down possible spillover effects proved hard due to the increased volatility. This time the effect prior to TARGET2-holidays proved not to be significant on average. Appendix 8 indicates how the Lagrange multiplier test for omitted variables shows that interest rate expectations were again correctly omitted from the model.

The importance of bidding behaviour to the spread in each MRO increased drastically during the sub-sample in question. The coefficient nearly doubled and taking into account the increase in both the marginal spread and in the bid-to-cover we can safely say, that the upward pressure to the spread from this variable increased markedly. Bid-to-cover was on average 1,5, but topped 2 in many cases as banks tried to secure their reserve needs from the ECB as opposed to the market. This obviously led to more competitive bidding and the marginal rate averaged 15,7 bps. This means bidding behaviour exerted 4,1 bps of upward pressure to the spread on average. The LIBOR-OIS spread leaped higher (64 bps on average and a coefficient of 0,053) and indeed described quite nicely market tensions in the overnight market as well. As these two variables tried to push the spread higher, ECB countered with its liquidity policy. Not only was the policy active in allotment decisions of MROs but also in LTROs. Increasing the amounts of 3-month LTROs and the introduction of 6-month LTROs provided an important counterforce. These three aforementioned variables are somewhat closely linked to each other through positive correlation and we are quite careful in drawing too precise conclusions on the exact individual magnitudes of these variables despite multicollinearity is fairly decisively ruled out in section 7.5. It is safe to say though, that the active liquidity policy allowed by the flexible framework proved its worth. The correlation also proves the ECBs determination to increase LTROs as tender spreads and risk spreads drifted higher. Notice also the 20 bps increase in the EONIA from the dummy variables *BNP* and *Lehman* highlighting the extremely adverse effects that these events had.

The mean reversion properties of the spread increased (or perhaps more appropriately the “stickiness” of the spread reduced) according to the smaller coefficient. Again this can be attributed to the active stance of the ECB regarding the conditions in the money market. They intervened swiftly and with force if EONIA seemed to wander too far away from the policy rate. A tool for this was the use of FTOs during the MP. Both providing and absorbing operations were carried out as deemed necessary. The number of such operations was 11 and 14, respectively.

The results for the variance equation show the absence of leverage effects but this time, as was to be expected, the persistency of the shocks to volatility increased (coefficient of 0,81). This time the volatility increased significantly in a statistical sense during the last MRO and at month ends. A typical result for a stress period is also the importance of market tensions to volatility. Table 14 shows that market tensions increased the volatility of the spread markedly.

7.3 Full allotment (15th of October 2008 – 4th of December 2009)

The modified model designed particularly for the full allotment framework provided some important findings. Firstly, our model was able to capture the nonlinear response of EONIA to liquidity conditions as opposed to the linearized demand curve in the model for regimes 1 and 2. Secondly, the calendar effects remained, and thirdly, the importance of the duration of central bank financing and communication of liquidity policy was established.

Dependent Variable: EONIA-MBR spread
Sample: 15th of October 2008 – 4th of December 2009
Included observations: 279
GED parameter fixed at 1 (Laplace distribution)

Mean equation	Coefficient	Std. Error	z-Statistic	Prob.
c	0,04291	0,01986	2,16098	0,031
Nsf	-0,02444	0,00054	-45,36656	0,000
Dm	0,06112	0,01538	3,97452	0,000
Dq	0,14154	0,02604	5,43662	0,000
Dtarget	-0,01322	0,00677	-1,95288	0,051
LTRO	-0,00005	0,00003	-1,70525	0,088
Dq109	0,76139	0,22492	3,38521	0,001
Libois	0,19203	0,00427	44,95021	0,000

Variance Equation	Coefficient	Std. Error	z-Statistic	Prob.
ω	-2,52239	0,61361	-4,11072	0,000
α	1,48249	0,28441	5,21256	0,000
γ	0,07572	0,14802	0,51155	0,609
β	0,79774	0,06511	12,25218	0,000
Libois	0,36361	0,30839	1,17907	0,238
Dm	1,04029	0,99862	1,04173	0,298
Dq	0,22752	2,65452	0,08571	0,932
Dtarget	-1,92612	1,94999	-0,98776	0,323
Dlastmro	0,12837	0,33997	0,37758	0,706

R-squared	0,86	Mean dependent	-0,51
Adjusted R-squared	0,86	S.D. dependent var	0,23
S.E. of regression	0,09	Akaike info criterion	-2,99
Sum squared resid	1,99	Schwarz criterion	-2,77
Log likelihood	434		
F-statistic	104,07		
Prob(F-statistic)	0,00		

Table 16. Results for regime 3.

The regression yielded the following relationship between net recourse to standing facilities (SF) and the spread. [34]

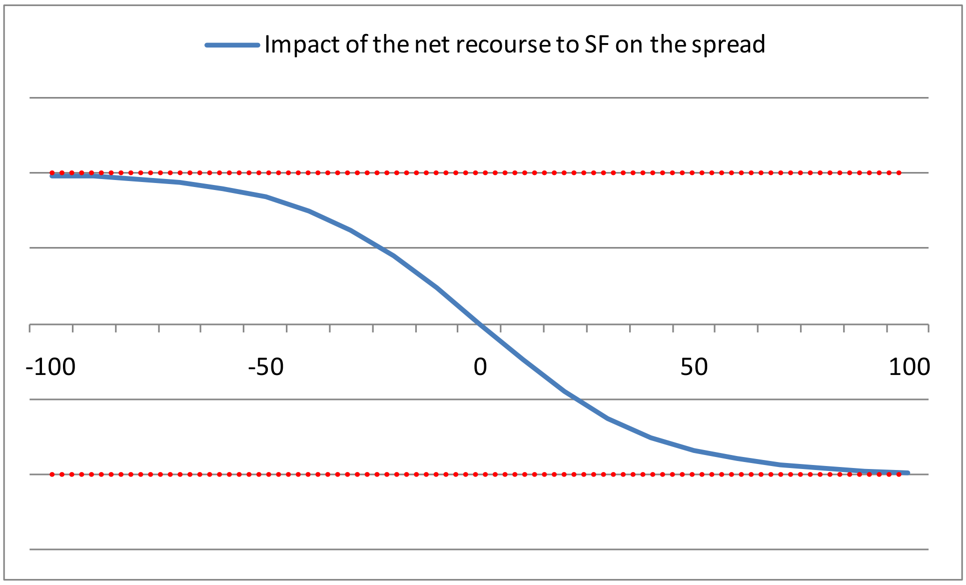


Figure 27. The non-linear impact of liquidity conditions on the spread within the interest rate corridor. The x-axis is in EUR billions. Net recourse defined as use of deposit facility (DF) minus marginal lending facility (MLF).

Figure 27 portrays how quickly the marginal effect of additional liquidity becomes irrelevant. Already with a net recourse to the DF of EUR 50 billion the impact is 84% of the spread between the rate on the DF and the MBR and at EUR 100 billion 98,5%. The implications of this finding are important. Firstly the liquidity conditions are critical to the behaviour of EONIA. Even a small change in aggregate liquidity conditions could result in major movements in the overnight rate. If the liquidity conditions are left to "wander" between 0 and 50 billion for extended periods the resulting volatility in EONIA could lead to disturbances in the transmission mechanism of monetary policy. Currently the ECB´s full allotment policy lets banks determine the aggregate liquidity conditions in the market but if they were to reduce their

[34] The effect is extrapolated equally to tight liquidity conditions although one could expect the response to be markedly different in such a scenario.

demand for excess liquidity as market conditions improve[35] it could mean we would end up fairly close to the range between EUR 0 and 50 billion. Some banks might still be shut out from the market or would simply prefer getting their liquidity from the central bank instead of the market to avoid transaction costs. The ECB should therefore aim to skip the inelastic part of the demand curve by moving decisively and quickly with explicit communication of its intentions from levels of liquidity, which keep the EONIA close to the bottom of the corridor to conditions where the minimum bid rate (MBR) could anchor the rate. The problem currently lies however in the relatively large difference between the two anchoring rates. Such a sharp rise in interest rates could prove costly to the economy in the process of crawling out of a recession as it would travel for example to EURIBOR fixings, with plenty of mortgages linked to these, or to government bond yields raising government expenditure on interest payments in a situation where they are struggling to convince markets of their sustainable fiscal positions.

