BANK FOR INTERNATIONAL SETTLEMENTS

BIS Working Papers

No 316

Funding liquidity risk: definition and measurement

by Mathias Drehmann and Kleopatra Nikolaou

Monetary and Economic Department

July 2010

JEL classification: E58; G21

Keywords: funding liquidity; liquidity risk; bidding behavior; central bank auctions; interbank markets

BIS Working Papers are written by members of the Monetary and Economic Department of the Bank for International Settlements, and from time to time by other economists, and are published by the Bank. The papers are on subjects of topical interest and are technical in character. The views expressed in them are those of their authors and not necessarily the views of the BIS.

Copies of publications are available from:

Bank for International Settlements
Communications
CH-4002 Basel, Switzerland

E-mail: publications@bis.org

Fax: +41 61 280 9100 and +41 61 280 8100

This publication is available on the BIS website (www.bis.org).

ISSN 1020-0959 (print)

ISBN 1682-7678 (online)

Funding liquidity risk: definition and measurement[1]

Mathias Drehmann[2] and Kleopatra Nikolaou[3]

First version: December 2008
This version: July 2010

Abstract

Funding liquidity risk has played a key role in all historical banking crises. Nevertheless, a measure based on publicly available data remains so far elusive. We address this gap by showing that aggressive bidding at central bank auctions reveals funding liquidity risk. We can extract an insurance premium from banks' bids which we propose as measure of funding liquidity risk. Using a unique data set consisting of all bids in the main refinancing operation auctions conducted at the ECB between June 2005 and October 2008 we find that funding liquidity risk is typically stable and low, with occasional spikes, especially around key events during the recent crisis. We also document downward spirals between funding liquidity risk and market liquidity. As measurement without clear definitions is impossible, we initially provide definitions of funding liquidity and funding liquidity risk.

JEL classification: E58, G21

Keywords: funding liquidity, liquidity risk, bidding behavior, central bank auctions, interbank markets

---

[1] The views expressed in the paper do not represent the views of the BIS or the ECB. We would like to thank Claudio Borio, Markus Brunnermeier, Ben Craig, Charles Goodhart, Philipp Hartmann, Bill Nelson, Kjell Nyborg, Kostas Tsatsaronis, Christian Upper and Götz von Peter as well as participants at European Economic Association Meeting 2009, the Money, Market and Finance conference 2007, the conference on "Central Bank Liquidity Tools" hosted by the Federal Reserve Bank of New York, the conference on "Liquidity" hosted by the CESifo and Deutsche Bundesbank, the Bank of England, the Monetary Authority of Hong Kong, the Bank of Canada, the Norges Bank, the BIS, and the University of Pireus, Finance Division for helpful comments. Mathias Drehmann (corresponding author): Bank for International Settlements, Centralbahnplatz 2, CH-4002 Basel, Switzerland, mathias.drehmann@bis.org. Kleopatra Nikolaou: European Central Bank, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany, kleopatra.nikolaou@ecb.int.

[2] Bank for International Settlements

[3] European Central Bank

Contents

1. Introduction

Funding liquidity risk has played a key role in all historical banking crises. Recent events are not different. The global credit crisis 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 based on readily available data remains so far elusive. This paper addresses this gap by showing that banks' bids during open market operations reveal funding liquidity risk.

Measurement without definition is, however, difficult if not impossible. In this paper we define *funding liquidity* as *the ability to settle obligations with immediacy.* It follows that, a bank is illiquid if it is unable to settle obligations in time. Consequently, we define *funding liquidity risk as the possibility that over a specific horizon the bank will become unable to settle obligations with immediacy*. In contrast to other definitions used by academics and practitioners, our definitions have important properties, shared by definitions of other types of risk. 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.

Ideally and in line with other risks, we would want to measure funding liquidity risk by the distribution summarising the stochastic nature of the underlying risk factors. This is impossible as these distributions cannot be estimated because of a lack of data, even for banks with access to more (confidential) information. Against this drawback, we propose a new approach to measure funding liquidity risk. We extract funding liquidity risk from observing the costs that banks are willing to pay in order to secure liquidity from the central bank. The underlying trade-off at the central bank auction is whether to obtain liquidity from the central bank directly or rely on other markets for liquidity. By submitting aggressive bids at the central bank auction, the bank is very likely to obtain funds from the central bank. Thereby it can insure against becoming illiquid. This is intuitive. But it can also be shown theoretically that banks bid more at higher prices, the greater their funding liquidity risk (Nyborg and Strebulaev, 2004, Välimäki, 2006). Using this insight, we show that aggregate funding liquidity risk can be measured by the sum of the premia banks are willing to pay above the expected marginal rate (ie the expected interest rate which will clear the auction) times the volume they bid, normalised by the expected amount of money supplied by the central bank. This measure can be interpreted as the weighted average insurance premium against funding liquidity risk.

We construct our measure with the help of a unique data set of 170 main refinancing operation (MRO) auctions, conducted between June 2005 and December 2007 in the euro area, involving some 1055 banks. MROs have a maturity of one week, which implies that we measure funding liquidity risk over a one week horizon. The aggregate supply of liquidity – also called total allotment – is determined by the ECB. The auction is price-discriminating, ie every successful bidder has to pay her bid. At the marginal rate bids may be rationed, so that everyone takes the same pro rata amount of the remaining liquidity. The marginal rate is the interest rate that equates aggregate demand with total allotment.

Ex ante the marginal rate is uncertain not only because the aggregate demand is unknown but also because the ECB can adjust the supply after all bids have been received. Gauging market expectations is a non-trivial task. The problem is further complicated by the endogeneity between the aggregate bids and the total allotment. For this reason we rely on a new survey dataset from Reuters, where market expectations about the marginal rate of each auction are revealed. By nature of being survey data, the information is treated as exogenous for all statistical purposes. To the best of our knowledge, this is the first time that this kind of data set has been used. The expected marginal rate and other publicly available data allow us to determine the expected total allotment.

We find that our proposed measure has intuitive properties. Prior to the crisis, the average insurance premium was less than one basis point. Funding liquidity risk increased rapidly after August 2007 and spiked after the rescue of Northern Rock. Following the failure of Bear Sterns liquidity risk rose sharply again, even though to less elevated levels. Unsurprisingly, our measure identifies record pressures in October 2008 after Lehman failed, when the average insurance premium rose to over 40 basis points. More generally, our measure shares characteristics such as a high degree of persistence with occasional spikes, which have been documented by market participants using banks' own models (see Matz and Neu, 2007, or Banks, 2005). Moreover, these properties are also shared by measures for market liquidity (eg see Amihud, 2002; Chordia et al., 2005; Pastor and Staumbaugh, 2003).

