

# Funding Liquidity Risk: Definition and Measurement \*

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## Abstract:

In this paper we propose definitions of funding liquidity and funding liquidity risk and present a simple, yet intuitive, measure of funding liquidity risk based on data from open market operations. Our empirical analysis uses a unique data set of all main refinancing operation auctions conducted at the ECB between June 2005 and October 2008. We find that our proxies for funding liquidity risk are typically stable and low, with occasional spikes, especially during the recent turmoil. We are also able to document downward spirals between funding liquidity risk and market liquidity.

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## 1. Introduction

Many historical episodes have highlighted the crucial role of funding liquidity for banking crises. The events since August 2007 have been no different. They bore all the hallmarks of a funding liquidity crisis as interbank markets collapsed and central banks around the globe had to intervene in money markets at unprecedented levels. Nonetheless, a concrete measure of funding liquidity risk using accessible data remains so far elusive. This paper addresses this gap by developing a measure based on banks' bids during open market operations. Our empirical analysis uses a unique data set of 142 main refinancing operation auctions conducted at the ECB between June 2005 and October 2008. Similar to measures of market liquidity, we find that our proxies for funding liquidity risk are typically stable and low, with occasional spikes, especially during the recent turmoil. Our measure also allows us to assess the interactions of market liquidity and funding liquidity risk. Even though downward spirals between both have been a key concern for most policy makers during this and previous crises, we are the first to provide robust empirical evidence.

Measurement without definition is, however, difficult if not impossible. In this paper we define *funding liquidity* as *the ability to settle obligations with immediacy*. Consequently, a bank is illiquid if it is unable to settle obligations in time. In this case the bank defaults, resulting in losses to shareholders and possibly depositors. Given this definition, it can be said that *funding liquidity risk is driven by the possibility that over a specific horizon the bank will become unable to settle obligations with immediacy*. In particular we show that funding liquidity risk has two components: future (random) in- and outflows of settlement assets such as money and future (random) prices of obtaining funding liquidity from different sources. In contrast to other definitions used by academics and practitioners we show in the first part of the paper that our definitions have important properties, shared by definitions of other risks. First, like solvency, funding liquidity is point-in-time and a binary concept as a bank is either able to settle obligations or not. Funding liquidity risk on the other hand can take infinitely many values depending on the underlying funding position of the bank. As any other risk, it is forward looking and measured over a specific horizon.

Our analysis also highlights that funding liquidity is best understood as a flow concept, i.e. a bank is liquid as long as outflows of money are less or equal to inflows and the stock of money. In a modern economy many different forms of money - or settlement assets more broadly - exist. For our analysis we focus on the most important settlement asset in the economy. In the Eurosystem, but also in most other economies, large value payment and settlement systems rely on central bank money as the ultimate settlement asset (see CPSS, 2003). Hence, the ability to settle is crucially linked with the ability to satisfy the demand for central bank money, which banks can obtain directly from the central bank at open market operations (OMO), the interbank market, by selling assets or by raising customer deposits.

Ideally and in line with other risks, we would want to measure funding liquidity risk by the distribution summarising the stochastic nature of in- and outflows and random prices banks need to pay to obtain the necessary funds. However, this information is unavailable. Instead, we observe banks' bids during open market operations. In the second part of the paper we draw on the relevant literature and argue that in equilibrium there is a relationship between banks' bids and liquidity risk, i.e. banks submit informed bids in the OMO taking into account information about future liquidity needs and future prices it has to pay to obtain it from other sources. Based on the model of Nyborg and Strebulaev (2004) as a basis, we argue that if there are frictions in interbank and asset markets, banks with higher funding liquidity risk will bid more aggressively, the more so the higher their funding liquidity risk. Hence, a higher spread indicates higher risk. This is intuitive as banks with higher funding liquidity risk are willing to pay a higher price to obtain funds from the central bank to hedge this risk.

Our measure significantly improves on other measures used for funding liquidity risk so far. Banks' own funding liquidity risk measurement such as gap analysis or stress testing is essentially equivalent to a very detailed analysis of the stock flow constraint we suggest in the first part of the paper (see Matz and Neu, 2007, or Banks, 2005). This is very data intensive and relies entirely on confidential information. Whilst we also use confidential data from the ECB, other central banks have similar data available. And our broadly similar measure of aggregate funding liquidity risk can be easily derived from public data provided by the ECB after each OMO. Therefore our method allows for a frequent and timely assessment of funding liquidity risk in an environment characterised by limited data availability.

Aggregate funding liquidity risk has also been measured by the spread between interest rates in the interbank market and a risk free rate (e.g. see IMF, 2008). This is the average price for obtaining liquidity in the interbank market. In this sense it reflects a key component of funding liquidity risk. However, the spread is not only determined by the average funding liquidity risk but impacted by several other factors (e.g. see Michaud and Upper, 2008). Gyntelberg and Wooldrige (2008) also show that during the recent turmoil the interbank market rate has become less representative of actual funding conditions because of increased uncertainty, dispersion in the credit quality across banks and greater incentives to strategically misreport funding costs.<sup>1</sup> But most importantly, the spread between interest rates in the interbank market and a risk free rate is purely a price measure and it does not reveal anything about market access, which maybe severely impaired during crisis, nor the volume of net-liquidity demand – the second component of funding liquidity risk.

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<sup>1</sup>. Interbank rates such as LIBOR are fixed by surveying a set of banks each day about their own funding costs. Findings by the Wall Street Journal indicated that actual interbank interest rates have been even higher than indicated by LIBOR during the recent turmoil. See *The Wall Street Journal*, "Bankers cast doubt on key rate amid crisis", 16 April 2008.

Our empirical analysis is based on a unique data set of 142 main refinancing operation (MRO) auctions conducted between June 2005 and December 2007 in the euro area. We effectively have information on the bidding schedules of each of the 877 participating banks in the relevant auctions. We find that our proxies have intuitive properties. Namely, they show persistence at low levels with occasional spikes that funding liquidity risk is supposed to have according to market practitioners (see Matz and Neu, 2007). Moreover, these properties are also shared by measures for market liquidity (e.g. see Amihud, 2002; Chordia et al., 2000, 2002; Pastor and Staumbaugh, 2003). As already discussed, we are also able to show that there are strong negative interrelationships between our measure of funding liquidity risk and a measure for market liquidity. In this sense higher funding liquidity risk implies lower market liquidity. We are able to show that this effect is only present during the turmoil. This is exactly what theory (e.g. Brunnermeier and Pedersen, 2007) would suggest as interactions should only occur once banks face funding liquidity risk.

The remainder of the paper is structured as follows. In Section 2 we introduce our definition of funding and funding liquidity risk. After providing a short overview of OMOs in the euro areas in Section 3, we analyse the sources of funding liquidity risk and show that higher funding liquidity risk will result in higher bids during OMOs in Section 4. Section 5 introduces our measures and Section 6 presents the bidding data on which our measures rely. In Section 7 we present the empirical measures and empirical evidence on their relationship with market liquidity risk. Finally, Section 8 concludes.

## **2. Definition of funding liquidity and funding liquidity risk**

### **2.1. Funding liquidity and funding liquidity risk**

We define *funding liquidity* as *the ability to settle obligations with immediacy*. Consequently, a bank is illiquid if it is unable to settle obligations in time. In this case the bank defaults, and shareholders and possibly also depositors incur losses. Given this definition it can be said that *funding liquidity risk is driven by the possibility that over a specific horizon the bank will become unable to settle obligations with immediacy*. In particular we show that funding liquidity risk has two components: future (random) in- and outflows of money and future (random) prices of obtaining funding liquidity from different sources.

It is worth to highlight important differences between funding liquidity and funding liquidity risk: Funding liquidity is essentially a binary concept, i.e. a bank can either settle obligations or it cannot. Funding liquidity risk on the other hand can take infinite many values as it is related to the distribution of future outcomes. Implicit in this distinction is also a different time horizon. Funding liquidity is associated to one particular point in time. Funding liquidity risk on the other hand is always forward looking and measured over a particular horizon. In this

respect, concerns about the future ability to settle obligations, i.e. future funding liquidity, will impact on current funding liquidity risk.

The distinction between liquidity and liquidity risk is straightforward and similar to other risks. For example, a similar distinction can be made between credit risk and default. For example a borrower can be in default or not. Whilst default is a binary concept measured at one particular point in time, credit risk is not. The credit risk associated with a loan is determined by the likelihood that the borrower will default over a particular horizon.<sup>2</sup> Therefore, credit risk is always used as a forward looking measure and can take infinite many values, depending on the underlying credit worthiness of the borrower.

Surprisingly a distinction in the definition of funding liquidity and funding liquidity risk is not made by practitioners and academics. In terms of funding liquidity, the IMF defines it as “the ability of a solvent institution to make agreed-upon payments in a timely fashion” (p. xi, IMF, 2008). This is very similar to ours, even though we argue that it may well be the case that an institution is liquid but solvent. Borio (2000), Strahan (2008) or Brunnermeier and Pedersen (2007) define funding liquidity as the ability to raise cash at short notice either via asset sales or new borrowing. Whilst it is the case that banks can settle all their obligations in a timely fashion if they can raise cash at short notice, the reverse is not true as a bank may well be able to settle its obligations as long as its current stock of cash is large enough. As the ability to raise cash can vanish (Borio, 2000) this definition is implicitly forward looking and therefore closer associated to funding liquidity risk. The definition of the Basel Committee of Banking Supervision is close to our definition even though it mixes the concepts of funding liquidity and funding liquidity risk. In their view liquidity is “the ability to fund increases in assets and meet obligations as they come due” and they argue that “within this definition is an assumption that obligations will be able be met at a ‘reasonable cost’ ” (p.2, BCBS, 2008).<sup>3</sup> While the first part is essentially equivalent to our definition of funding liquidity, the second part is in our view more related to funding liquidity risk even though it is unclear what ‘reasonable’ really means.

Our definition raises the question how banks settle obligations. As discussed in the introduction, many different settlement assets exist in an economy (see CPSS, 2003). Generally this is not realised as for example different forms of money in one currency are close substitutes and can be converted into each other at par. The most visible money constitutes of banknotes and coins, but this only plays a minor role as settlement asset. On the other hand, liabilities of commercial banks – which are also referred to as commercial bank money – represent the largest stock of money in the economy. Most transactions, especially those

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<sup>2</sup> A broader definition of credit risk also accounts for the stochastic nature of loss given default, changes in the underlying credit quality and changes in exposure at default.

<sup>3</sup> Even though it is implicit that the BCBS is defining funding liquidity it is interesting that this definition talks about liquidity in general.

involving private agents, are settled in commercial bank money. However, for banks funding liquidity risk management central bank money plays a crucial role as this is the one of the most, if not the most, important settlement asset. In the Eurosystem, but also in most other economies, large value payment and settlement systems rely on central bank money as the ultimate settlement asset (see CPSS, 2003).<sup>4</sup> Hence, the ability to settle is crucially linked with the ability to satisfy the demand for central bank money. Central bank money, in turn, consists mainly of deposits held by commercial banks with the central bank.<sup>5</sup> In Annex 2 the role of central bank money as a settlement asset is elaborated further.

## 2.2 Funding liquidity as a stock-flow concept

As has been pointed out by Drehmann, Elliot and Kapadia (2007) funding liquidity is related to flows. The authors also show that the theoretical literature on liquidity can be expressed as a flow constraint.<sup>6</sup> Given our definition, a bank is able to satisfy the demand for money, and hence is liquid, as long as at each point in time outflows of money are smaller or equal to inflows and the stock of money held by the bank. Following this reasoning, a stock flow constraint provides an easy and straightforward representation:

$$Outflows_t \leq Inflows_t + Stock\ of\ Money_t \quad (1)$$

Annex 1 provides a more detailed breakdown of in- and outflows and explains in depth that the key settlement asset for all components is central bank money. For our purposes, money in constraint (1) can therefore be thought of as central bank money.

For measuring funding liquidity risk, we focus on the net volume of liquidity (i.e. central bank money) needed in order to avoid illiquidity. This can be represented by a new variable which we call the net-liquidity demand (*NLD*). We construct this variable from the stock flow constraint. Namely we take the difference between all outflows (*Outflows*) and contractual (i.e. known) inflows (*Inflows<sup>due</sup>*) net of the stock of central bank money (*M*):

$$\begin{aligned} NLD_t &= Outflows_t - (Inflows_t^{due}) - M_t \\ &\leq p_t^D L_{new,t}^D + p_t^{IB} L_{new,t}^{IB} + p_t^A A_{sold,t} + p_t^{CB} CB_{new,t} \end{aligned} \quad (2)$$

*NLD* is the net amount of central bank money the bank needs to remain liquid. In case of a deficit (i.e. outflows are larger than inflows and the stock of money), the inequality highlights that *NLD<sub>t</sub>* has to be financed either by new borrowing from depositors ( $L_{new}^D$ ), from the interbank market ( $L_{new}^{IB}$ ), selling assets ( $A_{sold}$ ) or accessing the central bank ( $CB_{new}$ ). All these sources have different prices  $p$ . If there is a positive net liquidity demand which cannot be

<sup>4</sup> For a history of central banks' role in interbank payment systems see Norman et al (2006).