As a solution to this we would suggest controlling the market rate in the exit strategy by narrowing the corridor for a short time to facilitate the move higher. First, let us narrow the corridor to 50 bps with full allotment tender procedures (currently scheduled to continue on MROs until October 2010 (ECB Annual Report 2009, p. 19)), then to 25 bps if necessary. By doing so the ECB could smooth the transition and control the timing of the exit-strategy to a larger degree. Once neutral liquidity conditions would be established (or possibly clearly communicated policy of frontloading in the MP tightening towards neutral liquidity) the corridor could be widened back to appropriate figures. Furthermore, even if establishing neutral liquidity conditions would be deemed unwanted due to permanent frictions in the market, the ECB would have to resort to a new liquidity management framework in which the deposit facility (DF) rate could play a crucial role. The use of the interest rate corridor as a policy tool could be brought even a step further as suggested by Goodhart (2009, p. 3-4). Since we have already un-

[35] Under normal and perfect market conditions it is irrational for the banking system as a whole to borrow at the MBR and deposit excess funds back at the DF rate.

aligned the market rate from the MBR, there should be no stigma in communicating an asymmetric corridor and in a liquidity abundant situation the market rate is not likely to rise above the MBR in any case. In the exit-strategy the ECB could raise the DF rate and keep the emergency funding rate from the MLF at the prevailing level. The possible move to a lower spread between the DF rate and the MBR should however be used only as a temporary transition tool so as not to encourage reserve build up permanently by lowering the intermediation cost of the ECB. Like stated before, the narrower corridor could crowd out the private money market and should therefore be used with caution.

The reason we left out the Cochrane-Orcutt correction can be seen from appendix 5.1 describing the fit of the model. With an AR-process the autocorrelation in the residuals would be removed and we would not be able to see how our model predicted higher spreads ahead of the June and December 12-month operations. This observation offers some evidence of the importance of communication of liquidity policy and is a good example of a so called “open mouth-operation”. As these operations were pre-announced by the ECB, the market did not have to worry about the tightening of the liquidity conditions [36] as they were counting on participating in these tenders.

Interestingly, calendar effects remained despite the abundant liquidity conditions. The last day of March 2009 (Q1) had to be dummied out as the rise in the spread was very dramatic (+76 bps). In March many stock markets, banking shares in particular reached lows and prompted a large increase for the demand of reserves to bolster up balance sheets. On other quarter ends the effect was 14 bps. The end of month elevated the spread by 6 bps. Spill over effects were not apparent. This time the TARGET2-holidays did not induce significant upward pressure to the spread. Again, our

[36] The volume in MROs preceding these operations dropped to some extent as banks “made room” for the 12-month liquidity.

likelihood ratio test for omitted interest rate expectation variables shows that they were indeed correctly omitted from the model (see appendix 8).

As we mentioned earlier it was clear how also other aspects besides liquidity determined the level of the spread. Again, the results show that the LTROs and LIBOR-OIS acted as counterforces to each other. Average outstanding amount of LTROs was EUR 538 billion as opposed to an average LIBOR-OIS-spread of 73 bps, which however displayed a sharply declining trend as market conditions calmed whereas the outstanding LTRO increased to EUR 600-700 billion after the first 12-month operation in June. The increase in the duration of financing is likely behind the extremely static behaviour of EONIA just some 5-10 bps above DF rate since then. The LTROs, which have a maturity of at least an MP, could be viewed loosely as structural operations since they effectively removed the net liquidity deficit of the banking system and moved it to a situation of substantial and persistent surplus. On aggregate, the banking system was facing a liquidity surplus vis-à-vis the ECB hence removing the need to acquire intra-MP funds and removing liquidity uncertainty. Roughly all other deviation outside a range of 1-2 bps occurred at ends of months and quarters and obviously on the last day of the MP when liquidity absorbing FTOs were conducted. [37]

In the variance equation none of our exogenous variance regressors are statistically significant. An interesting finding in itself as it shows how the full allotment policy was able to decrease the volatility significantly especially after the 12-month operation, when EONIA was pressed firmly against the DF rate. Appendix 5.2, plotting the conditional standard deviation, shows how volatile the rate was in the run-up to the June 12-month auction and how it dropped in its aftermath. No leverage effect was found, but the persistence of shocks was again quite large with a coefficient of 0,8.

[37] Not part of our model here though. See the next section for an analysis.

7.4 Analysis of the behaviour on the last day of a maintenance period

This section is dedicated to the stylized analysis of the EONIA during the last day of MP. The separate analysis was chosen for its econometrical tractability as our basic model relies on lagged dependent variables, which would cause unwanted irregularities to the result due to their continuous nature as opposed to the cyclical spikes of the ends of MP. Also the last day is the driver of the interest rate determination process if the martingale property holds.

We start off with the question of structural demand for the DF. If such demand was to exist it would have important implications for the benchmark (BM) allotment published. Note the similarities between the structural demand for excess reserves and the possible structural demand for the DF. Both have a liquidity absorbing effect yet only the former is included in the calculation of the BM allotment. Was there to exist a similar demand for the recourse to the DF it could be argued that this absorbing effect should also be forecasted and calculations adjusted accordingly as otherwise the "neutral" allotment would lead consistently to tight liquidity conditions.

After conducting a crude analysis to capture this effect (similar to the one used by Välimäki (2008)) we note that the recourse to the “wrong facility” i.e. when the net recourse was on the MLF side, the gross recourse to the DF was EUR 690 million. Vice versa, the gross recourse to the MLF was slightly lower at EUR 606 million when the net recourse was on the DF side under normal market conditions. During regime 1 the net recourse was 13 times in MLF and 9 times in DF after 11 absorbing and 7 providing fine-tuning operations (FTO). The slightly higher number of absorbing FTOs reflects the marginal overallotment in MROs and otherwise unbiased AF forecasts.

The de facto FTO on the last day is evident from the fact, that only 4 out of 22 MPs had no last day FTO. The ECB was very keen to correct even the small expected liquidity imbalances as FTOs were conducted for as small cumulative imbalances as EUR 2 billion. The average absorbing FTO was

EUR 8,9 billion and providing FTOs averaged EUR 8 billion. Excess reserves proved to be steady averaging roughly 0,4-0,7% of the reserve requirement. One explanation for the at least seemingly non-existent demand for structural use of DF could indeed be the last day FTO as it provides a better yielding option to store excess liquidity. Appendix 1.1 highlights nicely how net standing facilities (SF) start to drift towards DF only on the second to last day - a further proof of the relatively small impact of structural demand for DF to liquidity policy under normal market conditions. A rough estimate of the linear impact of recourse to net SF on EONIA is obtained by a simple regression, where the net recourse is the sole independent variable. The coefficient is -5,8 bps per EUR 1 billion and highly significant portraying clearly the steepening of the demand curve on the last day (see results in section 7.1). Note the very high value of R^2, which illustrates how important the liquidity factor becomes on the last day as it alone is able to explain 63% of the movements of EONIA.

	Coefficient	Std. Error	t-Statistic	Prob.
c	0,022	0,021	1,080	0,293
Net SF (DF-MLF)	-0,058	0,010	-6,079	0,000

R Squared	0,65
Adjusted R Squared	0,63
Standard Error	0,09
Observations	22

Table 17. Response of EONIA to net SF on the last day of an MP in regime 1.

The picture is dramatically different in many perspectives if we take a look at how the banking system adjusted its position vis-á-vis the Eurosystem through the use of SF in the market turmoil. Appendix 1.2 depicts how the recourse to SF was steadily in the side of DF throughout the period and increasing further during the last MRO - a clear indication of structural demand for DF under market tensions. Net recourse during period 2 was only 4 out of 14 times on the side of MLF. The ECB conducted an FTO on the last day of every MP of which just one was providing. A result of fairly large overallotments even in the last MRO as the promise to target neutral liquidity conditions was guaranteed with the FTO instead of neutral allotment. Absorbing FTO amounts increased on average to EUR 23 billion excluding the last MP of the sample, which had a very large FTO of EUR 147,5 billion due to the almost full allotment nature of MROs in the MP in question after Lehman´s demise. Similar regression as in regime 1 reveals a linear response of -3,8 bps per EUR 1 billion net recourse to SF on the last day of an MP. Notice again the very high value of R^2 (0,70). A possible explanation for the change are the larger net recourses during the period compared to regime 1.