Our measure significantly improves on other measures of funding liquidity risk. A common reference point for practitioners, policy makers and academics of the tensions prevailing during the current financial crisis have been money market spreads. We find that the EURIBOR-OIS spread is much higher than our proposed measure. This is not unsurprising as the former is affected by a host of other risk factors and therefore is not a clean measure of funding liquidity risk (eg Gyntelberg and Wooldrige, 2008). Banks' own measures of funding liquidity risk are also not useful to measure funding liquidity risk on an aggregate basis, as they generally rely entirely on confidential information and contain a lot of judgement (eg Matz and Neu, 2007). Whilst we use confidential bidding data from the ECB, other central banks have similar data available. Furthermore, we show in the paper that a broadly similar measure of aggregate funding liquidity risk can be easily derived from public data provided by the ECB after each auction. Therefore, our method allows for a frequent and timely assessment of aggregate funding liquidity risk in an environment characterised by limited data availability.

Our measure also allows us to assess the interactions of market liquidity and funding liquidity risk. Whilst this has been shown theoretically (eg Brunnermeier and Pedersen, 2009) and anecdotal evidence points to these effects in the recent crisis, the interaction between both liquidity measures has not been shown empirically due to a lack of measures for funding liquidity risk. Using our measure, we are able to show that there are strong negative interrelationships between funding liquidity risk and a measure for market liquidity. In this sense higher funding liquidity risk implies lower market liquidity.

The remainder of the paper is structured as follows. In Section 2 we introduce our definition of funding and funding liquidity risk and discuss how this relates to other definitions in the literature. After providing a short overview of OMOs in the euro areas in Section 3, we show that higher funding liquidity risk will result in higher bids during OMOs in Section 4. Section 5 introduces our measure and Section 6 presents data used. In Section 7 we present the results. Further discussion is provided in Section 8. Finally, Section 9 concludes.

2. Definition of funding liquidity and funding liquidity risk

2.1. Funding liquidity and funding liquidity risk

Liquidity risk arises because revenues and outlays are not synchronised (Holmström and Tirole, 1998). This would not matter if agents could issue financial contracts to third parties, pledging their future income as collateral. Given frictions, this is not always possible in reality and agents may become illiquid. We define *funding liquidity* as *the ability to settle obligations with immediacy.* Consequently, a bank is illiquid if it is unable to settle obligations. Legally, a bank is then in default. Given this definition we define *funding liquidity risk as the possibility that over a specific horizon the bank will become unable to settle obligations with immediacy*.

It is worth to highlight important differences between funding liquidity and funding liquidity risk: Funding liquidity is essentially a binary concept, ie a bank can either settle obligations or it cannot. Funding liquidity risk on the other hand can take infinitely 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 with one particular point in time. Funding liquidity risk on the other hand is always forward looking and measured over a specific horizon. In this respect, concerns about the future ability to settle obligations, ie future funding liquidity, will impact on current funding liquidity risk. The distinction between liquidity and liquidity risk is, therefore, straightforward and analogous to other risks. For example, a similar distinction can be made between credit risk and default. Whilst default either occurs or does not, credit risk is associated with the likelihood that the borrower will default over a particular horizon.[4]

Surprisingly, a distinction in the definition of funding liquidity and funding liquidity risk has not been made by practitioners and academics so far. Borio (2000), Strahan (2008) or Brunnermeier and Pedersen (2009) 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 (sufficient) 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 to cover all outflows. As the ability to raise cash can vanish (Borio, 2000) this definition is implicitly forward looking and therefore associated to funding liquidity risk. The IMF defines funding liquidity as “the ability of a solvent institution to make agreed-upon payments in a timely fashion” (p. xi, IMF, 2008). This definition carries the notion that liquidity is related to the ability to settle obligations. However, it is crucial to distinguish liquidity and solvency as welfare losses associated with illiquidity arise precisely when solvent institutions become illiquid. 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, without incurring unacceptable losses” (p.1, BCBS, 2008). The first part of this definition is essentially equivalent to ours. However, it is unclear what ‘unacceptable losses’ really means.

Our definition raises the question how banks settle obligations. Most transactions, especially those involving private agents, are settled in commercial bank money. However, for transaction between banks central bank money plays a crucial role. 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).[5] While banks can create commercial bank money, the volume of central bank money is determined by central banks. Therefore, the ability to settle obligations, and hence funding liquidity risk, is determined by the ability to satisfy the demand for central bank money. In Annex 1 the role of central bank money as a settlement asset is elaborated further.

2.2 Funding liquidity as a stock-flow concept[6]

Based on our definition, it is easy to see that a bank is able to satisfy the demand for (central bank) money, and hence is liquid, as long as at each point in time outflows of (central bank)

---

4 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 the exposure at default.

5 Central bank money consists mainly of deposits held by commercial banks with the central bank. For a history of central banks’ role in interbank payment systems see Norman et al (2006). Central bank money has also been labelled high powered money in the monetary economics literature (eg see Friedman and Schwarz, 1963).

6 This section draws on earlier unpublished work by Drehmann, Elliot and Kapadia, which is now incorporated in Kapadia et al (2010).

money are smaller or equal to inflows plus the stock of (central bank) money held by the bank:

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

Annex 1 provides a more detailed breakdown of in- and outflows. For now, we focus on the net volume of money needed to avoid illiquidity. We construct the net-liquidity demand (*NLD)* from the stock flow constraint above. Namely, we take the difference between all outflows (*Outflows)* and contractual (ie known) inflows (*$Inflows^{due}$)* net of the stock of central bank money *(M):*

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

In case of a deficit (ie outflows are larger than inflows and the stock of money), the inequality highlights that NLD_t 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 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. Note that this means that ex-post inflows always equal outflows, as long as the bank does not fail. But ex-ante, equation (2) highlights that funding liquidity risk is driven by two stochastic components: future developments of *NLD (*ie volumes) and future prices of liquidity in different markets.