<sup>5</sup> Cash and central bank reserves have also be labelled as high powered money in the monetary economics literature (e.g. see Friedman and Schwarz, 1963).

<sup>6</sup> See also Drehmann (2007).

funded with new inflows, the bank will become illiquid and default. Conversely, if the bank has an excess supply of liquidity, no borrowing is necessary and the bank can sell the excess liquidity on the market.<sup>7</sup>

Whilst  $NLD_t$  is the funding liquidity constraint faced by the bank in each period, funding liquidity risk is related to future developments of  $NLD$ . For example, if funding liquidity risk is assessed over a one period horizon, then it could be analyzed by the distribution of  $NLD_{t+1}$ . Equation 2 shows that funding liquidity risk has two random components: volumes and prices.

Random volumes of  $NLD$  are the first component of funding liquidity risk. Although contractual obligations (whether in- or outflows) and their maturities are known, the possibility of defaulting counterparties can lead to some randomness. Moreover, other sources of outflows can be rather volatile. For example, off-balance sheet commitments can induce large swings in cash flows as seen during the recent crisis. Also note that outflows are partly endogenously determined. Indeed, under severe stress the bank may decide to cut back on new lending or reduce asset purchases. However, to ensure that franchise value is not lost, banks are generally reluctant to cut established credit relationships, unless absolutely necessary. Finally, some inflows are also endogenously and others exogenously determined. As we discuss in detail below, banks choose optimally from which source they want to obtain funding in case they face a shortfall and therefore endogenously affect inflows. Nonetheless, other inflows are exogenous, as depositors not only withdraw but also deposit money in the bank in a random fashion.

Random prices are the second component of funding liquidity risk. Ex-ante, prices of obtaining liquidity from different sources are, to some extent, uncertain. As we discuss in detail below, prices in the central bank auction and in the interbank market depend on the realisation of unknown shocks. The same holds for the price of liquidity from selling assets, especially in periods of turmoil. Nevertheless, certain prices are predetermined. These are the prices for customer deposits, as they are endogenously set by the bank. The prices for obtaining money from the central bank via the marginal facilities are also given.

The question for this paper is how to measure liquidity risk given the stochastic nature of  $NLD$ . Ideally and in line with other risks, we would want to measure funding liquidity risk by the distribution summarising the stochastic nature of in- and outflows and the random prices banks need to pay to obtain the necessary funds. However, even banks with access to far more data are unable to construct the full distribution. We circumvent this problem by focusing on an important liquidity source as shown in equation 2, e.g. central bank auctions, ( $CB_{new}$ ) and the banks' bids in terms of price and volume we observe during open market operations. While

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<sup>7</sup> Ex-post inflows always equal to outflows as long as the bank does not fail. High inflows are always absorbed by asset purchases or new lending, for example in the interbank market. If at the end of the period banks have excess inflows of central bank money they will deposit them with the marginal deposit facility at the central bank.

doing that, we have to bear in mind that in equilibrium there is a relationship between prices for liquidity in different markets, i.e. a bank submits informed bids in the main refinancing auctions (MRO), after taking into account information about its own liquidity needs and about the price and volume of liquidity it can get from other sources. In Section 4 below we show that bids, or more precisely the (adjusted) spread between the bid and the minimum bid rate, contain information about funding liquidity risk and can therefore be used as a proxy measure. There we also discuss price fluctuations in greater detail. However, before we discuss the theoretical background for our measure it may be useful to provide a more thorough discussion on the institutional background of open market operations in the euro area for those who are less familiar with OMOs.

### **3. Open Market Operations in the euro area**

In the euro area OMOs are mainly carried out as either main financing operations (MROs), which are conducted weekly and have a maturity of one week or as long term refinancing operations (LROs), which are conducted less frequently and have a maturity of 3 months. Additionally the ECB conducts fine tuning operations, if there is a need for an additional and extraordinary injection or absorption of central bank money.

As MROs form the basis of our measure we discuss them in more detail. From March 2005 until 7 October 2008 MROs were typically conducted as standard flexible rate tenders until. This means that during each MRO auction eligible banks can submit bids (volume and price) at up to ten different bid rates at the precision of one basis point (0.01%). Prices and volumes are unconstrained, except for the minimum bid rate, which equals the policy rate set by the Governing Council. Banks are only required to submit sufficient collateral for the allotted liquidity. The auction is price-discriminating, i.e. every successful bidder has to pay her bid. At the marginal rate, depending on the aggregate bid schedule, bids may be rationed, so that everyone takes the same pro rata amount of the remaining liquidity. An example of an aggregate bid curve is shown in Chart A1 in the Appendix, which also shows the marginal rate and the total allotment for this particular auction.

To calibrate the allotment volume in the weekly MROs, the ECB takes the sum of the outstanding autonomous factors (such as banknotes, government deposits and net foreign assets) and banks' reserve requirements.<sup>8</sup> The allotment volume that satisfies exactly these

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<sup>8</sup>In the Euro area individual banks have to fulfil reserve requirements. Banks are allowed to hold positive or negative (relative) reserve balances with the CB within a specified period (i.e. relative to their requirements banks can hold more or less. Negative current accounts, so-called intraday credit, have to be collateralised and will be referred to the marginal lending facility at the end of the day). However reserve requirements have to be fulfilled on average across the maintenance period (usually between 28 and 35 days). At the start of the maintenance period the reserve requirements are determined by the Eurosystem for each bank and remain fixed during the

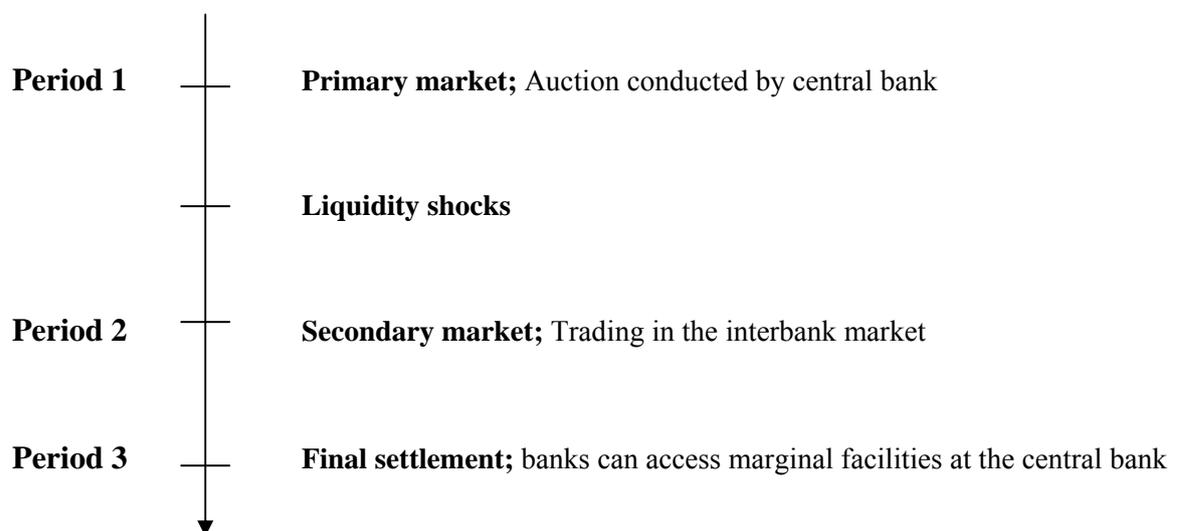
needs for central bank money in aggregate is called the "benchmark allotment". An ECB forecast of the autonomous factors on which basis the benchmark allotment is calculated is published prior to the bidding of the banks in the MRO.

In the period since August 2007, however, the ECB followed “frontloading” practices in deciding the allotted volume. In order to respond to the increased demand for liquidity for banks and help them to fulfil their reserve requirements earlier in the maintenance period, the ECB allotted significant amounts over the benchmark amount at the beginning of the maintenance period, linearly decreasing this amount towards the end, always trying to maintain balanced liquidity conditions at the end of the maintenance period (through absorbing the extra liquidity during the maintenance period with FTOs). As we discuss later, this development, however, is unlikely to reflect on our measure, given the adjustment we included for auctions of different sizes.

#### 4. Funding liquidity risk and bidding behaviour at OMOs

In this section we show that higher funding liquidity risk can be measured by the spread between the submitted bid and the minimum bid rate, by first analysing a stylised world where banks can only obtain liquidity from the central bank or the interbank market with or without frictions. In the last part of this section we broaden the discussion to analyse bidding behaviour when all sources of liquidity are considered.

**Figure 1: Stylised time line**



Following the seminar paper by Poole (1968), the literature has analysed a stylised time line focusing on the central bank and the interbank market when analysing bidding behaviour in

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period. The settlement day of the first MRO marks the start of the maintenance period. In addition, since April 2004, this is the day on which interest rate decisions of the Governing Council of the ECB become effective.

open market operations. For expositional purposes we will use the simplest case throughout the discussion in this section shown in Figure 1.

The stylised time line consists of three periods. In period 1, banks can acquire liquidity in the primary market by participating in the auction conducted by the central bank. Afterwards liquidity shocks materialise. It is important to stress that random volumes discussed above are nothing else than these liquidity shocks, implying random prices in period 2. In that period, banks trade in the interbank market. After interbank markets close in period 3, all obligations are settled and banks have to fulfil their reserve requirements set by the central bank.<sup>9</sup> At this point the market in aggregate may be short (or long) of liquidity and hence some banks may have to access the marginal lending (deposit) facility. Prices for the marginal facilities are considered key policy rates and are determined by the central bank, therefore they are already known in period 1. At the same time, these prices constitute an upper and lower bound for the interest rate in the interbank market in period 2, given that a bank with sufficient collateral can always recourse to the standing facilities at period 3 to settle any liquidity imbalances. In case of the euro area, banks pay 100bp on top of (below) the policy rate to access the marginal lending (deposit) facility.

At this point it is important to distinguish interbank markets with and without frictions as this will impact on interest rates in period 2, which in turn impact on the bids submitted by banks in the central bank auction – our variable of interest.

#### **4.1 Bidding with frictionless interbank markets**

Most theoretical models looking at bidding behaviour at open market operations conducted as price discriminating auctions are based on stylised set ups and rely on the assumption that interbank markets are frictionless and that central banks make no policy mistakes and always accurately provide the necessary (expected) amount of central bank money. For example, Välimäki (2002) and Ayuso and Repullo (2003) show that the optimal strategy for banks in such an environment is to only bid at the minimum bid rate. No bank is, therefore, willing to pay a premium above the minimum bid rate, in other words the spread is zero.

This result is intuitive. First consider the case where the central bank provides the correct amount of aggregate liquidity and banks are only subject to idiosyncratic liquidity shocks so that in period 2 there is no liquidity surplus or deficit. Given frictionless interbank markets, banks can always obtain sufficient funding in the secondary market, independent of the liquidity shocks they face. Hence, the interest rate in the interbank market equals the policy rate, which is also the minimum bid rate. This in turn implies that in period 1 bidding at the minimum bid rate is the only rational strategy and, the spread, which is our measure for

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<sup>9</sup> Most countries have positive reserve requirements for banks. However, theoretically it is only necessary that there is a threshold, e.g. zero, and banks would be penalised if their balances with the central bank would drop below this level.

funding liquidity risk, is therefore zero. And this is what it should be theoretically: funding liquidity risk in a frictionless interbank market without aggregate shocks is zero, as the bank is always able to settle all obligations with immediacy as it can obtain all necessary funds at a known and fixed interest rates from the interbank market.<sup>10</sup>

Aggregate liquidity shocks impact, however, on liquidity risk (see e.g. Allen and Gale, 2004a,b or Diamond and Rajan, 2005). Even with frictionless interbank markets, trading cannot eliminate the risk that the market in aggregate may be long or short of central bank money in period 3 following some aggregate shocks.<sup>11</sup> As prices for accessing the marginal facilities are fixed, the interest rates in period 2 purely reflect the expectations of the amount and likelihood of accessing either facility in period 3. However, the central bank is assumed to provide the right expected amount of aggregate liquidity so that the expected interest rate in the interbank market (at time 1) equals the policy rate. Given risk neutrality, all banks therefore bid at the minimum bid rate and spread above the policy rate would also be zero in such a set-up.

However, the assumption of risk neutral banks and frictionless interbank markets is unrealistic, particularly during times of stress. In the next section we show that if we relax these assumptions banks with higher liquidity risk bid more aggressively.

## **4.2 Bidding with interbank market frictions**

It has been theoretically shown that asymmetric information (e.g. Flannery, 1996), coordination failures (e.g. Rochet and Vives, 2002), uncertainty about future liquidity needs (e.g. Holmstrom and Tirole, 2001) or incomplete markets (e.g. Allen and Gale, 2000) are all frictions which lead to funding liquidity risk. Such frictions imply that a bank which has to raise liquidity in the interbank market has to pay a higher price to obtain it. In the extreme, prices may even be infinite if a bank is credit rationed (see Stiglitz and Weiss, 1981). Banks, who expect to be short, will anticipate this and bid more aggressively during the OMO to avoid paying higher interest rates in the secondary market or being rationed completely.