	Coefficient	Std. Error	t-Statistic	Prob.
c	0,058	0,032	1,799	0,100
Net SF (DF-MLF)	-0,038	0,007	-5,381	0,000

R Squared	0,72
Adjusted R Squared	0,70
Standard Error	0,10
Observations	13

Table 18. Response of EONIA to net SF on the last day of an MP in regime 2.

A look at appendix 1.3 reveals how under full allotment the recourse to DF decreases on the last day because of the FTO. They averaged EUR 148 billion during the period. The average recourses to MLF and DF on the last day were EUR 2,8 billion and EUR 73,3 billion respectively. This occurred despite the FTOs thus depicting the increased structural demand. The FTOs were conducted without a preset amount and with high bid-to-cover ratios. [38] The ECB also postponed the launch of the operation later to the afternoon (with a 15:35 CET deadline for counterparties as opposed to the previous 10:35 deadline) in order to give the counterparties more time to monitor their liquidity flows and therefore enable them to bid more precisely in the operation. Clearly the FTO was not enough to compel counterparties to aim at neutral liquidity conditions on the last day. The large use of MLF is most likely a symptom of some miscalculations on behalf of the banks as

[38] Not full allotment though but the marginal rate was relatively stable.

overbidding the tender would force them to square their liquidity positions then from the MLF. However, the effect is impossible to prove without access to bank specific data.

In regime 3 a regression does not indicate a statistically significant relationship between liquidity conditions and EONIA (results omitted for brevity). The last day of an MP EONIA is very likely driven more by the marginal rate in the FTO than the liquidity conditions as such. An increase in the average recourse to MLF on the last day (especially during late 2008 and early 2009) despite abundant liquidity conditions is another testimony of the extreme frictions in the money market.

7.5 Testing for possible multicollinearity

We now take a moment to reflect critically on the model. First of we test for possible multicollinearity since we have such a large number of predictors in our model making it vulnerable for linear relationships between two explanatory variables. We determine the variance inflation factors (VIF) for all variables in regimes 1 and 2.[39] A numerical value above 10 is usually perceived as the benchmark for multicollinearity.[40] From appendix 11 we determine the issue to be restricted to some of the liquidity policy and shock variables and comfortingly the level of multicollinearity seems to be relatively small for the variables we perceived to be most at risk, i.e. Libor-OIS, bidding variable *btcmarg* and LTRO outstanding amount. This actually rebuffs some of the reservations we made earlier, when discussing the plausible outcomes. Multicollinearity might cause standard deviations to be large but clearly that does not seem to be the case in our models as the significance levels for the variables were extremely high in most cases.

[39] The likelihood of multicollinearity in regime 3 is significantly smaller due to a more compact design.

[40] Although O´Brien (2007) is complacent even with significantly higher values and points out that the VIF value in itself is inadequate to measure multicollinearity. For this reason we are not too concerned with some of the higher values as our coefficients are still clearly significant.

As per the robustness of the results we do concur that the precise behaviour of EONIA did most likely change to some extent as a function of time despite our division into clearly different regimes. Further splitting of the sample would have caused problems as the sample size would have reduced. Therefore, the current division can be seen as a compromise and something that seems to, in light of the results, reflect the typical determination of the rate in different market environments.

8. CONCLUSIONS

This thesis has broadly defined the monetary policy implementation framework of the ECB and provided a stylized characterization of the money market turmoil during the financial crisis starting in 2007. This provided us with a backdrop on which to construct and calibrate our model and subsequently interpret the results of our estimations, which aimed empirically to quantify the effects of the financial crisis and changes to the monetary policy framework of the ECB.

To conclude, we would like to highlight a couple of things from our research. Firstly the unprecedented turmoil in the money markets and subsequent reaction from the ECB had substantial impact on the determination of EONIA, which experienced first an increase in volatility and later, after the changes to the monetary policy implementation framework, a un-alignment from the minimum bid rate. The reactions to the market frictions by the ECB were proven to have a crucial stabilizing effect on the market rate.

We have shown how the increased frictions in the money market magnified many of the already previously established effects contributing to the level of the rate. We found an increase in magnitude in the liquidity, calendar, bidding behaviour, market friction and refinancing pressure effects. Interest rate expectations were not found significant in line with expectations as the March 2004 reform effectively separated them from reserve fulfilment optimization. From a strictly liquidity perspective the EONIA was judged to present martingale properties, with the response to liquidity conditions increasing as the uncertainty surrounding the final liquidity conditions slowly dissipates towards the end of the maintenance period under regimes with the aim to target neutral liquidity conditions on average. The other effects mentioned before would however suggest, that the rate represents merely quasi-martingale properties.

As regards the era of full allotment our results are, according to our knowledge, the first to establish the EONIA response function to liquidity conditions deviating significantly from neutral. The contribution to the exit-strategies implemented is therefore to control the level of EONIA with the deposit facility rate in order to smooth out the liquidity effect visible, when the aggregate net use of the deposit facility is below 50 billion. The recent market developments after the maturity of the first 12-month operation have shown how a liquidity deficit filled with operations with maturities shorter than the maintenance period and banks controlling the level of liquidity obtained from these operations (i.e. full allotment) can cause significant fluctuations in the EONIA rate and cause upward pressure in EURIBOR fixings.

Further research areas that could draw from the results of this thesis are likely to surround issues related to the operational aspects of the monetary policy framework. For example understanding and measuring the structural demand for reserves and the pricing of liquidity risks related to this phenomenon. The seemingly rapid deterioration in market conditions should also be taken into account when discussing the possible new steady state in the money markets. This new steady state could impose additional requirements to the monetary policy implementation frameworks around the world. Attention should be focused on ensuring that the implementation would be flexible but also at the same time would encourage counterparties to trade actively in the money market and reduce the central bank´s intermediation. Key issues are therefore related to reserve requirements and open market operations as well as the use of the interest rate corridor. Voluntary reserve requirements could be an answer to the structural demand problem. The details of open market operations such as auction type, liquidity deficit and maturity structure might also provide answers to the issues highlighted by the financial crisis.

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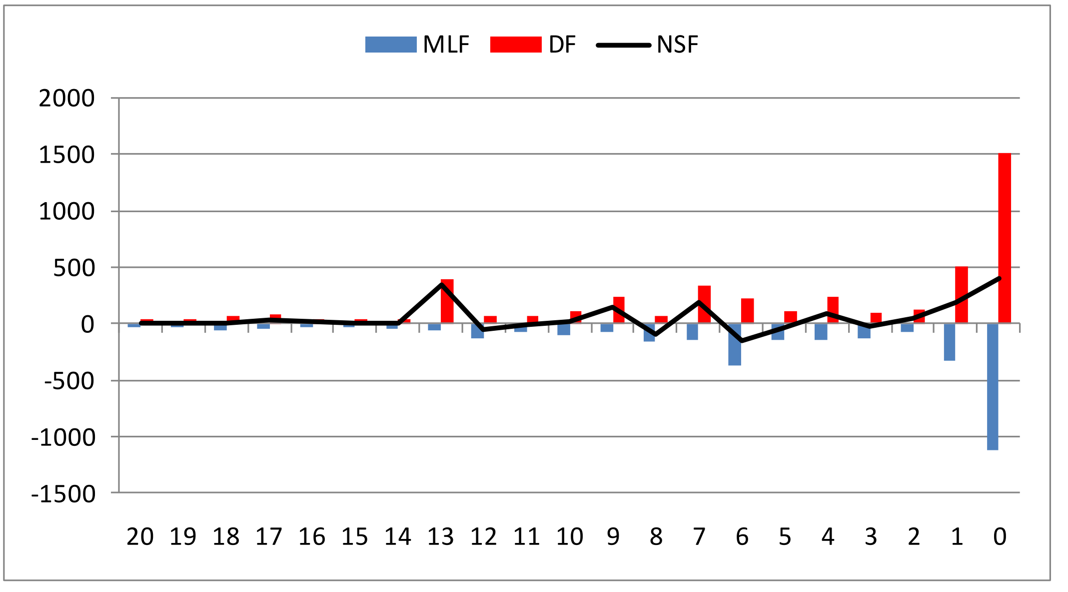
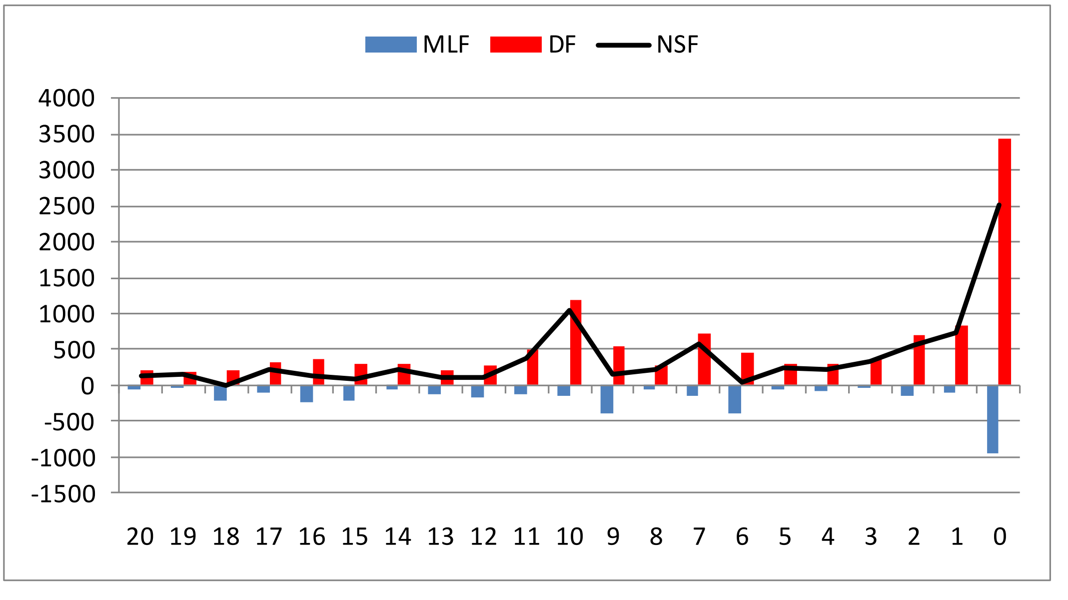
10. APPENDIX