The question for this paper is how to measure funding liquidity risk. Ideally, and in line with other risks, we would want to measure funding liquidity risk by the distribution jointly summarising the stochastic nature of in- and outflows as well as prices. But, even banks with access to far more data are unable to construct such a distribution. For example, it is impossible to estimate prices of, and access to, liquidity in different markets in stressed conditions, as crises occur too rarely to use standard statistical tools.

We propose a different approach to measure funding liquidity risk, which incorporates information on both volumes and price of liquidity. We observe banks' bids (rates and volumes) during central bank operations (or $p_t^{CB} CB_{new,t}$ in the language of equation (2)). In Section 4 we explain that banks with higher funding liquidity risk will bid more aggressively, and the more so, the higher their funding liquidity risk. A short overview over the institutional background of open market operations (OMOs) in the euro area may be useful in that respect.

3. Open Market Operations in the euro area

We use data from 1 June 2005 until 10 October 2008. During this time OMOs are mainly conducted as short-term main refinancing operations (MROs) or longer-term refinancing operations (LTROs). MROs are carried out weekly and have a maturity of one week. Traditionally MROs have provided the main bulk of liquidity to the euro area.[7] Additionally,

---

[7] This has changed with the onset of the crisis in August 2007, when the heightened uncertainties lead to an increase in the liquidity demand for longer horizons.

the ECB can undertake fine-tuning operations in case of a need for an additional and extraordinary injection or absorption of central bank money.

MROs form the basis of our measure. Note that this means that we measure funding liquidity risk over *a one week horizon*. In our sample, MROs are conducted as variable rate tenders.[8] The auction set-up is as follows: 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. The aggregate supply of liquidity – also called total allotment – is determined by the ECB. The auction is price-discriminating, ie every successful bidder has to pay her bid. The marginal rate is the interest rate when aggregate demand equals supply. 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. Banks are only required to submit sufficient collateral for the allotted liquidity.

Under normal conditions, the total allotment in the weekly MROs is determined by the benchmark allotment. This is the volume that satisfies exactly these needs for central bank money in aggregate and is calculated as the sum of the autonomous factor forecasts (such as banknotes, government deposits and net foreign assets) and banks' reserve requirements.[9] This forecast, technically called benchmark at announcement, is published prior to the auction. The ECB can deviate from the forecast and provide more or less liquidity after it received all the bids, even though the distribution of deviations is skewed towards the positive side. As central bank operations are primarily monetary policy operations with a purpose to steer market rates close to the policy rate, the ECB made use of this option to a larger extent after the beginning of the crisis. During this period the ECB "front-loaded" liquidity requirements. Front loading is an allotment practice, where the central bank provides liquidity above the benchmark in the beginning of the maintenance period, and close to or just below the benchmark towards the end of the maintenance period, possibly in combination with liquidity absorbing operations. In doing so, the central bank makes sure that banks fulfil their reserve requirements early in the maintenance period. In times of crisis this helps to stabilise the overnight rate. Clearly, market participants try to anticipate the ECB behaviour when submitting bids. We take this endogeneity into account when constructing our measure (see Section 5).

4. Funding liquidity risk and bidding behaviour at OMOs

In this section we show that funding liquidity risk is revealed by the price banks are willing to pay during open market operations. In particular we show that aggregate liquidity risk can be measured by the sum of the premia banks are willing to pay above the expected marginal

---

8 In October 2008 the ECB changed the tender procedure to full allotment at the fixed rate prevailing at the MRO, following the intensification of the crisis in the immediate aftermath of the Lehman collapse. 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 2008. However, we conjecture that volumes bid still reveal funding pressures as the rates in the interbank markets for "good" banks are below the policy rate.

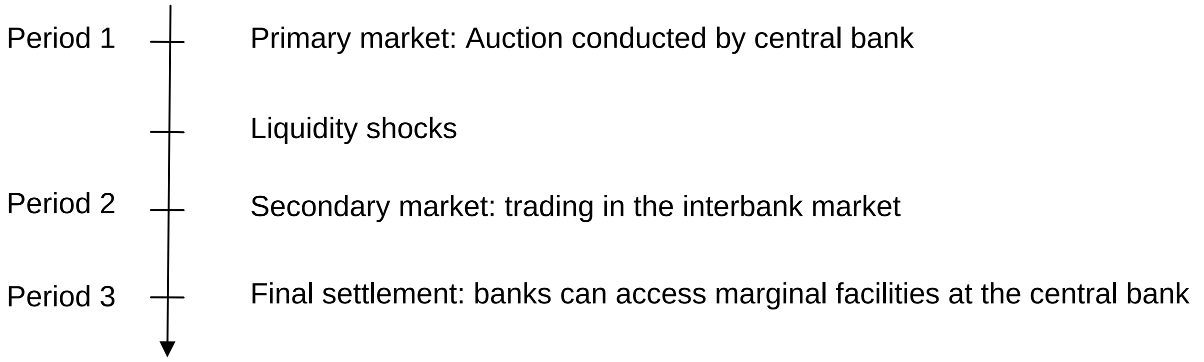
9 In the Euro area individual banks have to fulfil reserve requirements. Banks are allowed to hold positive or negative (relative) reserve balances with the CB within a specified period; ie relative to their requirements banks can hold more or less. Negative current accounts, so-called intraday credit, have to be collateralised and will be referred to the marginal lending facility at the end of the day. 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 period

rate times the volume they bid, normalised by the expected total allotment. This measure can be interpreted as the weighted average insurance premium against funding liquidity risk.

The theoretical literature assessing the bidding behaviour of banks during open market operations started with Poole (1968). It generally considers a stylised time line. In the simplest case, it consists of three periods (see Figure 1). 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. In period 2, 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.[10] 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. For our sample period, banks paid 100bp on top of (below) the policy rate to access the marginal lending (deposit) facility.

Figure 1

Stylised time line



To assess the bidding behaviour of banks and how this relates to liquidity risk, it is important to distinguish interbank markets with and without frictions. Note, that throughout the discussion we only consider price discriminating auctions, which is the auction design used by the ECB. Moreover, we follow the literature and assume throughout the theoretical discussion that the central bank accurately provides the necessary and known (expected) amount of central bank money, independent of the bids it receives.

4.1 Bidding with frictionless interbank markets

If interbank markets are frictionless and banks are risk neutral, Välimäki (2002) and Ayuso and Repullo (2003) show that it is optimal for banks to only bid at the minimum bid rate. No bank is, therefore, willing to pay a premium above the minimum bid rate.