Nyborg and Strebulaev (2004) show formally that, given frictions in the interbank market “short” banks (i.e. banks which do need to raise cash from the central bank or the interbank market to settle all obligations) will bid more aggressively than “long” banks (i.e. banks which have excess funds) as short banks want to avoid paying higher interest rates in the interbank market.<sup>12</sup> In particular, Nyborg and Strebulaev analyse the case where long banks have some

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<sup>10</sup> This is fully in line with the theoretical literature, which has shown that with fully connected interbank markets idiosyncratic liquidity shocks can be eliminated and liquidity risk vanishes (see Allen and Gale, 2000).

<sup>11</sup> An aggregate shock should be thought of as a state of nature, where bank specific shocks do not add up to zero.

<sup>12</sup> Formally, the results from Nyborg and Strebulaev will only carry over to a setting with a different interbank market frictions, if the friction implies that long players can charge a higher interest rate if short banks are sufficiently illiquid. If the interbank market is closed and only banks can trade in the interbank market this is the case. Nyborg and Strebulaev also assume that agents have full information on short and long positions prior to the OMO. However, imperfections in the interbank market are often associated with imperfect information. Nyborg and Strebulaev conjecture that with private information about positions, long players will aim to exploit their

market power during trading in the secondary market, so that they can “squeeze” short banks and demand higher interest rates. Acharya, Gromb and Yorulmazer (2008) document several banking crises where this effect seems to have played an important role.<sup>13</sup> Short banks clearly anticipate this when submitting their bid. They know they can avoid being squeezed if they obtain sufficient funds from the central bank during the OMO. It is therefore intuitive that banks bid very aggressively for the amount of funds necessary to avoid the squeeze. Nyborg and Strebulaev show that in equilibrium the threat of a squeeze induces short banks to submit bids above the minimum bid rate with a higher expected mean rate than the bids submitted by banks which are long. They also show that this price distortion is larger the larger the short position. Putting it in the language of our equation above, the higher the expected  $NLD$ , the higher  $p^{IB}$ , the higher the funding liquidity risk, and the more aggressively a bank will bid. Therefore a higher the spread reveals higher funding liquidity risk.

Fecht et al. (2008) find empirical support for this theory when analysing OMOs for German banks. Even though they cannot observe  $NLD$ , they know a bank’s liquidity position with the central bank prior to the auction, relative to the reserve requirement set by the central bank. Using this as a proxy, they document that short banks bid more aggressively especially in times when the liquidity imbalance across banks is large. However, in contrast to our paper they do not link this to funding liquidity risk.

Banks may also not be risk neutral, as is generally assumed, which implies that banks with high liquidity risk will bid more aggressively. During normal times the difference between bidding of risk neutral and risk averse agents may not be material, as interbank markets work nearly frictionless and banks can obtain any required amount of funding in the secondary market. The only face the risk of small price changes in LIBOR due to small aggregate shocks.<sup>14</sup> However, in stressed conditions, such as the recent crisis, where a banks’ inability to obtain liquidity in the secondary market can lead to failure, risk aversion can have significant consequences. Välimäki (2006) explores a model with risk averse banks, where deviations from a target level of central bank balances prior to trading in the interbank market are costly. Such a target level could for example be the result of frictions, where banks know that the desire to obtain large amount of funds would be penalised by rates above the market rate or it may even be impossible to raise the necessary amount of funds because of rationing. In line with Nyborg and Strebulaev, Välimäki shows that banks with a higher target level, or

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informational advantage. But in equilibrium short banks would still bid on average at higher rates to prevent the squeeze.

<sup>13</sup> In the model of Archarya et al (2008) long banks take advantage of their market power to strategically underprovided liquidity to short banks. They profit from their failure by buying up assets at fire sales prices if short banks turn out to be illiquid.

<sup>14</sup> As long as all banks lend freely in the interbank market, aggregate liquidity shocks in the market for central bank money are technically only driven by changes in autonomous factors. Autonomous factors constitute nearly completely of banknotes, government deposits and net foreign assets. All these factors can and do change between frequently OMOs even though these fluctuations are generally not large.

equivalently with a higher *NLD* in our set-up, bid more aggressively during the central bank auction and a higher spread will reveal higher funding liquidity risk.

The arguments so far establish that higher bids reveal higher funding liquidity risk if there are frictions in the interbank market and/or banks are risk averse. Therefore a higher spread will measure higher funding liquidity risk. However this measure of funding liquidity risk can only be a proxy. This can happen because bidding behaviour may also be influenced by other factors. Ewerhart et al. for example consider a model with frictionless interbank markets where values for collateral used for OMOs and the secondary market differ. This in turn induces banks to submit bids which are higher than the marginal rate during the OMO. It is also shown that at year-ends, banks engage in window-dressing, to establish favourable end of year balances (see Bindseil et al 2003). This should also hold for other reporting times. Clearly, these seasonality effects are unrelated to liquidity risk as they are driven by bank managers' desire to signal a specific balance sheet to the market rather than by a reaction to funding pressures.

On a more theoretical level, given a secondary market, bidding behaviour may also be influenced by the well-known “winner’s curse” problem: In single unit auction where bidders do not adjust their bid schedules, the bidder who is most optimistic about the value wins the auction and is therefore likely to overpay relative to the common value of the good (e.g. see Milgrom and Weber, 1982).<sup>15</sup> In anticipation of this, participants in the auction scale down their bid resulting in underbidding.

Therefore, our measure could suffer from the “winner’s curse” problem. For this problem, however, to be material it is necessary that market participants have asymmetric information about the value of the good in the secondary market. Bindseil et al. (2008) test for this and find that there is no evidence that market participants in OMOs in the euro area have private information about (post auction) interest rates in the interbank market. Hence, the winner’s curse problem does not seem to be material for our set-up and should therefore not impact on our measure.

### **4.3 Bidding with all sources of liquidity**

No model in the literature on bidding behaviour in OMOs takes into account all sources of funding liquidity shown in equation 2. In this section we briefly discuss the more general set-up using the stylised time line from above. In period 2 banks can therefore not only trade in the interbank market but also obtain liquidity from depositors or from selling assets. Both sources are considered in turn.

In practice, a bank cannot expect to rely on new customer deposits to weather liquidity shocks in period 2. On the one hand, the literature has shown that deposits can act as a natural hedge

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<sup>15</sup> In a multi-unit set-up the winner’s curse problem is also referred to as champion’s plague (Ausubel, 2004)

against liquidity risk stemming from issuing loan commitments and lines of credit (e.g. see Kashyap et al 2002, or Gatev and Strahan, 2006).<sup>16</sup> On the other hand, banks cannot rely on this, as they have a limited ability to actively attract new customer deposits in the short run (for example by raising rates) because of sluggish depositors' behaviour (see Gondat-Larralde and Nier, 2004). Overall, both in- and outflows of customer deposits can therefore be seen as a random component from the banks' risk management perspective. Essentially, they can be considered a liquidity shock within the discussed model framework, especially as we only measure liquidity risk over a one week horizon.

Asset sales are an alternative source of liquidity in the short run. In line with our analysis for interbank lending, the availability of this source depends to a large extent on the existence of frictions in the markets. In a frictionless world, where the central bank distributes the correct amount of liquidity so that on aggregate no expected liquidity surpluses or deficits exist, any bank which does not have access to the primary market of liquidity can acquire the necessary liquidity in the secondary market (interbank market) or in asset markets. The costs of obtaining liquidity from either source are equal as all price differentials are arbitrated away in a frictionless world. Hence, in such an environment the results from Section 4.1 apply, and banks only bid at the policy rate as liquidity risk would be minimal.

But frictions in asset as well as interbank markets are central in theories of liquidity risk. For example, several models have shown that if asset markets are characterised by cash-in-the-market pricing and there is an aggregate shortfall in liquidity, interbank market rates will be higher and asset prices will deviate from fundamentals, i.e. markets will be illiquid leading to distressed pricing (for an overview see Allen and Gale, 2007). Distressed pricing can also be a result of further frictions in trading, borne by margin requirements (Brunnermeier and Pedersen, 2007), limits to arbitrage (Schleifer and Vishny, 1997) and predatory trading (Carlin, Lobo and Viswanathan, 2007). Furthermore, frictions can lead to downward spirals between market and funding liquidity (see Gromb and Vayanos, 2002, or Brunnermeier and Pedersen, 2007). Within our hypothetical time line, the latter models essentially consider an extended period 2 where falling asset prices interact with funding liquidity needs.

The inverse relationship between funding and market liquidity risk can be characterised as follows: A downward liquidity spiral can start with a bank (or brokers in the Brunnermeier and Pedersen model) which is short of liquidity and cannot obtain it from the interbank market. Therefore it has to sell assets. If asset markets are characterised by frictions, (large) asset sales induce a fall in asset prices. These in turn imply that the bank has to post higher margins, i.e. liquidity outflows increase. To remain liquid banks have to sell more assets, which depresses

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<sup>16</sup> The rationale for this is a flight to quality as banks have access to emergency liquidity from the central bank and depositors are sheltered from bank failures by the deposit insurance scheme. Pennachi (2006) shows that the negative correlation between deposit inflows and draw down of committed credit lines cannot be observed prior to the introduction of deposit insurance

market prices even further (because of a lack of market liquidity), leading to further margin calls and so forth. The downward spiral can also start with falling asset prices.

Overall, whatever the friction, a bank which expects to be short in period 2 and knows that the markets are characterised by frictions will anticipate that it has to pay higher prices to obtain the necessary liquidity from any available source. Hence, our results of Section 4.2 generalise, i.e. banks with higher liquidity risk will bid more aggressively in the open market operations. Therefore the spread can be used as a measure of funding liquidity risk.

## 5. Measuring funding liquidity risk

In Section 4 we have shown that large bid volumes at prices above the expected marginal rate reveal funding liquidity risk. And the greater the volume bid at a higher price, the larger the funding liquidity risk. As we observe the bidding behaviour of all banks, we can easily derive our liquidity risk measure. It is simply based on the volume banks bid and the rate they are willing to pay, over and above the expected marginal rate, i.e. we look at the premium that banks are willing to undertake in order to acquire a specific volume of liquidity from the central bank.

We define the adjusted bid ( $AB$ ) of bank  $i$  at auction  $t$  as the bid price minus the expected marginal rate times the bid volume for bids which are above the expected marginal rate, that is

$$AB_{b,i,t} = (bid\_rate_{b,i,t} - E(marginal\_rate)_t) * volume_{b,i,t} \quad (3)$$

$$\text{if } bid\_rate_{b,i,t} > E(marginal\_rate)_t$$

where,  $bid\_rate_{b,i,t}$  is the price for liquidity the (allotted) and  $volume_{b,i,t}$  is the bid volume of bank  $i$ , submitting bid  $b$  (from 1 to  $B$ ) at time (auction)  $t$ ,  $E(marginal\_rate)_t$  is the expected marginal rate. In section 5.1 we show how we can estimate this based on information available at the time when bids are submitted.

Based on the individual normalised bids we can construct an aggregate proxy of funding liquidity risk by summing across the adjusted bids of all banks. Following that reasoning, our liquidity risk proxy ( $LRP$ ) is simply the sum of all individual adjusted bids across banks for each auction.

$$LRP_t = \frac{\sum_{i=1}^N \sum_{b=1}^B AB_{b,i,t}}{E(allotment)_t}, \quad (4)$$

where  $b$  (from  $b=1$  to  $B$ ) are the bids of each bank  $i$  (from  $i=1$  to  $N$ ) for each time (auction)  $t$ . We normalise the sum of the adjusted bid rates by the volume banks expect the central bank to

provide. The normalization of bids is necessary to ensure consistency across auctions which can differ in size. This will also ensure that our measure is unaffected by “frontloading” practices after August 2007 as discussed in Section 3.

Note that in equilibrium the expected marginal rate equals the policy rate. And without frictions and risk neutrality all banks will bid at this rate. Therefore, the premium that the bidders would be willing to pay in order to acquire liquidity would be zero. Consequently, under normal conditions our measure of risk would also be zero, a property that is very intuitive.

Chart A3.1 provides a graphical representation of our measure using one auction as an example. The two axes present the bid price (vertical) and the bid volumes (horizontal). *LRP* is nothing else than the normalised area under this demand curve (as suggested by the “area of interest” in the chart).

## 5.2 Estimating the expected marginal rate and allotment volume

In order to estimate the expected marginal rate and the expected allotment volume for the needs of our measure, we need to take into account several issues. To begin with, the two variables are determined in a simultaneous manner. Especially during the period of the turmoil, the ECB was sometimes adjusting the allotted volume, by offering amounts in excess of the benchmark, in order to accommodate lower marginal rates.