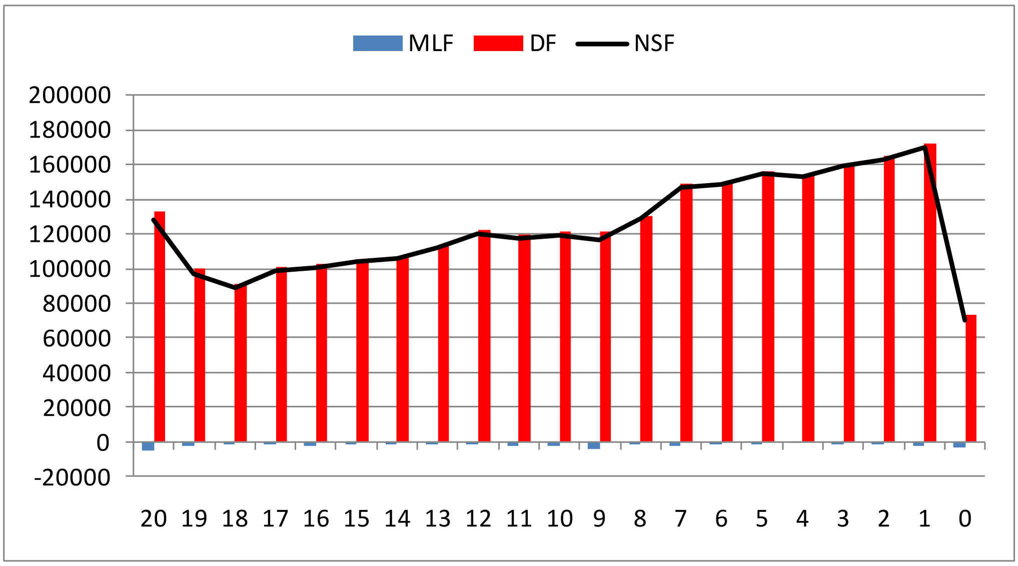
Appendix 1. Average recourses to standing facilities



Appendix 1.1. Average recourse to standing facilities during normal times.

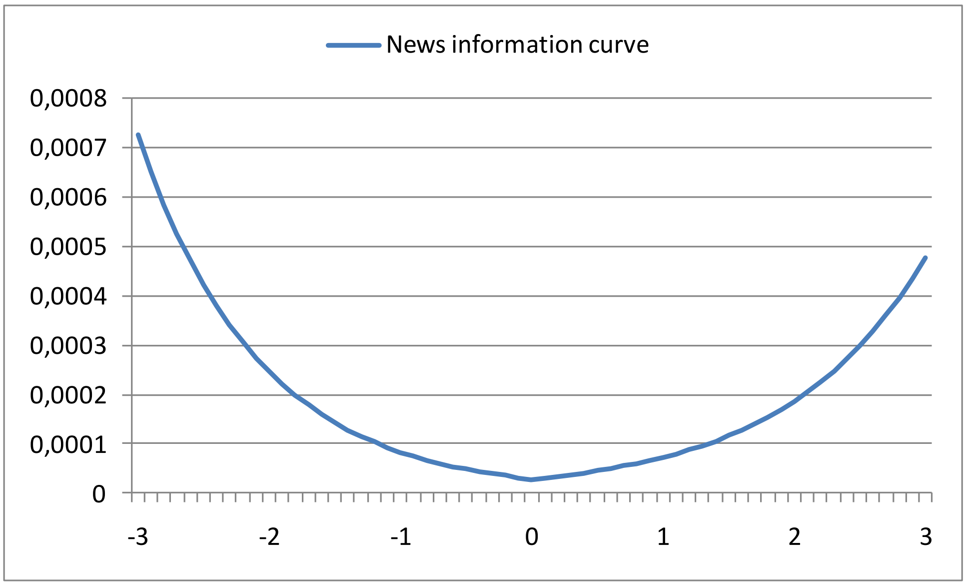


Appendix 1.2. Average recourse to standing facilities during the money market turmoil. Excluding the maintenance period 10th of September 2008 - 7th of October 2008 as an outlier.

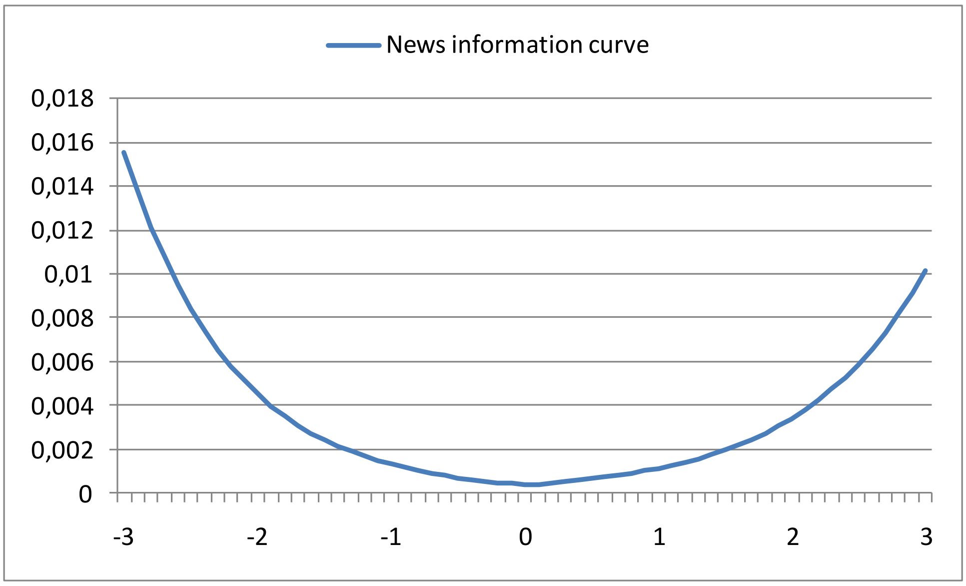


Appendix 1.3. Average recourse to standing facilities during full allotment.