This result is intuitive. First consider the case where banks are only subject to idiosyncratic liquidity shocks so that there is no aggregate liquidity surplus or deficit in period 2 or 3. As

[10] Most countries have positive reserve requirements for banks. However, theoretically it is only necessary that there is a threshold, eg zero, and banks would be penalised if their balances with the central bank would drop below this level.

long as banks are solvent, banks can always obtain the required funding in the secondary market as the (frictionless) interbank market allocates liquidity from those with a surplus to those with a deficit. Given the central bank provides the right amount of liquidity, the interest rate in the interbank market equals the minimum bid rate. With no uncertainty in period 2, bidding at the minimum bid rate in period 1 is the only rational strategy. Hence, our suggested measure would indicate zero liquidity risk, which is exactly what it should do. Theory has shown that funding liquidity risk is zero when interbank markets are frictionless and no aggregate shocks occur (eg Allen and Gale, 2000).

Even with frictionless interbank markets, however, trading cannot eliminate the risk that the market on aggregate may be long or short of central bank money in period 3. As prices for accessing the marginal facilities are fixed, the interest rate in period 2 purely reflects the expectations of the amount and likelihood of accessing either facility in period 3. But at time 1 banks expect that the interest rate in the interbank market equals the policy rate, as the central bank is assumed to provide the right expected amount of aggregate liquidity. Given risk neutrality, all banks therefore bid at the minimum bid rate as they are indifferent between obtaining liquidity in the primary auction or from the interbank markets. Hence, our proposed measure would indicate no risk. However, the assumption of risk neutral banks and frictionless interbank markets is unrealistic, particularly during times of stress. If we relax these assumptions, higher bids reveal higher liquidity risk.

4.2 Bidding with interbank market frictions

It has been theoretically shown that asymmetric information (eg Flannery, 1996), co-ordination failures (eg Rochet and Vives, 2002), uncertainly about future liquidity needs (eg Holmstrom and Tirole, 2001) or incomplete markets (eg 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 may have to pay more than the market rate to obtain it. In the extreme, prices may even be "infinite" if a bank is rationed (see Stiglitz and Weiss, 1981) or markets break down completely (Heider et al, 2009, or Diamond and Rajan, 2009).[11]

Banks with high liquidity risk anticipate this before they submit their bids. The underlying trade-off is whether to obtain liquidity from the central bank (period 1 in Figure 1) or rely on other markets for liquidity (period 2), which may be very costly. By submitting aggressive bids at the central bank auction, the bank is very likely to obtain funds from the central bank. Thereby it can insure itself against becoming illiquid. It is intuitive that a bank with higher risk is willing to pay a higher premium. Nyborg and Strebulaev (2004) show formally that, "short" banks (ie 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 (ie banks which have excess funds), even if all banks are risk neutral.[12] In particular, Nyborg and Strebulaev analyse the case where long banks have some market power during trading in the secondary

[11] Nikolaou (2009) provides an overview over the literature describing the role of interbank markets and funding liquidity risk.

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

market, so that they can "squeeze" short banks and demand higher interest rates.[13] Short banks can avoid being squeezed if they obtain sufficient funds from the central bank during the OMO. And to ensure that they get the required funds, they have to bid above the expected marginal rate. Nyborg and Strebulaev show that in equilibrium the threat of a squeeze induces short banks to submit on average bids above the minimum bid rate with a higher expected mean rate than the bids submitted by banks which are long. The authors also show, that the larger the short position, the larger are the volumes bid at higher prices.[14] Or putting it simply, banks bid more at higher prices, the greater their funding liquidity risk.

Aggressive bidding may also occur because banks may not be risk neutral. Once a bank becomes illiquid, it will default. It is therefore likely that is some circumstances the bank will act as if it is risk averse. Obviously, risk aversion implies that banks with high liquidity risk will pay a higher premium to insure against this risk. During normal times the effects of risk aversion should not be material as interbank markets are nearly frictionless and banks can obtain any required amount of funding in the secondary market. The only risk banks face, are small price changes for unsecured lending due to small aggregate shocks.[15] However, in stressed conditions the risk of becoming illiquid or having to pay high costs to obtain funds in the secondary market increases, so the effects of risk aversion on bid behaviour are more important.

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 be the result of frictions. For example, banks know that the desire to obtain very large amounts of money 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 equivalently with a higher *NLD*, bid more aggressively during the central bank auction. Again the more banks bid at rates above the expected marginal rate, the greater their funding liquidity risk.

4.3 Bidding with all sources of liquidity

No model in the literature on bidding behaviour in OMOs takes account of all sources of funding liquidity shown in equation 2. In reality, banks can trade in the interbank market but also obtain liquidity from depositors or from selling assets. However, within the one week horizon we consider here, banks cannot expect to rely on new customer deposits to weather unexpected liquidity shocks. In the short run, banks have a limited ability to attract a significant amount of new customer deposits (for example by raising rates) because of sluggish depositors' behaviour (see Gondat-Larralde and Nier, 2004).

Asset sales are therefore the only other alternative source of liquidity in the short run. Without frictions in any market, the costs of obtaining liquidity from the interbank market or from selling assets are equal as all price differentials are arbitraged away. In such an environment, the results from Section 4.1 apply and banks only bid at the policy rate. But as in the case of interbank market, frictions in asset markets are central in theories of liquidity

---

[13] Acharya et al (2008) document several banking crises where this effect seems to have played an important role.

[14] Fecht et al. (2009) find empirical support for this by analysing OMOs for German banks. They document that banks, which are below their reserve requirements, bid more aggressively especially in times when the imbalance across banks is large.

[15] 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. These factors can and do change between OMOs even though these fluctuations are generally not large.

risk (for an overview see eg Biais et al, 2005). In case of frictions in both asset and interbank markets, downward spirals between market and funding liquidity can emerge (Brunnermeier and Pedersen, 2009). A downward liquidity spiral can, for example, start with a bank (or brokers in the Brunnermeier and Pedersen model), which is short of funding 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, which increases liquidity outflows. To remain liquid banks have to sell even more assets, which depresses market prices even further (because of a lack of market liquidity), leading to further margin calls and so forth. Banks with high liquidity risk will expect these effects. Therefore, they will bid more aggressively in the primary auction to obtain the required funds. Using our proposed measure of funding liquidity risk, we show that these downward spirals can actually be documented during the crisis.