Based on that, for the needs of the estimation we work on a system of two simultaneous equations. One on the total allotment and one on the spread between the realised marginal rate and the policy rate. After proper estimation of the system, using rolling windows 3SLS estimation procedures, we keep the explained part of the two equations and treat it to obtain the expected marginal rate and allotment volume of auction  $t$ . Namely, the two regressions are as follows:

$$\begin{aligned} total\_allotment_t = & \alpha_0 + \alpha_1 * spread_t + \alpha_2 * benchmark_t \\ & + \alpha_3 * excess_{t-1} + \alpha_4 * mper\_end + \varepsilon_t \end{aligned} \quad (\text{Eq. 5})$$

and

$$spread_t = \beta_0 + \beta_1 * total\_allotment_t + \beta_2 * spread_{t-1} + \beta_3 * euribor_t + \eta_t, \quad (\text{Eq. 6})$$

where *total allotment* is the volume of liquidity allotted in auction  $t$ , *spread* is the difference between the realised marginal rate and the policy rate in auction  $t$ , *benchmark* is the benchmark at announcement, which is public knowledge before the auction is conducted at time  $t$ , *excess* is the difference between the benchmark at allotment and the total allotment at the previous auction, *mper\_end* is a dummy variable which takes on the value of 1 on the last day of each maintenance period and *euribor* is the difference between the policy rate and the 1-week Euribor on the day of the auction. Note that the variables used refer to information that is

public knowledge at the time of the auction - with the exception of the spread and the total allotment, which are determined simultaneously at time  $t$ .

The use of the variables is intuitive. The total allotment in each auction is likely to be adjusted if the marginal rate deviates substantially from the minimum bid rate, given that these operations are primarily monetary policy operations with a purpose to steer market rates close to the policy rates. However, the benchmark at announcement should give a good idea of the minimum liquidity needs of the system at times of the crisis. The amount allotted above the benchmark in the previous auctions can give an estimate of the excess liquidity demand, that market participants may expect to persist, despite the frontloading. At the end of the maintenance period, however, since the excess liquidity has to be balanced out, it is likely that the behaviour of the allotment volume is different. In the same vein, the spread between the marginal rate and the policy rate can be compromised by the allotment decision on that day, but it is likely that its previous behaviour shows some persistence. In the mean time, in the decision on what bid to submit, the opportunity cost measured by the prevailing market rate for (approximately) the same horizon is a determining factor on whether to tap the ECB or the market for liquidity.

The estimation is being conducted as a 30-day rolling window estimation procedure using the 3-Stage-Least-Squares method. The latter is a combination of two-stage least squares and seemingly unrelated regression. It provides consistent estimates of linear regression models, where the explanatory variables are correlated with the error term. It also extends ordinary least squares analysis to systems of equations with correlated error terms. Given the endogeneity in the determination of the marginal rate and the allotment volume, the 3SLS method is the appropriate estimation method, which effectively controls for the interactions between our variables. Rolling windows estimation is ideal in case of structural breaks in the data, which are likely to exist given the outbreak of the crisis. A window at thirty (30) observations was chosen<sup>17</sup>, in a way that the start date and end date successively increase by one observation (i.e. one week). The choice of 30 observations gives us the minimum number of necessary parameters in order to achieve efficient asymptotic estimates, while at the same time it minimises the effect of the turmoil at its outbreak, as it is relevant only to a limited number of samples.

After estimation, we keep the explained part of the two equations as the expected marginal rate and the expected allotment volume for auction  $t$ .

## **6. Data**

Our analysis profits from a unique data set of 142 MROs conducted by the ECB from June 2005 to 7 October 2008. This was the date of the last MRO before temporary changes to the

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<sup>17</sup> Windows of length 24, 40, 50, 52 and 60 observations were also tried.

auction design of the ECB were implemented. These changes involved switching from variable rate tender to fixed rate – full allotment tenders. They also included a symmetric narrowing of the ECB corridor from 100bps to 50 bps. Under the new framework, only the volumes of liquidity demand are revealed but not the price. As a result, our measure as presented here does not apply on the new auction design after October 2007.

Our source of data is the ECB and Reuters. ECB data for MRO auctions allow us to follow the bidding behaviour of each of the 877 banks that took part at least once over these years. Information includes an anonymous but unique code for each bidder, the submitted bid schedule (bid rate and bid volume) of each bank and the allotted volume. These data are not publicly available. However, data on the policy rate (minimum bid rate), the marginal rate, the maintenance periods, the benchmark and the settlement dates of the auctions are publicly available and taken from the ECB's internet site. Data on the euribor (Ric name: EURIBORSW=) are taken from Reuters.

The Annex provides an overview over the distribution of the individual bid rates, the spreads over the policy as well as the marginal rate and volumes. More specifically, Chart A3.2 displays the individual bid rates, as well as the policy and marginal rate. Each data point corresponds to a single dot in the graph. Therefore it is easy to have a first impression of the variability of the individual rates in each auction and the levels they tended to concentrate on. For example, it becomes clear that the turmoil period is associated with a larger variability in bid rates and more aggressive bidding, as suggested by the amount and extent of bids above the marginal rate. Moreover, Charts A3.3. and A3.4 present the evolution of the variables which enter into the regressions described at Section 5.2. As it can be seen from the charts, the behaviour of almost all variables changed significantly after the outbreak of the turmoil in August 2007. Notably, it is possible from all three charts to see that certain days of special interest, such as year ends, the collapse of Bear Stearns in March 2008, and, most importantly, the collapse of Lehman Brothers in September 2008 elicit distinct behaviours of the data.

## **7. Results**

### **7.1 Regression results**

Before moving on to present the LRP measure, we briefly present the results of the 3SLS estimation of the system formed by Eq. 5 and Eq. 6, as described in Section 5.2. The estimation results of the rolling regression on spreads are summarised in Graph A3.5, whereas Graph A3.6 presents the corresponding results from the Allotment equation.

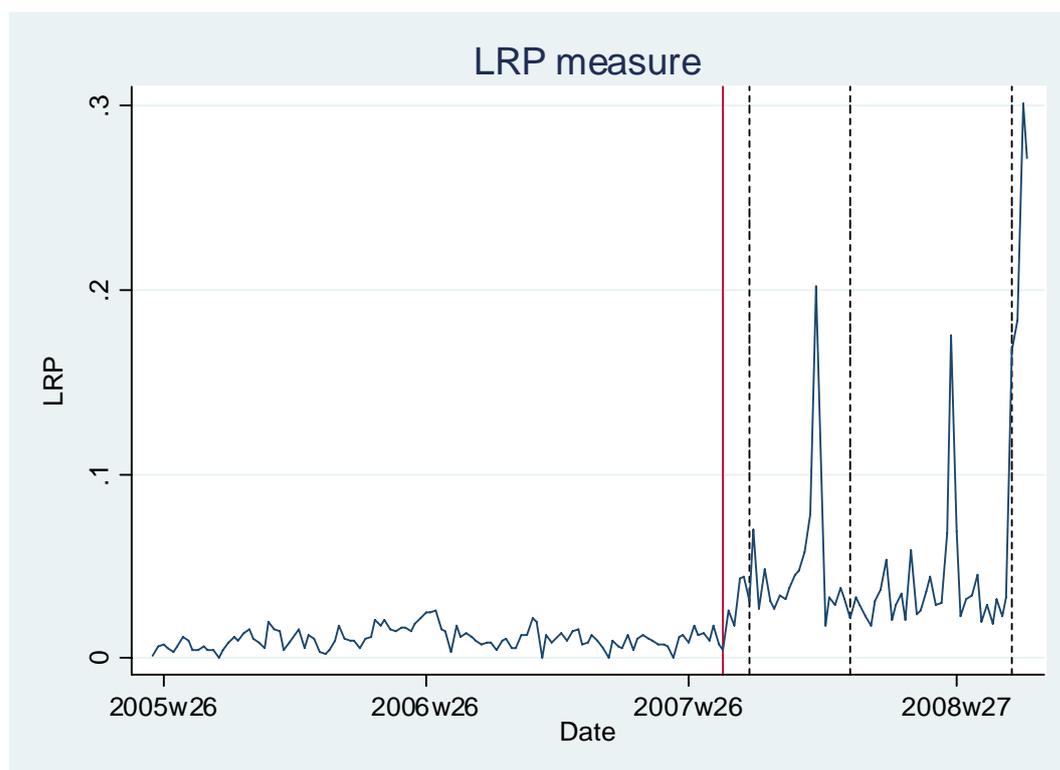
The charts show the values of the estimated parameters for each equation, together with their t-statistics. The fit appears to also be satisfactory, mainly for the period before the turmoil. After the outbreak, in August 2007, our results verify that in its efforts to stabilise money markets, the marginal rate, as well as the total allotment were in several occasions higher than anticipated.

- To be completed -

## 7.2 Funding liquidity risk measure

Our aggregate measure of funding liquidity risk is presented in Chart 1. End-of year effects are excluded. Chart 1 clearly suggests that funding liquidity risk is time varying and persistent, but subject to occasional spikes. These properties bode well with measures for market liquidity (Amihud, 2002; Chordia et al., 2000, 2002; Pastor and Staumbaugh, 2003; Brunneimeier and Pedersen, 2007).

**Chart 1 LRP**



Note: The chart presents the LRP measures excluding the last operation of each year. The red horizontal line indicates the beginning of the turmoil (here 14 August 2007 when the first MRO was undertaken after the turmoil started). The horizontal black lines indicate dates of important events, the failure of Northern Rock (13 September 2007), the failure of Bearn Sterns (16 March 2008) and the failure of Lehman Brothers (15 September 2008).

The time series of our liquidity risk measures *LRP* reveal that liquidity risk lies at a more elevated level and has much more pronounced spikes towards the end of our sample. Most practitioners would certainly agree that these months have witnessed the most pronounced

events in terms of funding liquidity in our sample. This change in level coincides perfectly with the beginning of the turmoil in August 2007. Since then, the measure increased significantly as we observe the reaction of the banking system to the credit market turmoil. After the initial reaction in August, a peak was reached in September, when Northern Rock had to be rescued by the UK government. After a short lived fall, *LRP* rose again as tensions continued in interbank markets leading up to the end of 2007, even though we excluded the actual year end. A relative tranquil period followed, despite the fall of Bear Sterns, until the next large spike, which had to do with end-of-semester tensions. However, the largest spike, by far, coincides with the beginning of October 2008, when money market was reportedly frozen following the failure of Lehman Brothers in mid-September 2008.

Table 1 provides the summary statistics for this data. It is apparent that *LRP* increases during the turmoil following 9 August 2007 and almost triples on average. The increase in volatility is also enormous, more than six-fold.

**Table 1: Statistics**

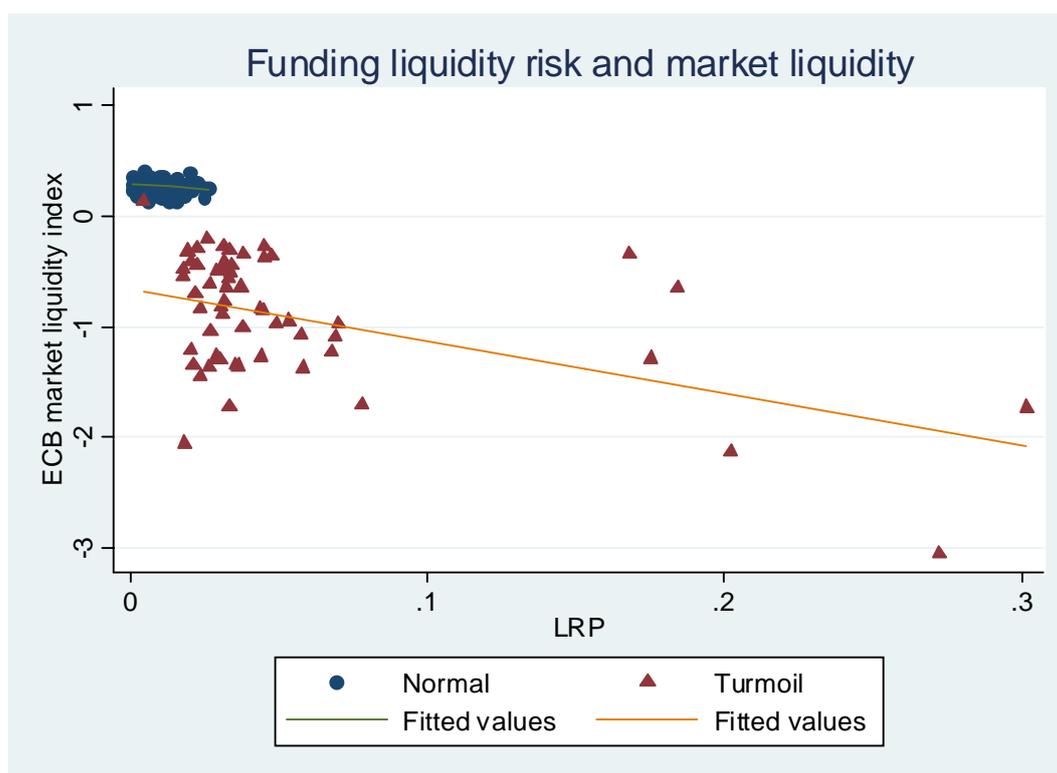
	LRP		
	Normal	Turmoil	Ratio
<b>Mean</b>	0.011	0.053	5.055
<b>Variance</b>	0.006	0.060	10.723
<b>min</b>	0.001	0.004	7.451
<b>max</b>	0.026	0.000	0.000
<b>Obs</b>	111	59	0.532

Note: *Normal* indicates the period from June 2005 until 7 August 2007. *Turmoil* is the remaining period until 7 October 2008. *Ratio* equals *Turmoil/Normal*. Year ends are excluded.