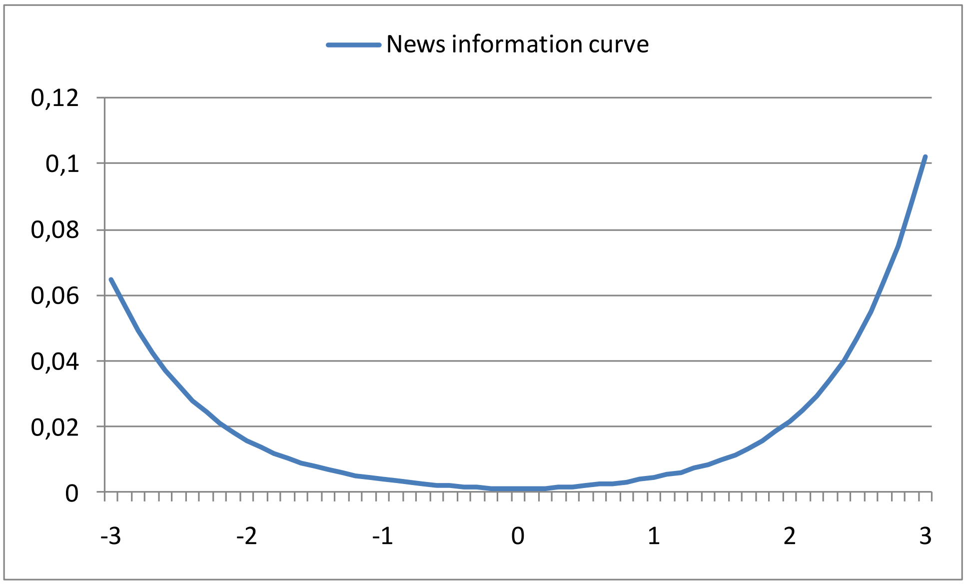
Appendix 2. News impact curves



Appendix 2.1. News information curve for EGARCH-model in regime 1. On the x-axis we have the standardized error (news) and on the y-axis variance.

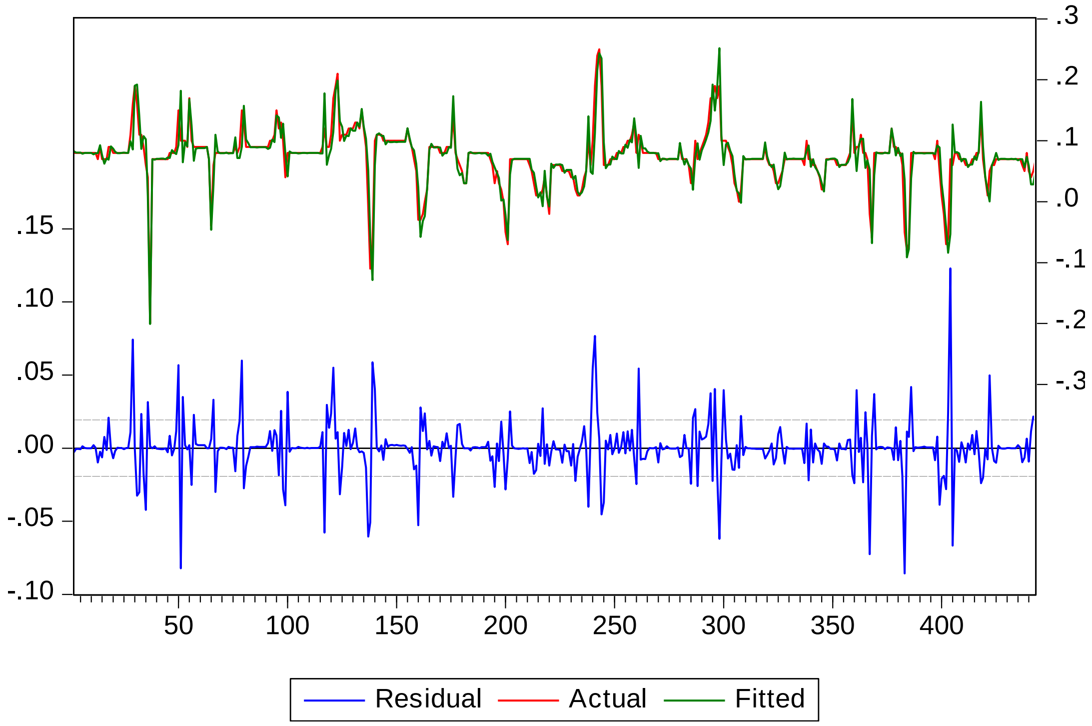


Appendix 2.2. News information curve for EGARCH-model in regime 2. On the x-axis we have the standardized error (news) and on the y-axis variance.

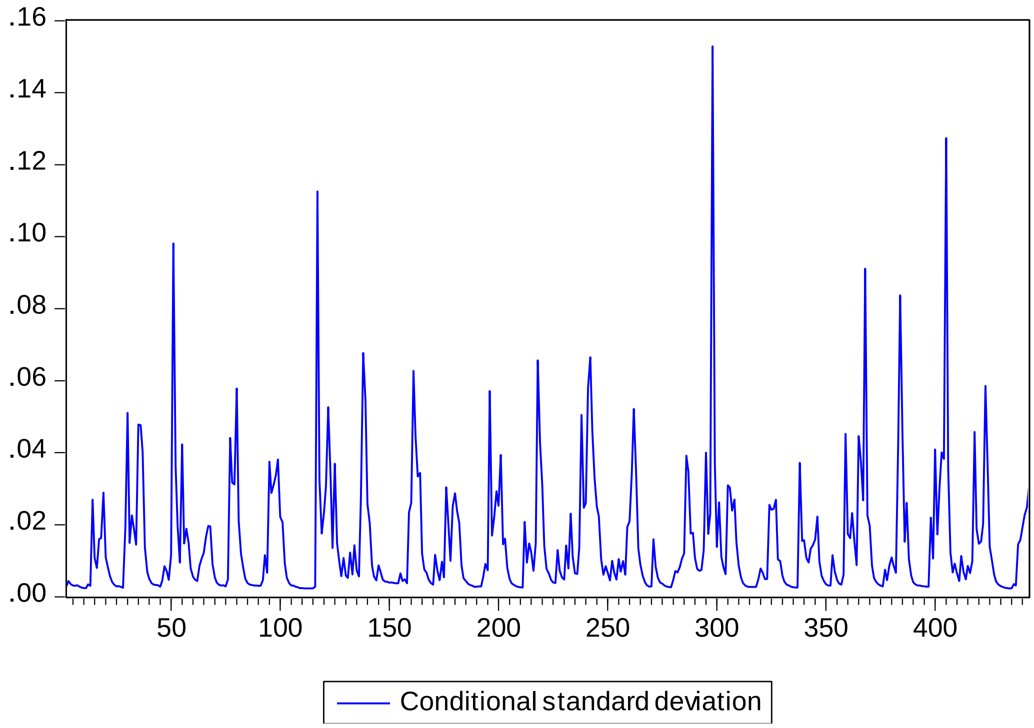


Appendix 2.3. News information curve for EGARCH-model in regime 3. On the x-axis we have the standardized error (news) and on the y-axis variance.

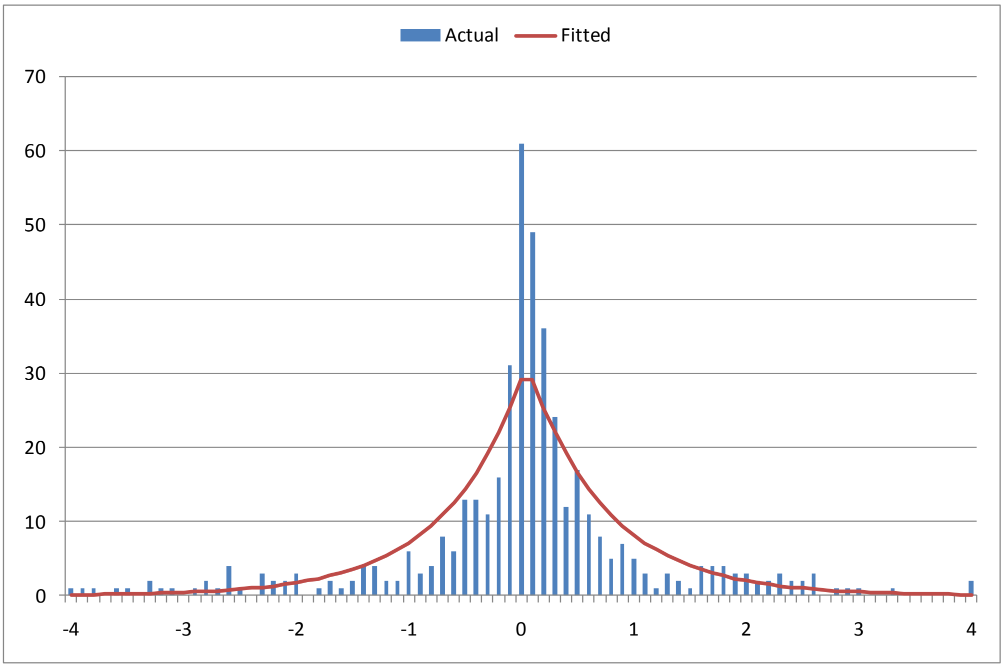
Appendix 3. Fit of the model for regime 1.