Before we turn to the empirical analysis we should point out that our measure of funding liquidity risk may also be influenced by other factors. First, there could be collateral effects as the ECB accepts a larger pool of collateral than can be used in the securitised interbank markets. We do not expect this to bias our results in a significant fashion, as interbank markets work to a large extend on an uncollateralised basis.[16] Second, it has been shown that at year-ends, banks bid more aggressively to engage in window-dressing and establish favourable end of year balances (see Bindseil et al 2003). Clearly, such seasonality effects are unrelated to liquidity risk as they are not driven by a reaction to funding pressures. This, however, affects primarily year-end auctions, which we therefore drop.

Third, bidding behaviour may also be influenced by the well-known “winner’s curse” problem which results in underbidding (eg see Milgrom and Weber, 1982).[17] 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. (2009) find no evidence that this is the case for OMOs in the euro area. Hence, the winner’s curse problem should not impact on our measures.

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 as a bidder can be relatively certain that she will get the liquidity requested without being rationed.[18] Our measure is, therefore, simply based on the volume banks bid at rates above the expected marginal rate.

We define the adjusted bid (*AB*) as

---

[16] The broad collateral framework of the ECB may render the ECB auctions relatively more attractive than the secured money market. Ewerhart at al (20010) show theoretically that this may lead banks to bid more aggressively. During normal times this effect should not be large as liquidity is readily available in all money market segments. In crisis the may be different. However, during the recent crisis , the ECB has broadened its collateral eligibility rules to accommodate the large liquidity demand of the banking system, given the breakdown of several money market segments. Therefore, it is unclear what the net-effect is on our measure during the crisis.

[17] In a multi-unit set-up the winner’s curse problem is referred to as champion’s plague (Ausubel, 2004).

[18] In theory, the expected marginal rate equals the minimum bid rate. However, the marginal rate has been on average 6 bps above the policy rate even in normal times. In section 5.1 we will explain in detail how we measure the expected marginal rate as well as the expected total allotment empirically.

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

(3)

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

where, $bid\_rate_{b,i,t}$ and $volume_{b,i,t}$ are the rate and volume of bank *i* (from *1 to N*), which submits *b* bids *(from 1 to B)* at time (auction) *t*. $E(marginal\_rate)_t$ is the expected marginal rate. $AB_{b,i,t}$ are the total costs a bank is willing to pay to ensure that it obtains the $volume_{b,i,t}$ of cash from the central bank. In this sense, it is an insurance cost against funding liquidity risk.

Given *AB* it is easy to construct an aggregate liquidity risk insurance premia (*LRP)* by summing across all adjusted bids of all banks.

$$LRP_t = \frac{\sum_{i=1}^{N} \sum_{b=1}^{B} AB_{b,i,t}}{E(allotment)_t} * 100 \qquad (4)$$

We normalise the sum of the adjusted bid rates by the volume banks expect the central bank to provide. The normalization is necessary to ensure consistency across auctions which differ in size. This will also ensure that our measure is unaffected by "frontloading" practices after August 2007 as discussed in Section 3. Furthermore, the normalisation implies that *LRP* is the value weighted average spread banks are willing to pay to ensure that they obtain liquidity from the central bank. Or putting it simply *LRP* is the average insurance premium banks are willing to pay to insure against funding liquidity risk. The multiplication by 100 implies that it is measured in basis points. An alternative interpretation is shown in Graph A3.1 using one auction as an example. As can be seen *LRP* is simply the normalised area under the aggregate demand curve.

5.1 Estimating the expected marginal rate and allotment volume

As we discussed previously, the central bank can adjust the supply of liquidity after all bids have been received. The market will anticipate this when forming their expectations about the marginal rate and the total allotment volume, which we require as inputs for our measure. Gauging market expectations is a non-trivial task. The problem is further complicated by the endogeneity between the aggregate bids and the total allotment. For this reason we rely on a new survey dataset from Reuters, where market expectations about the marginal rate of each auction are revealed (these data are described in detail in Section 6). Using this data set we can treat the expected marginal rate as an exogenous variable to determine the expected total allotment (TA) by a simple OLS regression:

$$TA_t = \alpha_0 + \alpha_1 * E(spread)_t + \alpha_2 * benchmark + \alpha_4 * end + \varepsilon_t \qquad (5)$$

All regressors in equation (5) are known when bids are submitted. *E(spread)* is the expected spread between the expected marginal rate and the policy rate, which is known before bids are submitted.[19] *benchmark* is the benchmark at announcement. At the end of the maintenance period it is likely that the behaviour of the allotment volume is different as the excess liquidity has to be balanced out. To account for this we insert a dummy variable *end* which equals 1 on the last auction of each maintenance period.

---

[19] The policy rate is set on the monthly meetings of the Governing Council of the ECB. It is announced on the first Thursday of every month and is valid for the maintenance period that spans the period during two consecutive announcements. It is effective from the MRO immediately following the announcement and for all consequent MROs within the same maintenance period.

We use a 30-day rolling window estimation procedure. Rolling windows estimation is ideal in case of structural breaks in the data, which are likely to exist given the outbreak of the crisis.[20] We choose a 30 day window as this provides us with the necessary amount of data in order to achieve efficient asymptotic estimates, while at the same time it minimises the effects of changes which occurred during the crisis, for which we only have 59 observations.

6. Data

Our analysis benefits from a unique data set of 175 MROs conducted by the ECB from June 2005 to 7 October 2008. To avoid the contamination of our measure by window-dressing, we drop the last operation in each year. We also do not consider the operation conducted on 18 Dec 2007 as this had a maturity of 2 weeks. In total we have therefore 171 MROs in our sample.

Overall, 1055 banks took part at least once in any of these auctions. We have information on 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.[21]

We combine this information with data from a Reuters poll surveying expectations of the marginal rate. To our knowledge, this is the first time these data are used. The poll is conducted on a weekly basis. Reuters asks a number of banks (usually the same panel of 25 to 30) every week about their expectations about the marginal rate. These banks represent the largest banks in the euro area as well as some mid-size dealers. The number of banks may vary slightly per week depending on availability. We use the mean of this survey as the expected marginal rate. Graph 1 shows that before the crisis, the market anticipates the marginal rate well. Afterwards a gap emerges. Interestingly, the market seems to consistently underestimate the marginal rate in the early stages of the crisis.