### 7.3 Funding liquidity risk and market liquidity

In section 4.3 we have discussed that market and funding liquidity are strongly interrelated. Once there are frictions and banks are constrained, downward spirals of falling asset prices and higher funding liquidity risk can emerge. Whilst the theoretical expositions are clear and many observers attribute the recent turmoil to these interactions, it has not been shown empirically due to a lack of measures for funding liquidity risk. Using our measure we are able to empirically support these interactions by looking at the interrelationships between our measure *LRP* and an index of market liquidity used by the ECB Financial Stability Review (see ECB, 2008) (see Chart A3.7 Annex 3 for a time series). This index is a weighted average of different market liquidity measures such as bid-ask spreads in FX, equity, bond and money markets.

**Chart 2: Interactions between funding liquidity risk and market liquidity**



Note: *Normal* indicates the period from June 2005 until 7 August 2007. *Turmoil* is the remaining period until 7 October 2007. *Fitted values* are based on the regression using the whole sample.

Chart 2 shows a scatter plot of *LRP* and the ECB market liquidity index. A clear negative relationship can be seen, i.e. when market liquidity is drying up (i.e. is low), funding liquidity risk is high (which would be equivalent to saying that high funding liquidity risk is associated with high market liquidity risk). The red line shows the predicted values based on a simple regression of the index on *LRP*. These results are shown in Table 2. The scatter plot already suggests that the negative relationship is primarily driven by the turmoil. The econometric analysis supports this as there is no significant relationship between our measure of funding liquidity risk and market liquidity prior to the turmoil.<sup>18</sup> However, once the turmoil unfolds a significant negative relationship emerges. This is exactly what the theory predicts as these interactions should only emerge once banks become funding constraint. Therefore this analysis supports theoretical insights.

<sup>18</sup> Similar results emerge when undertaking the same analysis with *LRP\_M* and the spread between the marginal and policy rate. Interestingly, the R-squared is highest for *LRP* (.76) and lowest for *LRP\_M* (.26) whilst the regression with the spread between the marginal and policy rate has an explanatory power of .66 (R-squared is given for the regression using the full sample).

**Table 2: Regression results of market liquidity index on LRP**

	<b>Coefficient</b>	<b>Std Error</b>	<b>t-stat</b>	<b>R-squared</b>
<b>Full sample</b>				
Market liquidity	-0.037	0.004	-10.220	0.727
constant	0.019	0.002	8.150	
<b>Normal</b>				
Market liquidity	-0.016	0.009	-1.700	0.003
constant	0.015	0.003	5.810	
<b>Turmoil</b>				
Market liquidity	-0.045	0.012	-3.660	0.295
constant	0.010	0.013	0.800	

*Normal* indicates the period from June 2005 until 7 August 2007. *Turmoil* is the remaining period until 7 October 2008.

## 8 Robustness checks

### 8.1 Analysis of LRP with other market liquidity measures

#### 8.1.1 Other ECB market liquidity measures

As already mentioned the ECB index presented above nests separate money market indices, namely a composite index of FX, equity and bond markets, and a money market index.<sup>19</sup> Given the nature of the turmoil, it is plausible that our results are mainly driven by developments in money markets. Although the behaviour of the overall index is mainly driven by developments in the liquidity situation of money markets, it is nevertheless interesting to note that our results hold, also when we exclude the effect of money market liquidity and focus on a composite index of FX, equity and bonds markets. These results appear in the Table 3 below. A graphical representation of the various liquidity measures and our measure is also available in Chart A3.8 in the Annex.

- TO BE COMPLETED \_ -

<sup>19</sup> As discussed in the Financial Stability Review, Box 9 (ECB, June 2007), “the financial market liquidity indicator combines eight individual liquidity measures. Three of them cover bid-ask spreads: (1) on the EUR/USD, EUR/JPY and EUR/GBP exchange rates; (2) on the 50 individual stocks which form the Dow Jones EURO STOXX 50 index and; (3) on EONIA one month and 3 month swap rates. Three others are return-to-turnover ratios calculated for: (4) the 50 individual stocks which make up the Dow Jones EURO STOXX 50 index; (5) euro bond markets and; (6) the equity options market. The last two components which measure the liquidity premium are gauged by: (7) spreads on euro area high-yield corporate bonds which are adjusted to take account of the credit risk implied in these spreads by expected default frequencies (EDFs) and; (8) euro area spreads between interbank deposit and repo interest rates. The composite indicator is a simple average of all the liquidity measures normalised on the period 1999-2006”.

**Table 3: Regression results of market liquidity measures on LRP**

LRP on money market liquidity					LRP on FX, equity and bond market liquidity			
	Coef	Std Error	t-stat	R-squared	Coef	Std Error	t-stat	R-squared
<b>Full sample</b>								
Market liquidity	-0.037	0.004	-9.560	0.727	-0.281	0.039	-7.160	0.727
constant	0.006	0.003	2.040		0.124	0.014	8.770	
<b>Normal</b>								
Market liquidity	-0.035	0.009	-3.700	0.003	0.042	0.015	2.780	0.003
constant	0.007	0.001	5.620		-0.005	0.006	-0.930	
<b>Turmoil</b>								
Market liquidity	-0.038	0.013	-3.030	0.295	-0.248	0.080	-3.090	0.295
constant	0.005	0.017	0.280		0.127	0.026	4.960	

*Normal* indicates the period from June 2005 until 7 August 2007. *Turmoil* is the remaining period until 7 October 2008.

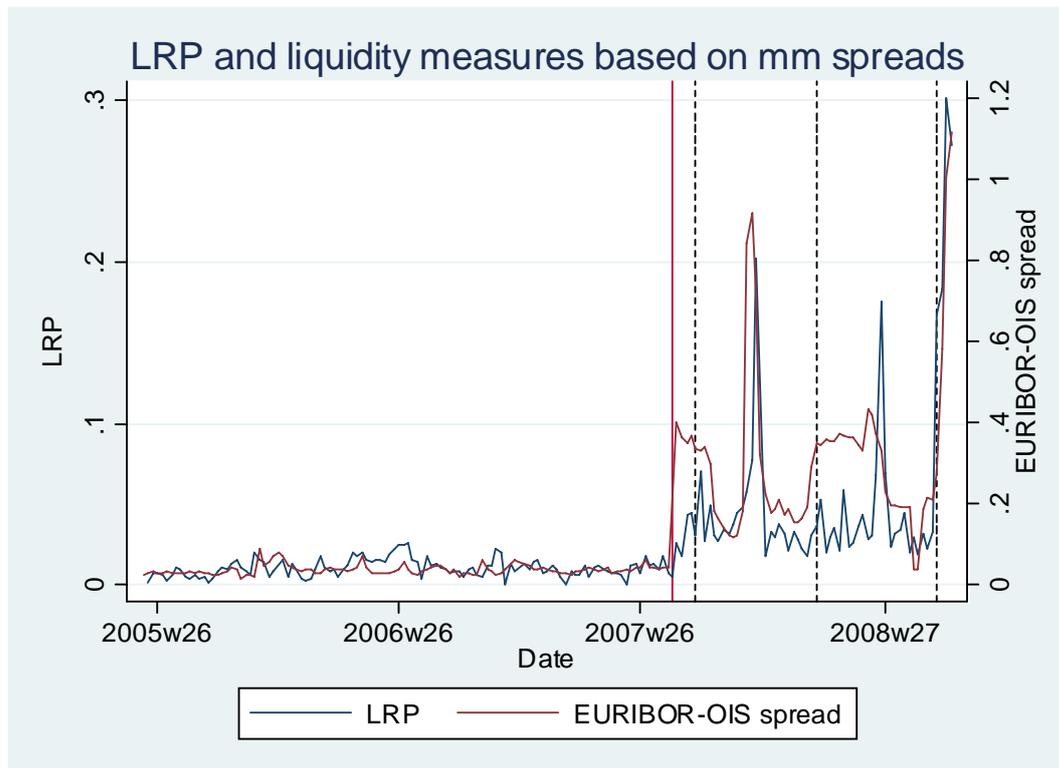
### 8.1.2 Money market measures

A typical measure commonly used by central banks, academics and practitioners to indicate money market conditions in the euro area markets has been the spread between the EURIBOR and the OIS.<sup>20</sup> This spread gives an indication of stress conditions in the markets, as it can be influenced by credit (given that the unsecured deposit market contains higher credit risk than the swap market) and liquidity risk (as we stress above, the risk of becoming illiquid increases the price of liquidity), as well as expectations about monetary policy rate changes (usually the OIS rate adapts at a faster rate to such expectations, given its vicinity to the overnight rate and therefore to the policy rate). We would therefore expect a positive correlation between our measure and this type of spread. Indeed, comparing the liquidity measure derived from ECB operations with the 1 week Euribor-OIS spread in Chart 3 it is obvious that such a relationship indeed holds

- TO BE COMPLETED \_ -

<sup>20</sup> The EURIBOR is the rate at which Euro interbank term deposits are offered by one prime bank to another prime bank within the EMU zone, and is published at 11:00 a.m. (CET). A representative panel of banks provide daily quotes of the rate that each panel bank believes one prime bank is quoting to another prime bank for interbank term deposits within the euro zone. On the contrary, the OIS (overnight interest swap) rates are market traded swap rates, where counterparties exchange fixed for floating payments, with the floating leg tied on the overnight, EONIA rate.

**Chart 3: Interactions between funding liquidity risk and Euribor-OIS spread**



Note: The chart presents the LRP measures excluding the last operation of each year and the Euribor-OIS spread for the same dates. The red horizontal line indicates the beginning of the turmoil (here 14 August 2007 when the first MRO was undertaken after the turmoil started). The horizontal black lines indicate dates of important events, the failure of Northern Rock (13 September 2007), the failure of Bear Stearns (16 March 2008) and the failure of Lehman Brothers (15 September 2008).

### 8.2 LRP measures based on public data

Even though our measure requires confidential information, a simple liquidity risk proxy is publicly available. This can be seen by rewriting equation (3) and (4) as

$$\overline{AB}_{b,i,t} = (bid\_rate_{b,i,t} - policy\_rate_t) * volume_{b,i,t} \quad (7)$$

and

$$LRP_{public}_t = \frac{\sum_{i=1}^N \sum_{b=1}^B \overline{AB}_{b,i,t}}{total\_allotment_t}, \quad (8)$$

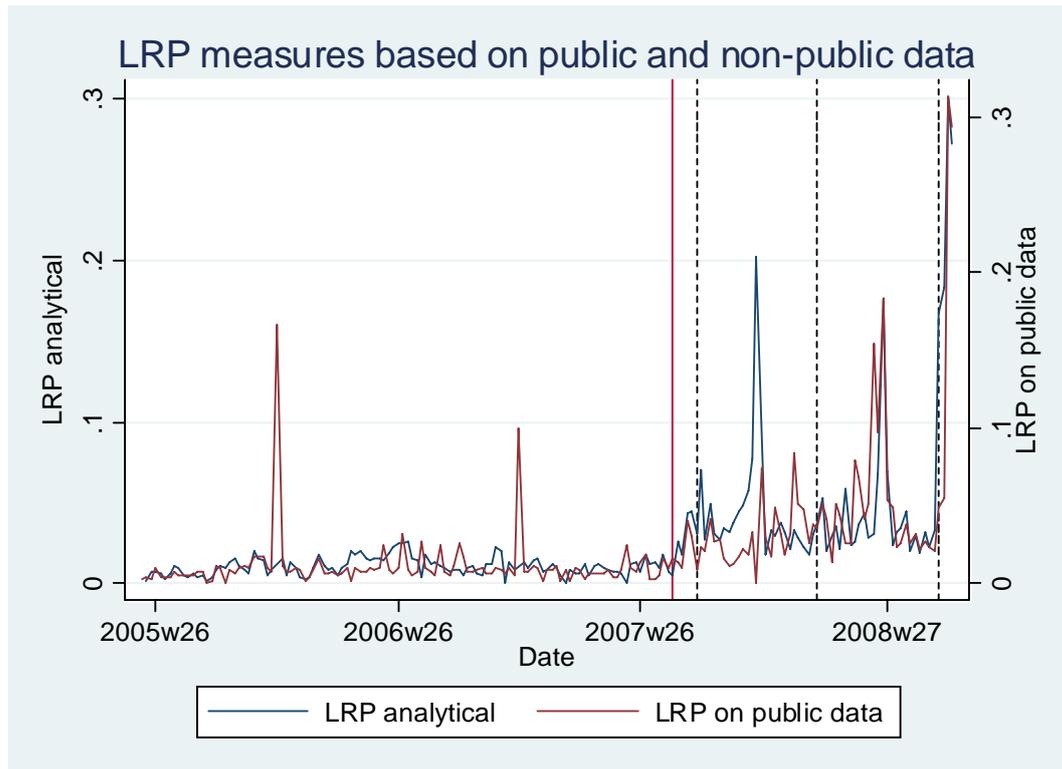
If  $LRP_{public}$  considers only bids, which are satisfied ( $bid\_rate \geq marginal\_rate$ ), it collapses to the weighted average bid rate minus the policy rate.<sup>21</sup> The weighted average bid rate and the

<sup>21</sup> The weighted average bid rate (WABR) is calculated as the sum of the bid rate times the volume, normalised by the percentage allotted and the total allotment for all successful bids.

policy rate and the marginal rate are series reported by the ECB after each auction. Historical time series are also available from the ECB website.<sup>22</sup> In that sense, these measures are particularly useful for policymakers and market observers, who would want a quick and easy proxy to monitor funding liquidity risk conditions in the economy in real time.