Appendix 3.1. Fit of the model in regime 1.

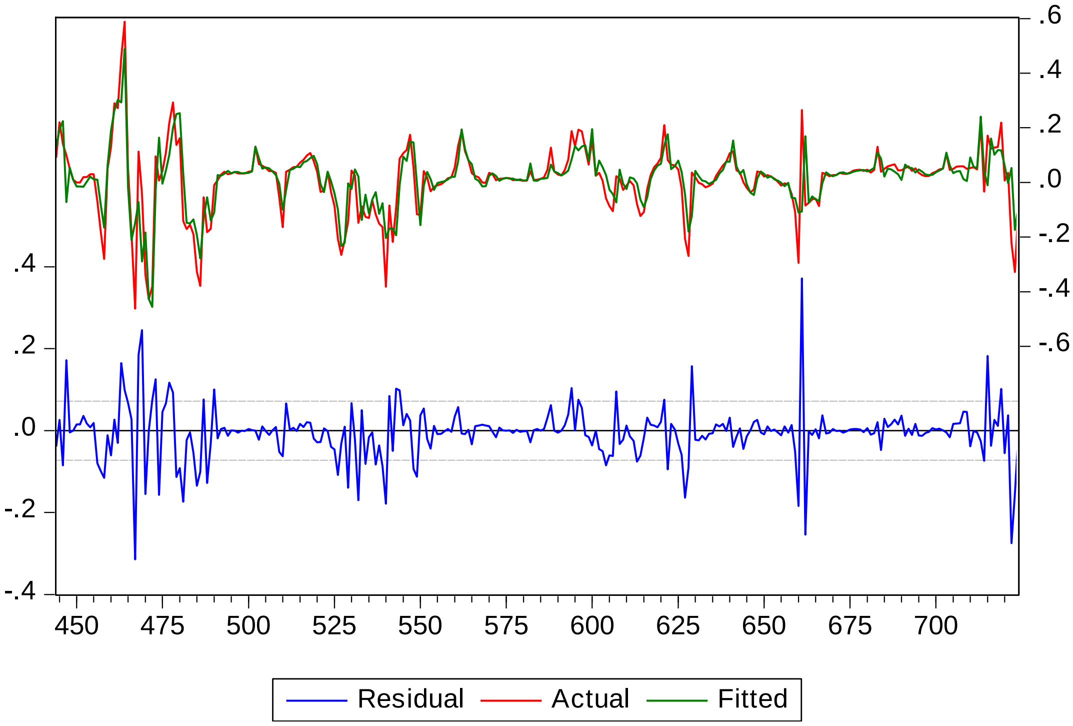


Appendix 3.2. Conditional standard deviation of regime 1.

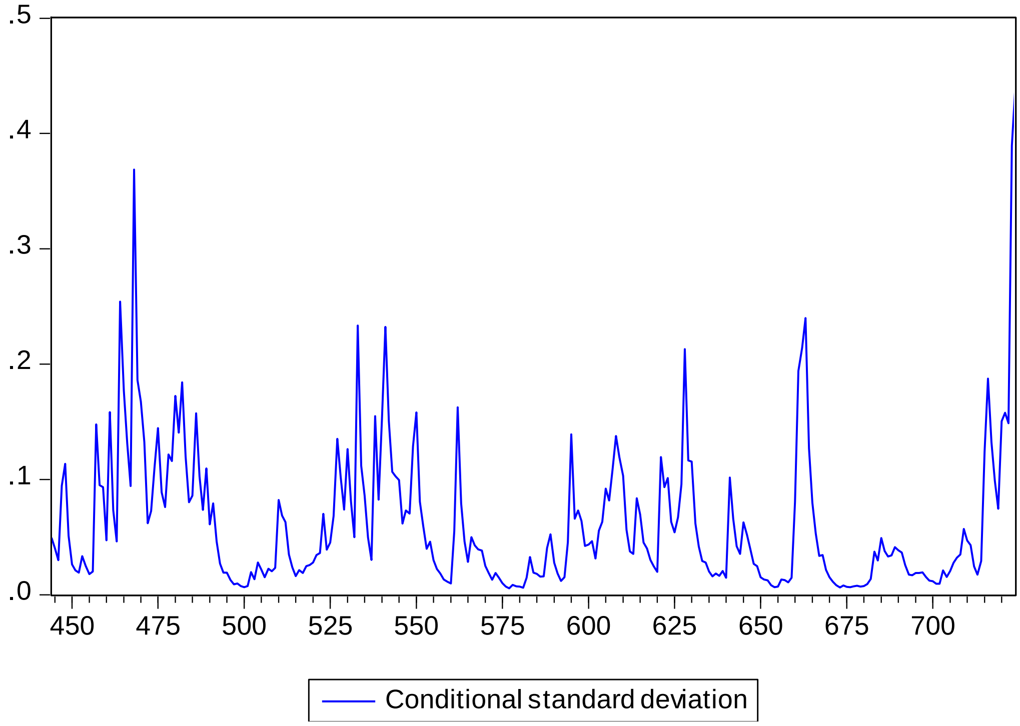


Appendix 3.3. Actual and fitted structure of standardized residuals in regime 1.

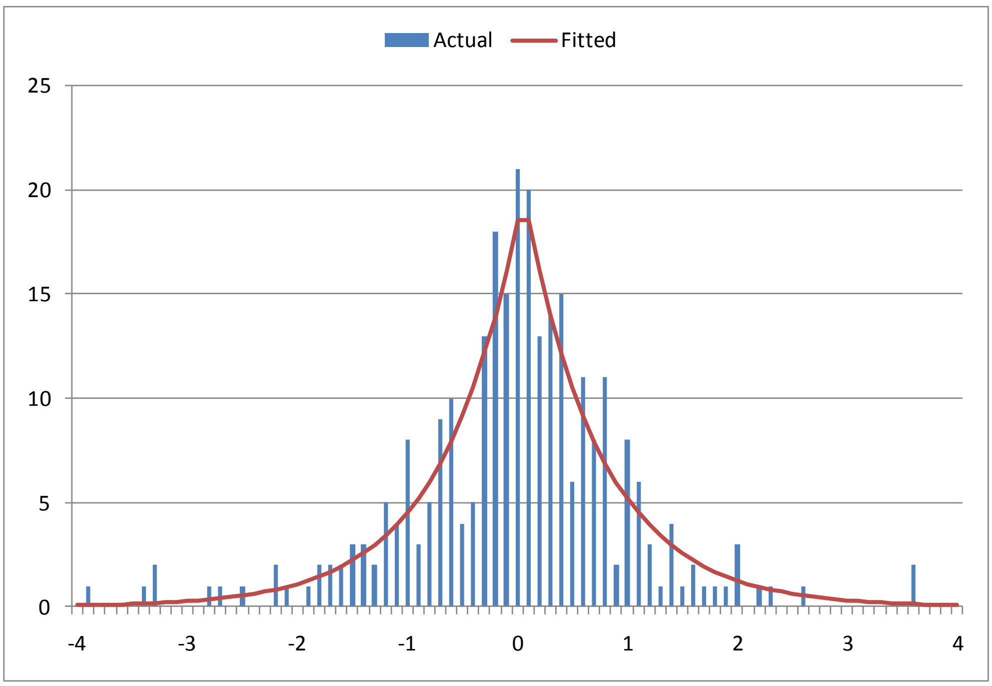
Appendix 4. Fit of the model for regime 2.



Appendix 4.1. Fit of the model in regime 2.