Graph A3.2 in the Annex provides an overview over the components of the individual bids. The left-hand panel shows the individual bid rates as spreads above the minimum bid rate. Each data point corresponds to a single dot in the graph. It is apparent that the crisis 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 expected marginal rate. The right-hand panel of Graph A3.2 shows the volumes bid for bid rates above the expected marginal rate. In line with equation 4, we normalise each submitted bid volume by the expected total allotment. In contrast to the rates, volumes bid do not change dramatically before and during the crisis, even though some increase is apparent.

Graph A3.3 presents the evolution of the total allotment and the benchmark at announcement. Prior to August 2007 the benchmark is a very good predictor for the actual allotment. On average, the difference during this period is only 0.4%. This changed with the beginning of the crisis, when the ECB started the frontloading practices described in Section 3.

---

[20] Windows of length 24, 40, 50, 52 and 60 observations were also tried. Results are broadly similar and available on request.

[21] http://www.ecb.eu/mopo/implement/omo/html/index.en.html

7. Results

7.1 Regression results

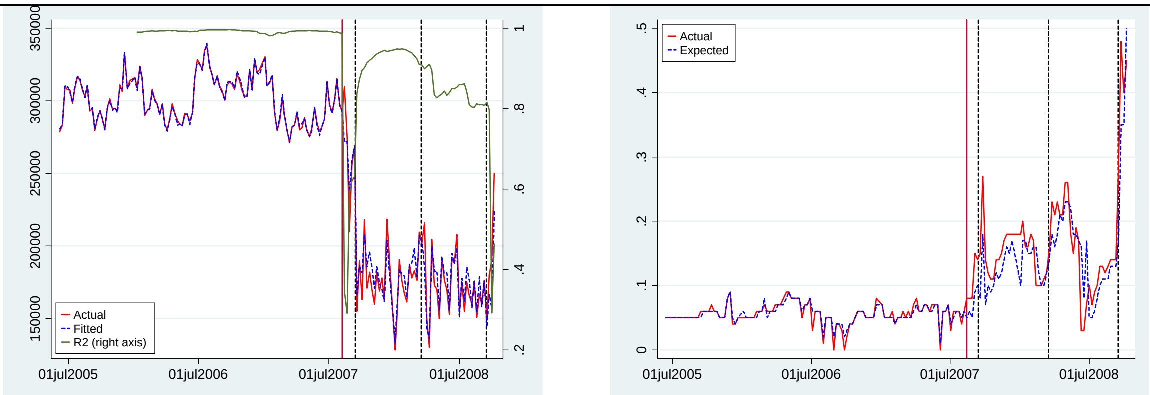
Before moving on to present LRP we briefly present the results of the regression determining the expected allotment as described in equation (5). Graph 1 below shows the actual versus fitted values and the R^2.

As a general result the fit is rather good. Before the crisis the total allotment can be nearly perfectly forecasted as the benchmark at announcement is very close to the actual allotment. During the crisis the fit continues to be quite good (around 80%), with the notable exceptions of the outbreak of the turmoil in August 2007 and the incident of the Lehman collapse at the end of our sample. These two exceptions are technically grounded, given the structural breaks in the data (validated by appropriate Chow tests) and are also economically reasonable, given that both incidents occurred suddenly and therefore expectations about volumes would consider only the pre-crisis information set.

Graph 1

Total allotment and the marginal rate: Expected versus actual

Total allotment[1]	Spread between the actual and expected marginal rate[2]



[1] Regressions are based on 30 observations rolling window. For each rolling regression, we show the last predicted value, except for the beginning of the sample where we use the first regression to derive the predicted values. [2] Expected rates are taken from the Reuters poll. The red horizontal line indicates the beginning of the crisis (7August 2007).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).

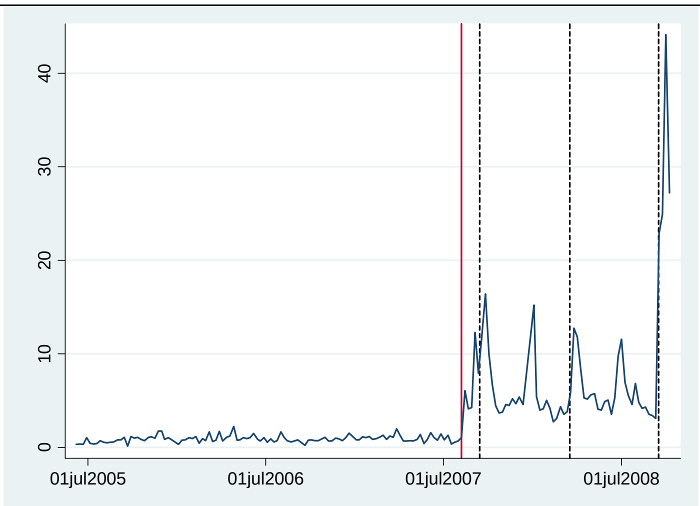
7.2 The LRP measure

Our aggregate measure of funding liquidity risk is presented in Graph 2. Unsurprising, *LRP* reveals that liquidity risk is much greater and has much more pronounced spikes towards the end of our sample. The change in level coincides perfectly with the beginning of the crisis. Prior to the crisis, banks on average paid below 1 basis point to insure against funding liquidity risk (see Table 1). The average insurance premium increased rapidly after August 2007, and reached a first peak of more than 16 basis points after Northern Rock had to be rescued by the UK government. A relative tranquil period followed, but liquidity risk rose again at the end of the year. The failure of Bear Sterns, was also followed by a pronounced spike, even though this was less significant than the spike following the failure of Northern Rock. Tensions subsequently subsided but rose towards the end of June 2008. To some extent this may reveal window dressing effects and uncertainties about half year results. The largest spike in funding liquidity risk occured at the beginning of October 2008, when money markets broke down completely following the failure of Lehman Brothers. At this point, the average insurance premium was more than 44 basis points (see Table 1).

The graph clearly shows that funding liquidity risk is time varying and persistent, but subject to occasional spikes. These characteristics have been documented by market participants using banks' own models (see Matz and Neu, 2007, or Banks, 2005), but are also common for measures of market liquidity (Amihud, 2002; Chordia et al., 2005; Pastor and Staumbaugh, 2003).