- TO BE COMPLETED -

**Chart 4: LRP measure based on public data**



Note: The chart presents the LRP measure based on public and non-public data. The series exclude the last operation of each year. The red horizontal line indicates the beginning of the turmoil (here 14 August 2007 when the first MRO was undertaken after the turmoil started). The horizontal black lines indicate dates of important events, the failure of Northern Rock (13 September 2007), the failure of Bear Stearns (16 March 2008) and the failure of Lehman Brothers (15 September 2008).

## 8 Conclusion

In this paper we propose definitions of funding liquidity and funding liquidity risk and present a simple, yet intuitive measure of funding liquidity risk, based on information from the

$$WABR = \frac{\sum_{i=1}^N \sum_{b=1}^B bid\_rate_{b,i,t} * volume_{b,i,t} * percentage\_allotted}{total\_allotment_t}$$

In our case, we use the allotted volumes, which is

effectively equal to the *volume\*percentage\_allotted*.

<sup>22</sup> <http://www.ecb.eu/mopo/implement/omo/html/index.en.html>

liquidity providing operations of the central bank. We define *funding liquidity* as *the ability to settle obligations with immediacy*. Accordingly, *funding liquidity risk is driven by the possibility that over a specific horizon the bank will become unable to settle obligations with immediacy*. We show that funding liquidity risk has two components: future (random) in- and outflows of money and future (random) prices of obtaining funding liquidity from different sources. Given banks anticipate prices for liquidity in interbank and asset markets, we can show that higher funding liquidity risk in turn leads to higher bids during open market operations conducted by the central bank.

Using information from a data set of 142 main refinancing operations conducted by the ECB from June 2005 to October 2008, we construct two measures of funding liquidity risk, which aim to take into account the (normalised) information of both the price and the quantity of the liquidity demanded. Unsurprisingly, we find that the resulting measures record spikes after August 2007, indicating the presence of increased funding liquidity risk as would have been expected. We also find that our measures bear resemblances with market liquidity and have properties such as low levels, persistence and occasional spikes, which the literature has already identified. Finally we are able to find evidence that there is indeed an inverse relationship between funding liquidity risk and market liquidity risk.

Our analysis is only a starting point in using bidding data to assess funding liquidity risk. It would certainly be interesting to implement our measure for different jurisdictions, such as the United States. There the provision of central bank money is significantly different. Daily OMOs are only conducted with a narrow set of broker dealers, who rely on settlement banks to settle all their transactions (hence they generally settle in commercial bank money). More in line with the auctions described above which should be the newly introduced Term Auction Facility.<sup>23</sup> Here banks can bid directly for central bank money with the maturity of one month. Even though the auction is conducted as a single-price auction format it should be possible to use bids as a measure for funding liquidity risk based on our approach.

Overall, this paper introduces the idea that a proxy for funding liquidity risk can be constructed from bidding data in the central bank auctions. An empirical proxy for funding liquidity risk was missing up to now in the literature. So far, it was thought that such a measure would require a large data set using private information from banks. However, given equilibrium relationships banks' bids during open market operations will reflect funding liquidity risk. Our idea therefore simplifies matters considerably and allows us to construct for the first time a proxy for funding liquidity risk. We are therefore able to provide, for the first time, empirical evidence that funding liquidity risk has similar properties as market liquidity and that funding liquidity co-moves with market liquidity, as suggested by the relevant literature. In that sense our paper provides a useful contribution to the liquidity literature not only because it opens up

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<sup>23</sup> For further details see <http://www.federalreserve.gov/monetarypolicy/taf.htm>.

ways of further empirical research on liquidity, an area of research hindered by the unavailability of proxies, but also because it can be used as a very efficient tool for policy analysis and monitoring.

## **Bibliography**

**Acharya, V. A., Gromb, D. and Yorulmazer, T. (2008).** "Imperfect competition in the interbank market for liquidity as a rationale for the central bank", mimeo

**Allen, F. and Gale, D. (2000).** "Financial Contagion," *Journal of Political Economy*, Vol. 108 (1), 1-33.

**Allen, F. and Gale, D. (2004a).** "Financial Fragility, liquidity and asset prices," *Journal of the European Economic Association*, Vol. 2 (6), 1015-1048.

**Allen, F. and Gale, D. (2004b).** "Financial intermediaries and markets," *Econometrica*, Vol. 72 (4), 1012-1061.

**Allen, F. and Gale, D. (2007),** *Understanding financial crises*, Oxford University Press.

**Amihud, Y. (2002),** "Illiquidity and Stock Returns: Cross-Section and Time-Series Effects," *Journal of Financial Markets*, 5, 31--56.

**Ausubel, L. (2004).** "An Efficient Ascending-Bid Auction for Multiple Objects", *American Economic Review*, Vol. 94 (5), 1452-1475.

**Ayusi, J. and R. Repullo (2003),** "A model of the open market operations of the European Central Bank", *Economic Journal*, 113, 883-902

**Banks, E. (2005),** "Liquidity Risk: Managing Asset and Funding Risk," Palgrave Macmillan

**Basel Committee on Banking Supervision (BCBS), 2008,** *Principles for Sound Liquidity Risk Management and Supervision – Draft for Consultation*

**Bindseil, U., Nyborg, K. G. and Strebulaev, I. A. (2008),** "Repo auctions and the market for liquidity", mimeo

**Bindseil, U., B. Weller and F. Wuertz (2003),** "Central banks and commercial banks' liquidity risk management", *Economic Notes*, 32.1, 37-66

**Borio, C. (2000).** "Market Liquidity and Stress: Selected Issues and Policy Implications", *BIS Quarterly Review* November, 38-51

**Brunnermeier, M. K and L. H. Pedersen (2007),** "Market Liquidity and Funding Liquidity," *CEPR Discussion Papers 6179*, C.E.P.R. Discussion Papers

**Chordia Tarun, A. Sarkar and A. Subrahmanyam (2005)**, “An empirical analysis of stock and bond market liquidity”, *The Review of Financial Studies*, 18(1), 85-128

**Chordia, T., R. Roll, and A. Subrahmanyam (2000)**, “Commonality in Liquidity,” *Journal of Financial Economics*, 56, 3-28.

**Committee on Payment and Settlement Systems (CPSS) (2003)** “The role of central bank money in payment systems,” Bank for International Settlements

**Diamond, D. W. and Rajan, R. G. (2005)**. "Liquidity shortages and banking crises", *Journal of Finance*, Vol. 60 (2), 615-647.

**Drehmann, M. (2007)**, "Discussion on Banks, markets and liquidity by F. Allen and E. Carletti", in *The structure and resilience of the financial system*, (Eds, Kent, C. and Lawson, J.), Reserve Bank of Australia.

**Drehmann, M., J. Elliot and S. Kapadia (2007)**, “Funding liquidity risk in a systemic context,” mimeo

**ECB (2004)**, *The use of central bank money for settling securities transactions*

**ECB (2007)**, *Financial Stability Review*, December

**ECB (2008)**, *Financial Stability Review*, June

**Fecht, F., Nyborg, K. G. and Rocholl, J. (2008)**, "The price of liquidity: bank characteristics and market conditions", *mimeo*.

**Flannery, M. J. (1996)**. "Financial Crises, Payment System Problems, and Discount Window Lending", *Journal of Money, Credit and Banking*, Vol. 28 (4), 804-24.

**Friedman, M. and A. Schwarz (1963)**, *A monetary history of the United States*, Princeton University Press, Princeton

**Furfine, C. (2002)**, "The Interbank Market during a Crisis", *European Economic Review*, Vol. 46 (4-5), 809-20.

**Gatev, E and Strahan, P E (2006)**, "Banks' advantage in hedging liquidity risk: theory and evidence from the commercial paper market", *Journal of Finance*, Vol. 61(2), pages 867-92.

**Gondat-Larralde, C. and Nier, E. (2004)**, "The economics of retail banking - an empirical analysis of the UK market for personal current accounts", *Bank of England Quarterly Bulletin*, Spring.

**Gyntelberg, J. and Wooldridge, P. (2008)**, "Interbank Rate Fixings during the Recent Turmoil", *BIS Quarterly Review*, Vol. 59-72.

**Holmström, B. and Tirole, J. (2001)**. "LAPM: A Liquidity-Based Asset Pricing Model", *The Journal of Finance*, Vol. 56 (5), 1837-1867.

**IMF (2008)**, *Global Financial Stability Report*, April

**IIF (2007)**, *Principles of Liquidity Risk Management*

**Kashyap, A., Rajan, R. G. and Stein, J. C. (2002)**. "Banks as Liquidity Providers: An Explanation for the Coexistence of Lending and Deposit-Taking", *Journal of Finance*, Vol. 57 (1), 33-73.

**Matz, L and P. Neu (2006)**, *Liquidity Risk: Measurement and Management*, Wiley

**Michaud, F.-L. and Upper, C. (2008)**, "What Drives Interbank Rates? Evidence from the Libor Panel", *BIS Quarterly Review*, Vol. 47-58.

**Norman, B, R. Shaw and G. Speight (2006)**, "The history of interbank settlement arrangements: exploring central banks' role in the payment system", Bank of England *mimeo*

**Nyborg, K. G. and Strebulaev, I. A. (2004)**. "Multiple Unit Auctions and Short Squeezes", *The Review of Financial Studies*, Vol. 17 (2), 545-580.

**Pastor, L. and R. F. Stambaugh (2003)**, "Liquidity Risk and Expected Stock Returns," *Journal of Political Economy*, University of Chicago Press, vol. 111(3), pages 642-685.

**Pennacchi, George (2006)**, "Deposit Insurance, Bank Regulation and Financial System Risk," *Journal of Monetary Economics* 53, 1-30.

**Poole W. (1968)**, "Commercial Bank Reserve Management in a Stochastic Model: Implications for Monetary Policy," *Journal of Finance*, December, 769-91

**Rochet, J. C. and Vives, X. (2004)**. "Coordination Failures and the Lender of Last Resort: was Bagehot Right after All?", *Journal of the European Economic Association*, Vol. 2 (6), 1116-1147.

**Strahan, P. E. (2008)**, "Liquidity Production in 21st Century Banking", *NBER Working Paper No. W13798*

**Stiglitz, J. and Weiss, A. (1981)**, "Credit Rationing in Markets with Imperfect Information", *American Economic Review*, Vol. 71 (3), 393-410.

**Välimäki, T. (2002)**. "Variable rate liquidity tenders", *Bank of Finland Discussion Papers* 24 .2002.

**Valimaki, T. (2006)**. "Why the marginal MRO rate exceeds the ECB policy rate?," *Bank of Finland, Research Discussion Papers* 200/2006.

## Annex 1: Funding liquidity and the role of central bank money

In this Annex we provide a more granular view of the key components of the funding liquidity constraint and explain the role of central bank in greater depth. In section 2 we argued that a funding liquidity constraint can be represented by

$$\text{Outflows}_t \leq \text{Inflows}_t + \text{Stock of Money}_t \quad (1)$$

**Table A1.1: Components and sources of in- and outflows of money**

	Outflow	Inflow
Depositors	$(L_{new}^D + A_{due}^D + AI_{due}^D)$	$(L_{due}^D + LI_{due}^D + A_{new}^D)$
Interbank	$(L_{new}^{IB} + A_{due}^{IB} + AI_{due}^{IB})$	$(L_{due}^{IB} + LI_{due}^{IB} + A_{new}^{IB})$
Asset market	$A_{sold}$	$A_{bought}$
Off-balance sheet items	$OB_{out}$	$OB_{in}$
Central Bank	$(CB_{due}^{MRO} + CBI_{due}^{MRO} + CB_{out}^{other})$	$(CB_{new}^{MRO} + CB_{in}^{other})$

Where:

- $L/A$  are liabilities and assets of the bank;<sup>24</sup>
- $LI/AI/CBI$  are interest payments paid or received by the bank;
- $IB/D$  stands for interbank and other depositors (or borrowers);
- $due$  stands for assets and liabilities which are contractually due in the period;
- $new$  stands for assets and liabilities newly issued;  $new$  can also include liabilities or assets which are rolled over;
- $OB$  are off-balance sheet items which can contribute to *out*- or *in*flows;
- Assets can also be *sold/bought* on the secondary market;
- $CB^{MRO}$  are central bank balances obtained from the weekly main refinancing operations;
- $CB^{other}$  are *in*- and *out*flows of central bank balances obtained directly from the central bank but not in the weekly refinancing operations, for example by accessing the marginal lending or deposit facility or participating in fine tuning operations.<sup>25</sup>

Note: Liquidity will also be determined by other cash flows which can be inflows such as fees and commissions or new equity capital, or outflows such as costs or dividend payments.