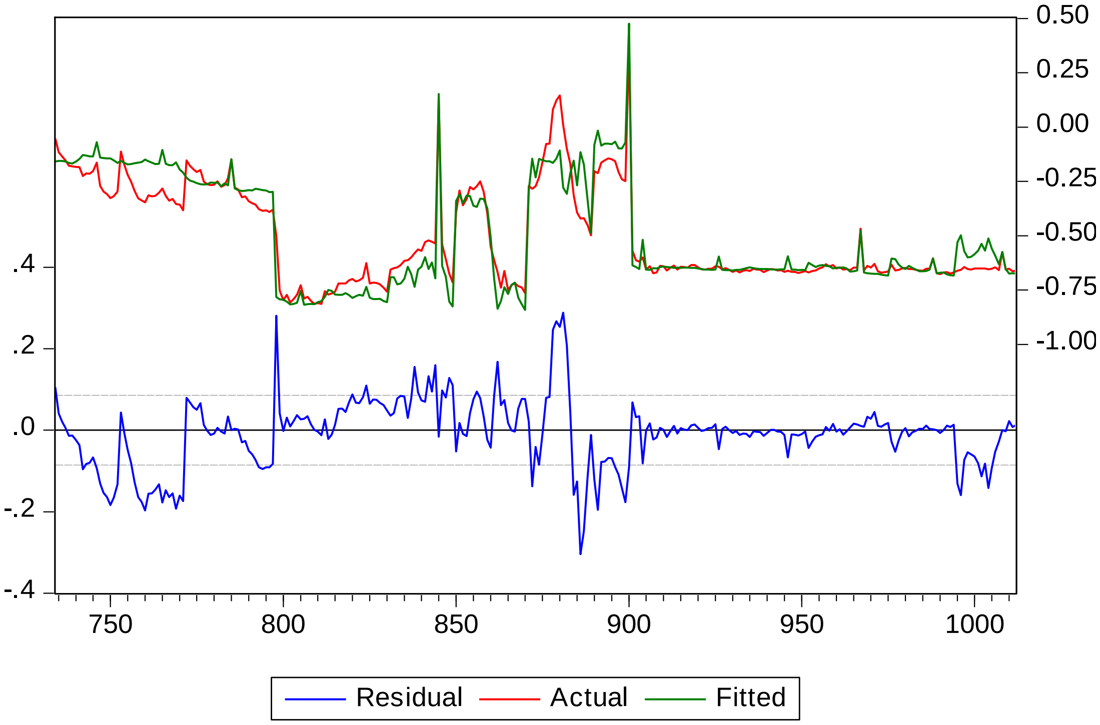


Appendix 4.2. Conditional standard deviation of regime 2.

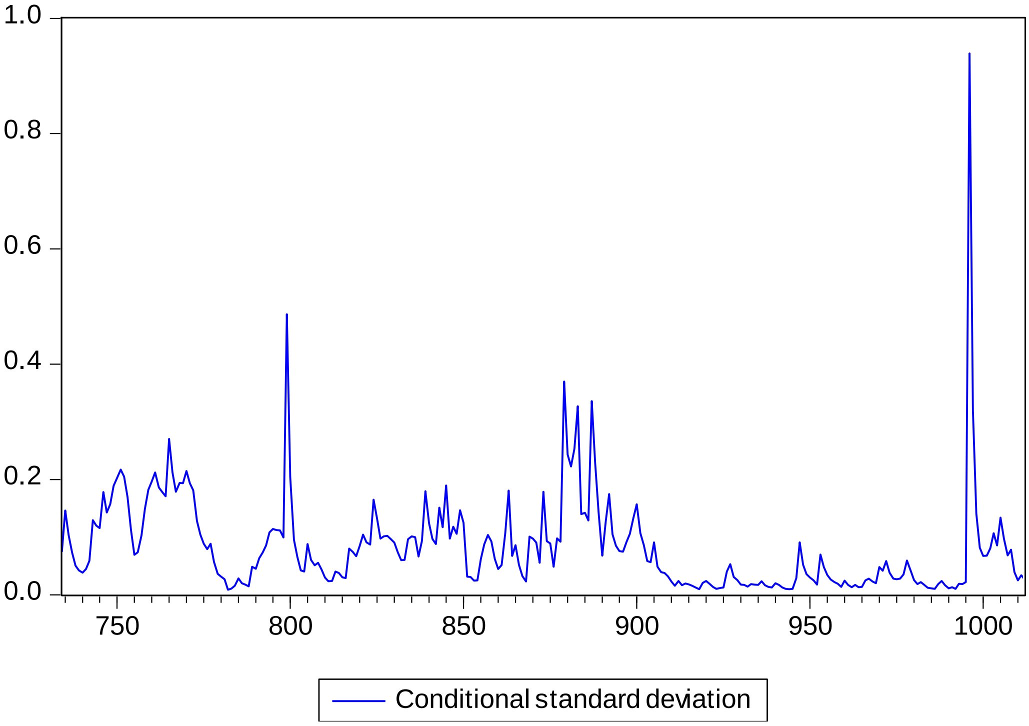


Appendix 4.3. Actual and fitted structure of standardized residuals in regime 2

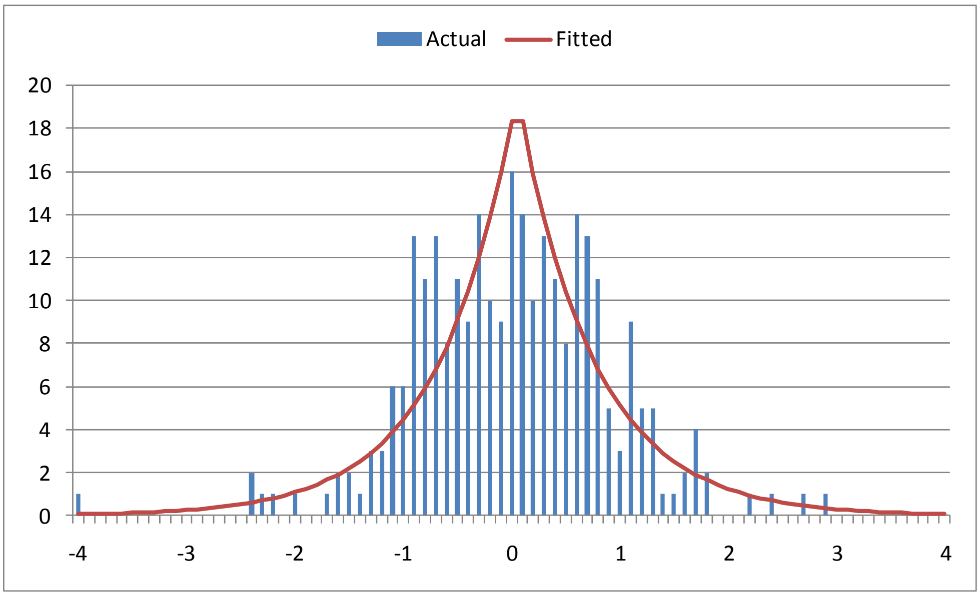
Appendix 5. Fit of the model for regime 3.



Appendix 5.1. Fit of the model in regime 3.



Appendix 5.2. Conditional standard deviation of regime 3.



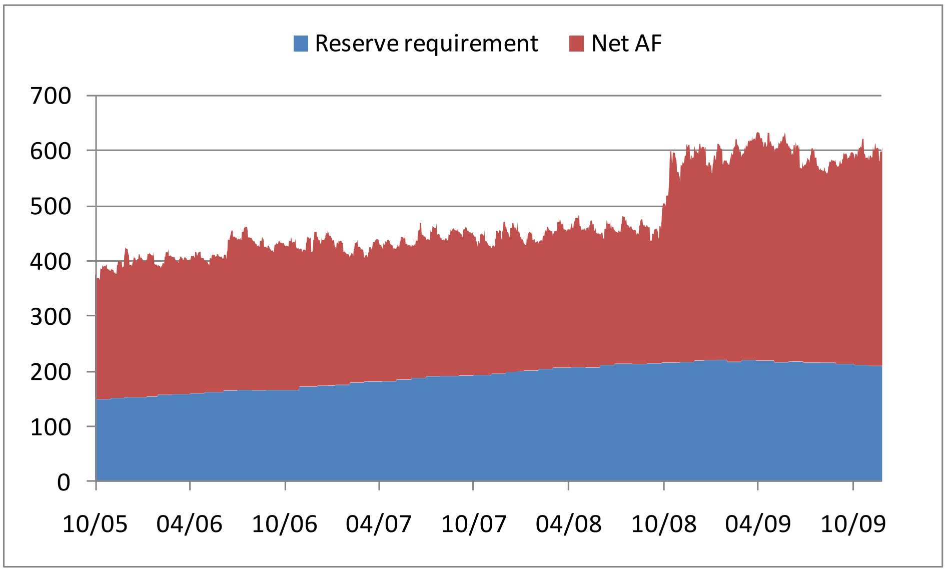
Appendix 5.3. Actual and fitted structure of standardized residuals in regime 3.

Appendix 6. Descriptive statistics of the standardized residuals.