Graph 2

LRP



Note: The red horizontal line indicates the beginning of the crisis (7 August 2007).The horizontal black lines indicate 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). In basis points.

Table 1

Statistics of the liquidity risk

LRP

	Normal	**Crisis**	**Ratio**
Mean	0.9	7.6	8.7
Std.	0.4	7.1	19.1
Min	0.1	2.7	20.0
Max	2.2	44.1	19.9
# Observations	112	59	

Note: *Normal* indicates the period from June 2005 until 7 August 2007. *Crisis* is the remaining period until 7 October 2008. *Ratio* equals *Crisis/Normal.* LRP is measured in basis points.

7.3 Funding liquidity risk and market liquidity

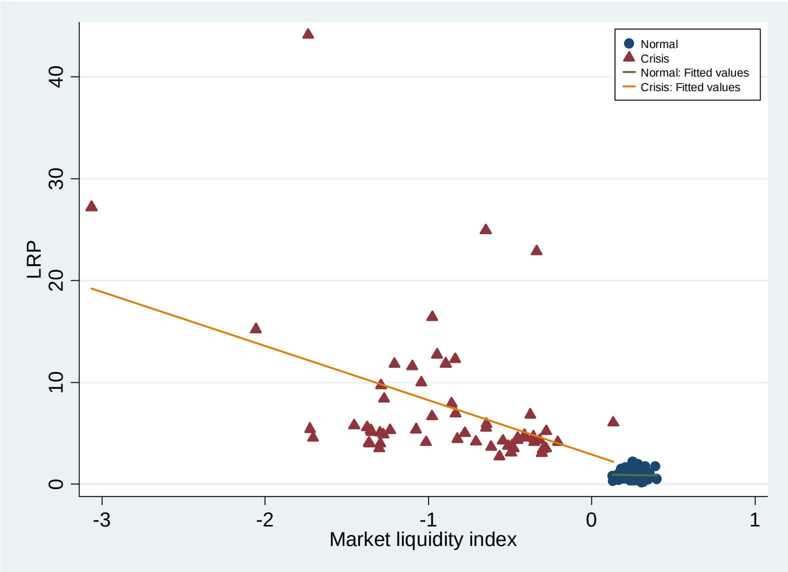
As discussed in Section 4.3 market and funding liquidity are strongly interrelated and downward spirals of market and funding liquidity risk can emerge in crises. Whilst the theoretical expositions are clear and anecdotal evidence points to these effects in the recent crisis, the interaction between both liquidity measures has not been shown empirically due to a lack of measures for funding liquidity risk.

Using our measure we are able to assess this question in a more robust fashion. We use a broad measure of market liquidity for the euro area (see ECB, 2007) which is shown in Graph A3.4 (left-hand panel) in the Annex. This index of market liquidity is a weighted average of different market liquidity measures such as bid-ask spreads in FX, equity, bond and money markets.[22]

Graph 3 shows a scatter plot of *LRP* and the market liquidity index. A clear negative relationship can be seen, ie when market liquidity is drying up (ie 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 orange and green lines show the predicted values based on a simple regression of the index on *LRP* during normal times and the crisis.

Graph 3

Interactions between funding liquidity risk and market liquidity



Note: *Normal* indicates the period from June 2005 until 7 August 2007. *Crisis* is the remaining period until 7 October 2007. *Fitted values* are based on the regression using the specified sub-samples.

[22] As discussed in ECB (2007) (Box 9), "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".

The regression results are shown in Table 2. The scatter plot already suggests that the negative relationship only emerges during the crisis. The econometric analysis supports this as there is no significant relationship between our measure of funding liquidity risk and market liquidity prior to the crisis.[23] However, once the crisis unfolds a significant negative relationship emerges. This is exactly what the theory predicts as these interactions should only emerge once banks become funding constraint. The relationship during the crisis is also economically significant. The estimates imply that for example a fall of the market liquidity index by 3 standard deviations is associated with a 14 basis points increase in the average liquidity insurance premium. This is approximately the difference between levels of *LRP* after the failures of Northern Rock or Bear Sterns and pre-crisis levels. Note that we do not want to imply any causal relationships with this thought experiment as market and funding liquidity risk are determined simultaneously in equilibrium.

The market liquidity index used above combines different money market liquidity measures, which we can separate into two composite indices, namely a FX, equity and bond markets index and a money market index. Given the nature of the crisis, it is plausible that our results are driven by developments in money markets. However, our results hold, even when we focus solely on the composite index of FX, equity and bonds markets (see Table A2.1 in the Annex).

Table 2

Regression results of LRP on the market liquidity index

	Coefficient	**R-squared**	**Observations**
Full sample			
Market liquidity	-5.7***	0.48	171
Constant	2.5***		
Normal			
Market liquidity	-0.4	0.003	112
Constant	1.0***		
Crisis			
Market liquidity	-5.3***	0.17	59
Constant	2.9*		

The independent variable is *LRP* for all regressions. *Normal* indicates the period from June 2005 until 7 August 2007. *Crisis* is the remaining period until 7 October 2008. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

8. Discussion

Ideally, we would provide a comparison with banks' own measures of funding liquidity risk and how this relates to their bidding behaviour. However, this information is unavailable. A typical measure commonly used by central banks, academics and practitioners to assess

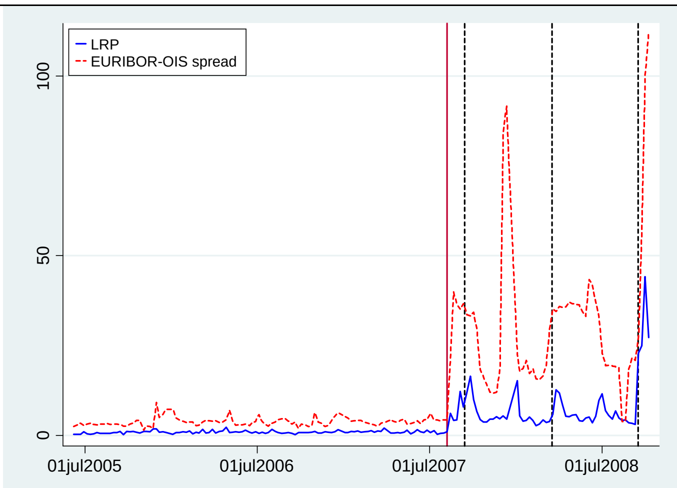
[23] To see whether the results are driven by outliers, we dropped the 5% highest LRP values in the sample as a robustness check. We continue to find the same qualitative results.

money market conditions is the spread between unsecured interbank rates and the overnight index swap rate (eg see IMF, 2008).