Table A1.1 provides an overview of key components of in- and outflows and attributes them to the five main funding sources. Note that in order to keep sub-indices to a minimum,  $t$  was dropped in Table A1.1. The reader should keep in mind that time plays an important role for funding liquidity. For liquidity risk management purposes, banks also have to distinguish between different currencies the bank is active in. The stock flow constraint has to hold in each

<sup>24</sup> These include assets and liabilities in both the banking and trading book.

<sup>25</sup> In the Eurosystem reserves are also remunerated which constitute are part of  $CB_{in}^{other}$ .

currency but as long as foreign exchange markets are functioning, (funding) liquidity can be transferred. We therefore ignore currency differences in our analysis. The analysis of the stock flow constraint and its components gets also more complicated if the banking system is tiered and some small banks use corresponded banks to participate in the settle and payment system or the central bank auctions. Even though tiering is not uncommon in banking systems, we do not take account of this in our discussion below, but instead focus on the main systemically important banks which also participate in the auctions.

The first source of inflows and outflows is driven by behaviour of depositors. A bank receives an inflow of money if borrowers pay back their loan and/or interest ( $A_{due} + AI_{due}$ ) or by receiving new deposits ( $L_{new}$ ). Similarly, outflows can be a result of depositors withdrawing money ( $L_{due}$ ), the bank paying interest ( $LI_{due}$ ) or the bank issuing new loans ( $A_{new}$ ). Note that not all withdrawals of depositors have to necessarily lead to a change in central bank balances. A large bank can settle a lot of transactions on its own book. If for example consumer A pays company Y and both have an account at the same bank this transaction gets settled in the bank's own money. If however company Y has an account with another bank, the transfer between the banks is ultimately settled in central bank money. Even though it may be the case that, depending on the settlement system, only net transfers between both banks at the end of the day are settled in central bank money (CPSS, 2003)

The second source is different from the first one only insofar as we distinguish between interbank markets and other depositors/borrowers. Distinguishing is important because the behaviour of interbank markets and other depositors is significantly different. The latter are generally very sluggish to react and do not monitor banks very well (see Gondat- Larralde and Nier, 2004). A further important difference between depositors and the interbank market is that all transfers between large banks are settled in central bank money. In the euro area these transfers take place in TARGET2<sup>26</sup> which is a real time gross settlement system (RTGS), i.e. payments are settled continuously and in gross rather than net amounts.

Whether in- and outflows are secured or not does not matter for the flow analysis. Therefore, repo transactions are also contained in the interbank flows. However, depending on the legal structure, repos can also be asset sales/purchases with a binding agreement to reverse the trade in the future. Asset sales/purchases are the third component in the stock flow constraint. For the conceptual analysis it is not important to distinguish asset sales/purchases from the trading book from those of the banking book. However, practically they differ as equity and bonds held in the trading book can often be traded on organised exchanges in relatively liquid markets (in the sense of market liquidity).<sup>27</sup> Whilst assets held in the banking book are sold and purchased for example via securitisation programmes “over the counter”. This requires more

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<sup>26</sup> TARGET2 became operational in November 2007 and replaced the previous TARGET system.

<sup>27</sup> Depending on the settlement system, securities settlement generally involves central bank money, especially in the euro area (see ECB, 2004) again indicating the crucial role for central bank money in the economy.

time and effort and markets tend to be less liquid, especially during times of stress as could be observed recently (ECB, 2007). Practically, asset sales from the trading and banking book also differ how they are settled. Whilst many over the counter transactions are settled in the payment system and hence involve central money, the interaction of central bank money and securities settlement systems is more complex. A survey by the ECB (2004) highlights the range of practices in the euro area. Settlement can be effectively real time as in Crest in the UK or there can be settlement cycles such as the overnight cycle use by Monte Titoli (Italy) where central bank money is only involved to settle net amounts. Nonetheless, central bank money to achieve finality in the settlement of at least net-transfers always plays an important role.

The fourth source is cash in- and outflows from off-balance sheet activities. An important part of liquidity demands from off balance sheet items ( $OB_{out}$ ) are committed credit lines to companies or off-balance sheet vehicles such as conduits (see IIF, 2007, BIS, 2006). Essentially, a drawn credit line is a new obligation for the bank. In that sense they could be included in  $L_{new}$ . However, for expositional purposes we present them in a separate group as they proved to be a key transmission channel from liquidity problems in the structured credit to the interbank market during the recent turmoil (see ECB, 2007). In addition, margin calls, which are also part of  $OB_{out}$ , can have a significant impact on cash flows. However, as part of their contingency preparation, banks themselves generally have contingent liquidity lines with other banks ( $OB_{in}$ ).

The last source of the stock flow constraint is for our empirical analysis the most important one as banks can obtain new central bank money from the central bank directly. These are also important from a system perspective as all transactions discussed so far do not change the amount of central bank money but represent a transfer from bank A to bank B. Only direct interactions can change the aggregate amount of central bank money in the economy.

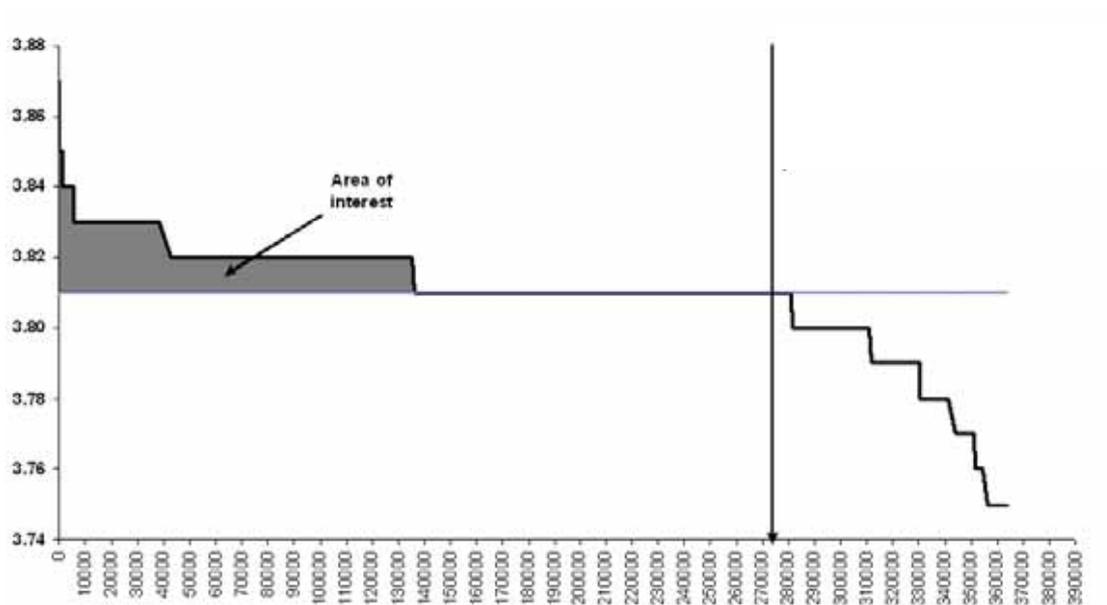
Given our empirical measure we distinguish MROs and other interactions with the central bank. MROs are based on repo-arrangements and have a maturity of one week. Hence, new borrowing ( $CB_{in}^{MRO}$ ) can only be obtained against collateral but the transaction is reversed at the end of the maturity. At this point the bank faces an outflow of central bank money, which also includes interest payments ( $CB_{due}^{MRO} + CBI_{due}^{MRO}$ ). In- and outflows of central bank money ( $CB_{in}^{other}$  or  $CB_{out}^{other}$ ) are also generated when banks access the marginal lending or deposit facility (also referred to as the discount window) or if banks participate in fine tuning operations or long term refinancing operations. In the Eurosystem reserves are also remunerated which constitutes another type of inflows of central bank money. In an extreme case, the central bank may also act as a lender of last resort. This is also captured by  $CB_{in}^{other}$ .<sup>28</sup>

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<sup>28</sup> Banks' direct access to central bank money differs significantly across jurisdictions as has been shown in the short discussion in Section 7 about differences in the US and Europe. Collateral accepted is also different for

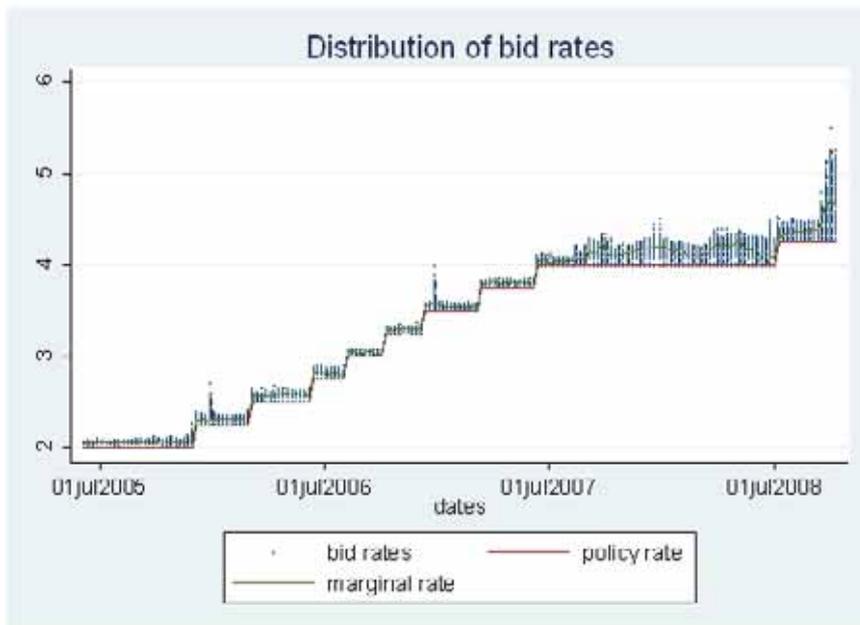
## Annex 3: Additional Charts

**Chart A3.1: A central bank auction and the funding liquidity risk measures.**



Note: Horizontal line is expected marginal rate and vertical line indicates expected total allotment

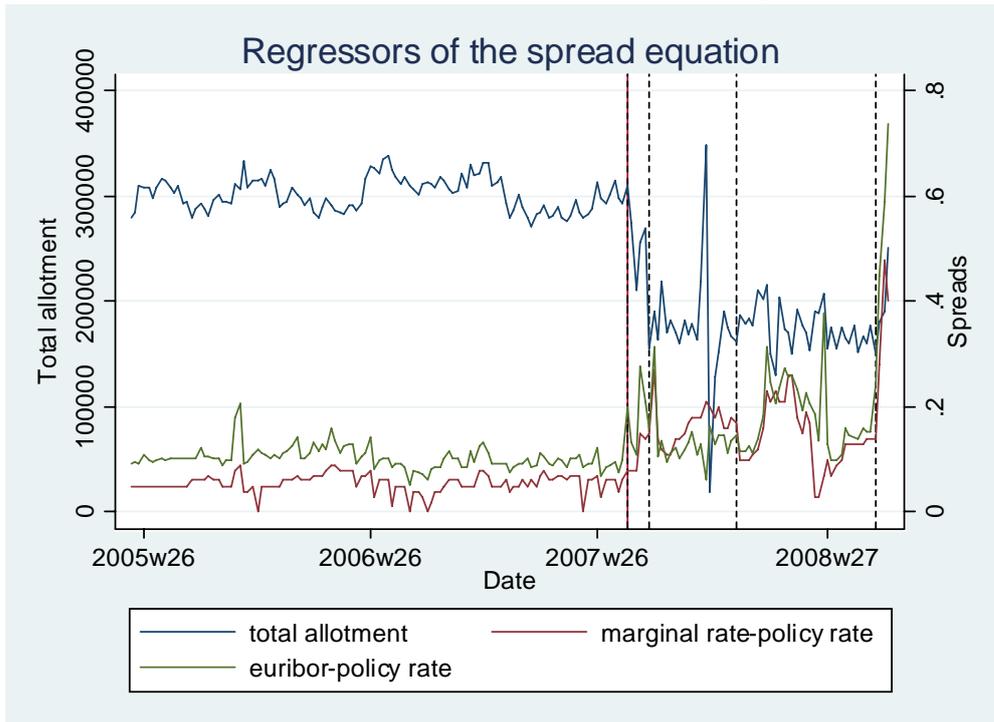
**Chart A3.2: Bid rates in ECB MRO auctions**



Note: The chart presents the individual bid rates of all banks participating in the ECB MROs from June 2005 until 7 October 2007. It also presents the unique policy rate and marginal rate for each auction.