	Regime 1	Regime 2	Regime 3
Mean	0,00	-0,07	-0,05
Median	0,00	-0,01	-0,01
Max	4,90	3,57	2,83
Min	-4,03	-4,00	-5,97
St. Dev.	1,15	1,01	0,93
Skewness	-0,08	-0,35	-0,78
Kurtosis	6,28	5,49	8,50

Appendix 6.1. Descriptive statistics of the standardized residuals.

Appendix 7. Liquidity deficit.



Appendix 7.1. Liquidity deficit broken down to its constituents – the reserve requirement and net AF. In EUR billions.

Appendix 8. Omitted variables tests.

Omitted Variables test

Omitted Variables: *fwmbr0, fwmbr1, fwmbr2, fwmbr3, fwmbr4*

Regime 1	Value	df	Probability
Likelihood ratio	6,1	5	0,3012

LR test summary:

	Value	df
Restricted LogL	1168,0	414
Unrestricted LogL	1171,0	409

Regime 2	Value	df	Probability
Likelihood ratio	2,5	5	0,7752

LR test summary:

	Value	df
Restricted LogL	396,3	251
Unrestricted LogL	397,6	246

Regime 3	Value	df	Probability
Likelihood ratio	7,4	5	0,1925

LR test summary:

	Value	df
Restricted LogL	436,0	271
Unrestricted LogL	439,7	266

Appendix 8.1. Results of the test for omission of interest rate expectation variables. Regime 3 performed manually as Eviews is unable to calculate this for custom non-linear functions.

Appendix 9. Wald tests for coefficient equality.

Wald Test:

Equation: Regime 1

Test Statistic	Value	df	Probability
F-statistic	7,80	(3, 405)	0,0000
Chi-square	23,40	3	0,0000

Null Hypothesis Summary:

Normalized Restriction (= 0)	Value	Std. Err.
C(2) - C(8)	-0,0048	0,0010
C(4) - C(8)	-0,0020	0,0022
C(6) - C(8)	-0,0016	0,0006

Restrictions are linear in coefficients,

Wald Test:

Equation: Regime 2

Test Statistic	Value	df	Prob.
F-statistic	3,49	(3, 242)	0,0164
Chi-square	10,47	3	0,0150

Null Hypothesis Summary:

Normalized Restriction (= 0)	Value	Std. Err.
C(2) - C(8)	-0,0176	0,0056
C(4) - C(8)	-0,0083	0,0042
C(6) - C(8)	-0,0025	0,0028

Restrictions are linear in coefficients,

Appendix 9.1. Wald test for equivalent coefficients of liquidity shock variables during the last MRO in regimes 1 and 2.

Appendix 10. Q-test for autocorrelation

Q-statistic test for autocorrelation

Q-statistic probabilities adjusted for 1 AR-term

	Regime 1				Regime 2			
Lag	AC	PAC	Q-Stat	Prob	AC	PAC	Q-Stat	Prob
1	0,01	0,01	0,03		0,08	0,08	1,69	
2	0,08	0,08	2,87	0,09	0,05	0,04	2,35	0,125
3	-0,09	-0,09	6,10	0,047	0,08	0,08	4,23	0,121
4	-0,03	-0,04	6,52	0,089	-0,06	-0,07	5,23	0,155
5	-0,01	0,01	6,56	0,161	-0,01	-0,01	5,25	0,262
6	-0,05	-0,06	7,82	0,166	-0,07	-0,07	6,59	0,253
7	-0,03	-0,03	8,19	0,225	-0,08	-0,06	8,51	0,203
8	0,00	0,01	8,19	0,316	-0,02	-0,01	8,68	0,276
9	-0,07	-0,08	10,32	0,243	-0,01	0,01	8,70	0,369
10	0,01	0,00	10,33	0,324	0,07	0,07	9,97	0,353
11	0,00	0,01	10,33	0,412	0,01	-0,01	10,00	0,441
12	0,07	0,05	12,48	0,329	-0,08	-0,10	11,96	0,366
13	-0,01	-0,02	12,56	0,402	-0,01	-0,02	11,99	0,447
14	0,04	0,03	13,11	0,439	0,05	0,06	12,62	0,477
15	-0,09	-0,08	16,58	0,279	-0,11	-0,10	15,89	0,32
16	0,03	0,03	17,05	0,316	-0,04	-0,03	16,33	0,36
17	0,00	0,02	17,05	0,383	-0,10	-0,09	19,33	0,252
18	0,11	0,10	22,72	0,159	0,07	0,11	20,77	0,237
19	0,02	0,02	22,86	0,196	-0,06	-0,09	21,78	0,242
20	-0,01	-0,02	22,89	0,242	-0,09	-0,09	24,24	0,187
21	0,05	0,07	23,91	0,246	0,00	-0,01	24,24	0,232
22	0,05	0,06	25,16	0,24	-0,03	0,00	24,44	0,272
23	-0,04	-0,04	25,73	0,264	0,00	-0,01	24,44	0,325
24	-0,03	-0,03	26,10	0,296	0,06	0,03	25,60	0,32
25	0,02	0,06	26,36	0,335	0,01	0,02	25,65	0,371
26	-0,03	-0,04	26,82	0,365	-0,04	-0,05	26,13	0,401
27	-0,04	-0,03	27,74	0,372	0,10	0,09	29,48	0,29
28	-0,04	-0,03	28,53	0,384	0,03	-0,01	29,73	0,327
29	0,02	0,03	28,75	0,425	0,07	0,08	31,06	0,314
30	-0,05	-0,08	30,11	0,409	0,01	-0,01	31,07	0,362

Appendix 10.1. Q-statistic test for remaining autocorrelation with 1 AR-term for regimes 1 and 2.

Appendix 11. Variance inflation factors

Regime1

Variable	Coefficient variance	Centered VIF
MP1AFM	5,12E-06	10,9
MP1POL	2,95E-05	9,8
MP2AFM	1,80E-05	52,7
MP2POL	7,62E-05	6,2
MP3AFM	2,08E-06	3,7
MP3POL	4,95E-05	5,4
MP4AFM	7,88E-07	1,7
MP4POL	4,15E-05	3,4
MRO1AFM	1,24E-07	1,4
MRO1POL	8,08E-06	5,8
MRO2AFM	9,95E-08	2,8
MRO2POL	4,90E-06	12,4
MRO3AFM	6,05E-07	2,2
MRO3POL	1,23E-05	11,8
MRO4AFM	4,09E-07	1,4
MRO4POL	1,50E-05	3,6
LASTM	1,77E-05	1,8
LASTQ	6,12E-05	1,3
SPTARGET	1,04E-04	1,7
BTCMARG	1,07E-02	4,0
LTROOUT	1,01E-08	2,0
LIBOIS	1,88E-02	2,0
DEVMEAN	6,04E-03	4,7
OUTLIER	8,09E-05	7,5
OUTLIER2	2,10E-03	41,2
OUTLIER3	2,31E-04	1,0
AR(1)	6,32E-03	2,7

Appendix 11.1. Variance inflation factors for regime 1.

Regime 2

Variable	Coefficient variance	Centered VIF
MP1AFM	7,18E-05	6,6
MP1POL	2,35E-05	3,8
MP2AFM	1,50E-04	4,9
MP2POL	2,18E-05	10,2
MP3AFM	5,54E-05	6,1
MP3POL	9,55E-06	15,9
MP4AFM	2,93E-05	4,3
MP4POL	1,01E-05	4,6
MRO1AFM	7,90E-06	2,5
MRO1POL	3,94E-07	6,8
MRO2AFM	5,19E-06	1,8
MRO2POL	4,25E-07	4,8
MRO3AFM	4,63E-06	1,7
MRO3POL	4,05E-07	3,9
MRO4AFM	2,32E-05	7,9
MRO4POL	1,43E-06	11,6
LASTM	2,77E-04	1,9
LASTQ	6,14E-03	4,3
SPTARGET	1,55E-03	1,8
MROBEF	1,26E-03	1,3
BTCMARG	1,17E-02	4,6
LTROOUT	1,27E-07	5,7
LIBOIS	5,95E-03	3,5
CRISISLAST	3,56E-03	8,7
SLTRO3M	5,57E-03	2,8
DEVMEAN	9,18E-03	7,4
BNP	3,01E-03	2,2
LEHMAN	3,81E-04	1,3
AR(1)	9,84E-03	5,2

Appendix 11.2. Variance inflation factors for regime 2.