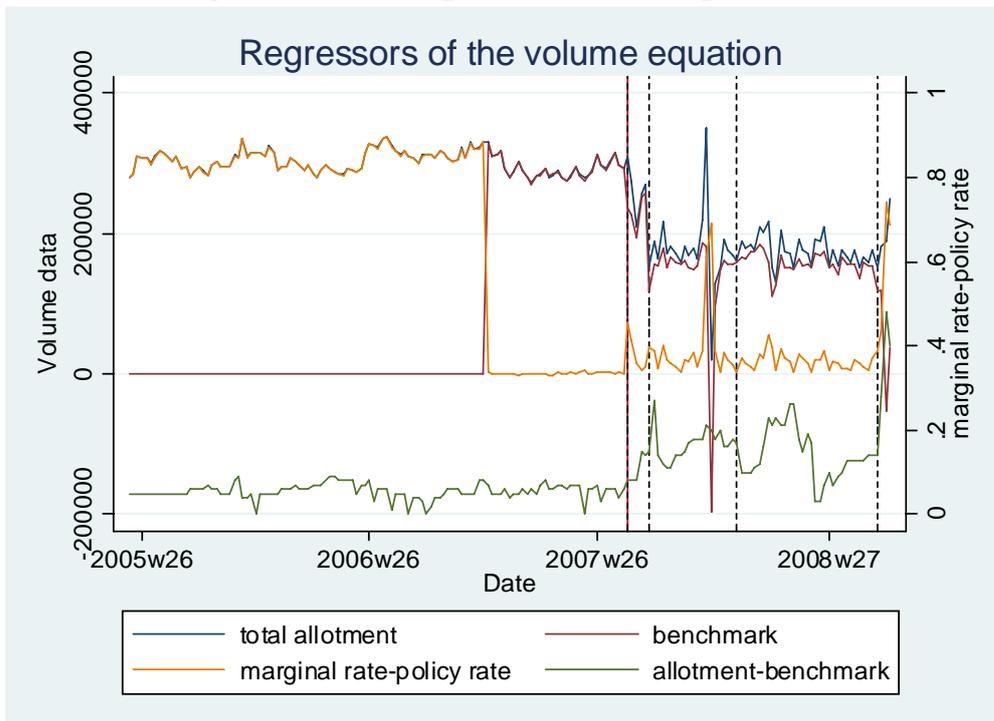
different countries. In many countries such as the US accessing the marginal facilities is also associated with a stigma and may have reputational repercussions for the bank. Stigma in the euro area is less pronounced.

**Chart A3.3. Regressors of the expected marginal rate equation**



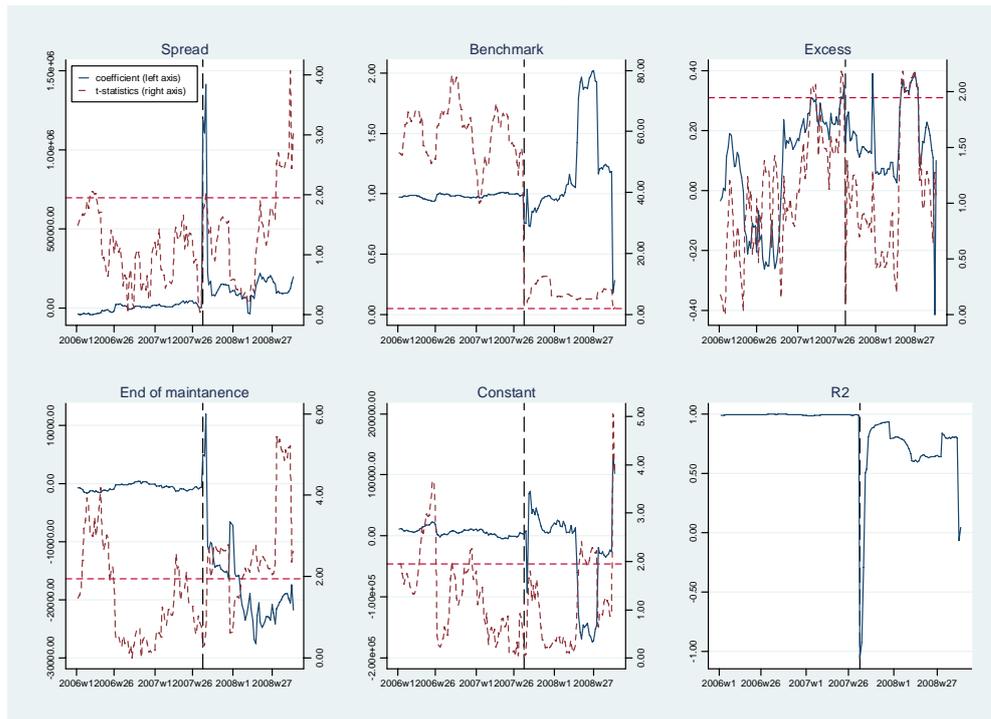
Note: The Chart presents the variables that enter in the regression (X), as described in Section 5.2

**Chart A3.4. Regressors of the expected allotment equation**



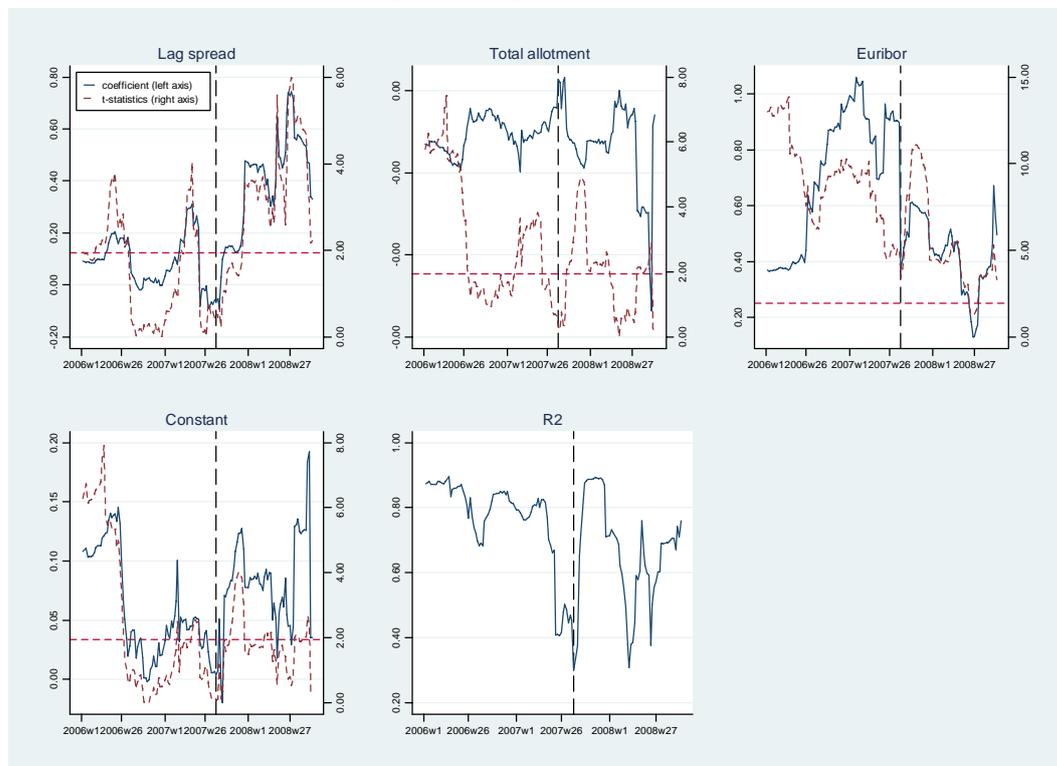
Note: The Chart presents the variables that enter in the regression (X), as described in Section 5.2

**Chart A3.5: Results for the allotment regressions**



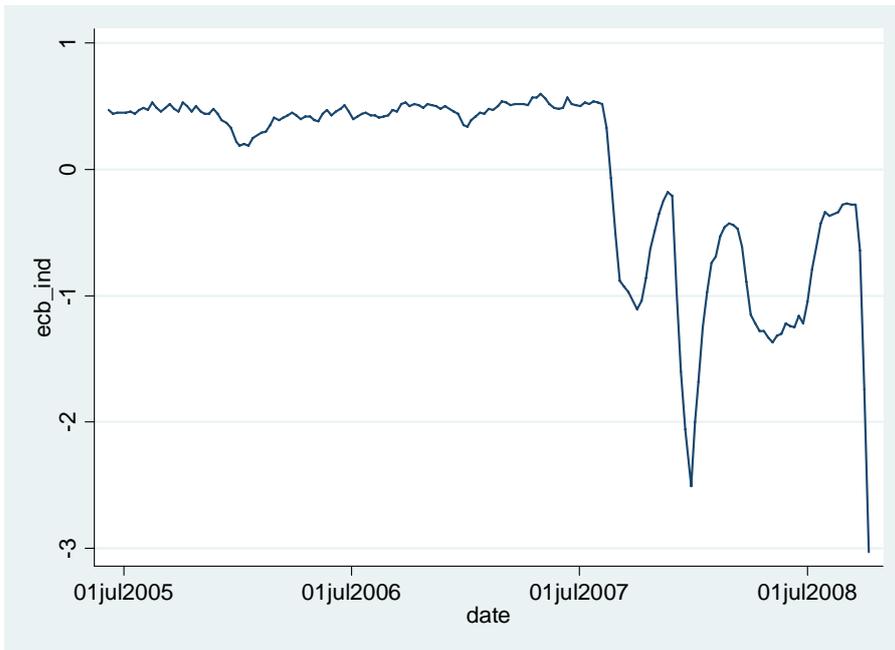
Note: Black vertical line indicates the first auction after the beginning of the crises in August 2007. Horizontal line is the 5% confidence level (right axis)

**Chart A3.6: Results for the spread regression**



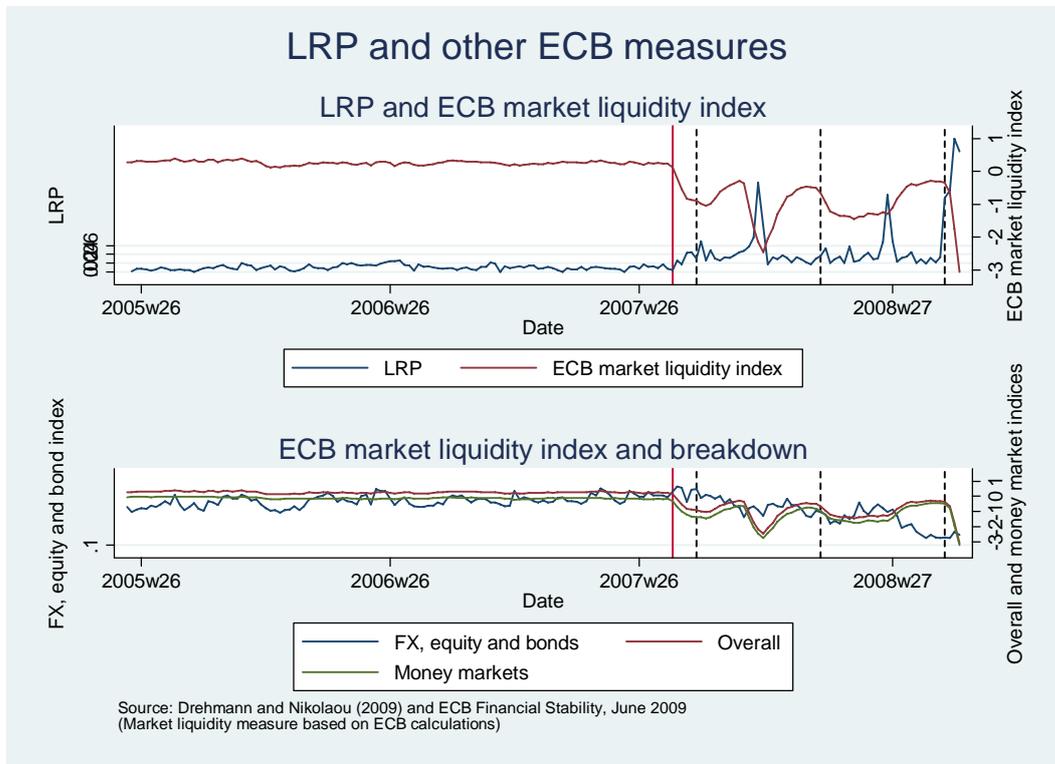
Note: Black vertical line indicates the first auction after the beginning of the crises in August 2007. Horizontal line is the 5% confidence level (right axis)

**Chart A3.7: ECB financial market liquidity indicator**



Note: For further information see Chart 3.1 ECB (2008)

**Chart A3.8: LRP and ECB market liquidity measures**



Note: The chart presents the LRP measures excluding the last operation of each year and various ECB market liquidity measures for the same dates. The red horizontal line indicates the beginning of the turmoil (here 14 August 2007 when the first MRO was undertaken after the turmoil started). The horizontal black lines indicate dates of important events, the failure of Northern Rock (13 September 2007), the failure of Bear Sterns (16 March 2008) and the failure of Lehman Brothers (15 September 2008).