However, spreads are not a clean measure of funding systemic liquidity risk because of several reasons. First, the spread between interbank rates and the OIS rate is not only determined by funding liquidity risk but also be counterparty credit risk. These components cannot be easily disentangled (for an analysis during the crisis see Michaud and Upper, 2008). Second, interbank market rates may not be representative of actual funding conditions during a crisis because of increased uncertainty, dispersion in the credit quality across banks and greater incentives to strategically misreport funding costs (Gyntelberg and Wooldrige, 2008). By construction interbank rates such as Euribor are not a transaction based price measure but an index based on a daily survey amongst a large number of panel banks.[24] During the turmoil, while unsecured lending in various term market segments essentially froze, academics and market participants considered such indexes (Euribor or Libor) void of essential information and therefore not really suggestive of the reality in markets (Brousseau et al 2010). Last, and in contrast to our measure, spreads between unsecured interbank rates and the overnight index swap rate do not reveal any information about the volume banks need to obtain to remain liquid. As discussed in Section 2.2, this is a key component of funding liquidity risk.

Graph 4

LRP and the Euribor-OIS spread



Note: In basis points. The red horizontal line indicates the beginning of the crisis (7 August 2007).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).

Graph 4 plots our measure of funding liquidity risk against the spread between unsecured interbank rates and the overnight index swap rate. Given that we look at a one week measure for the euro area, the relevant spread is the 1 week Euribor-OIS spread. The graph shows that the Euribor-OIS spread is much higher than *LRP*. On average the difference is around 3 basis points in normal times but increases to more than 20 basis points during the

[24] For example, for the construction of Euribor banks are asked to quote “the rate…that each panel bank believes one prime bank is quoting to another prime bank for inter-bank term deposits within the euro zone” (Euribor, 2009).

crisis. This is not unsurprising, given that *LRP* reflects funding liquidity risk more cleanly, whereas the Euribor includes credit risk and possible measurement biases.

8.1 LRP based on public data

Our measure requires confidential information in terms of bidding data and data from Reuters on expected marginal rates. Given the relevance of our measure, we construct two alternative liquidity risk measures using public information.

To construct the first alternative, we substitute the information contained in the confidential bidding data with the weighted average bid rate *(WABR).*[25] This variable takes account of successful bids, ie bids that are above the actual marginal rate. We therefore re-engineer our equation (3) to take account of bids above the marginal rate rather than the expected marginal rate. We can rewrite the adjusted bids as

$$\overline{AB}_{b,i,t} = (bid\_rate_{b,i,t} - E(marginal\_rate)_t)*volume_{b,i,t} \quad \text{if } bid\_rate_{b,i,t} > marginal\_rate_t \tag{3'}$$

and the liquidity risk insurance premia using public information and the expected marginal rate from Reuters ($LRP_{semi\text{-}public}$) as

$$LRP_{semi\text{-}public_t} = \frac{\sum_{i=1}^{N}\sum_{b=1}^{B}\overline{AB}_{b,i,t}}{E(total\_allotment)_t} \tag{4'}$$

It can be easily shown that $LRP_{semi\text{-}public}$ collapses to the weighted average bid rate times the ratio of the total allotment over the expected allotment minus the expected marginal rate.

$$LRP_{semi\text{-}public_t} = WABR_t * \frac{total\_allotment_t}{E(total\_allotment)_t} - E(marginal\_rate)_t \tag{6}$$

Graph 5 (left-hand panel) shows that *LRP* and $LRP_{semi\text{-}public}$ provide roughly the same information. Before the crisis, the difference between the two is minimal and at most 0.3 basis points. Significant discrepancies arise only during the severe periods of stress in the crisis, when the measure based on public information underestimates *LRP* by 25-60%.

Unfortunately, the Reuters data are not generally available, although Reuters plans to publicise the expected marginal rate against a fee. In principle it is possible to estimate the expected marginal and the expected allotment rate jointly using 3SLS. Indeed, the regression results for the spread match the Reuters expectations rather closely.[26] Alternatively, we can drop all expectation operators in equation (3') and (4'), so that (6) simply collapses to the weighted average bid rate minus the (actual) marginal rate. This measure (LRP_{public}) does not take account of expectations about the marginal rate or the allotment volume. However, the

---

[25] WABR is available at http://www.ecb.eu/mopo/implement/omo/html/index.en.html. It 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 above or at the marginal rate, or $WABR = \left(\sum_{i=1}^{N}\sum_{b=1}^{B} bid\_rate_{b,i,t} * volume_{b,i,t} * percentage\_allotted\right) / total\_allotment_t$.

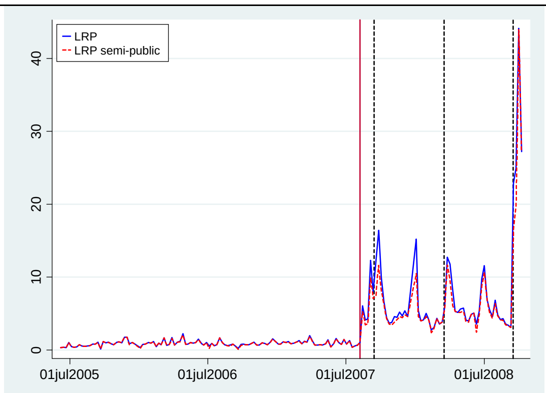
[26] We estimated the spread between marginal rate and the policy rate and the total allotment jointly, using the lagged spread, the total allotment and the 1 week Euribor-OIS spread as explanatory variables for the spread and equation (5) for the total allotment. Results are available on request.

marginal rate and the weighted average bid rate are published immediately after each auction. LRP_{public} is, therefore, particularly useful for policymakers and market observers, who want a quick and easy proxy to monitor funding liquidity risk conditions in the economy in real time. As a rough proxy, such an approach may be okay. However, the right-hand panel in graph 5 shows that LRP_{public} significantly differs from our suggested measure of funding liquidity risk. Before the crisis the correlation between the two is only 0.23. During the crisis it increases to 0.65 but the absolute difference between the two can be up to nearly 20 basis points.

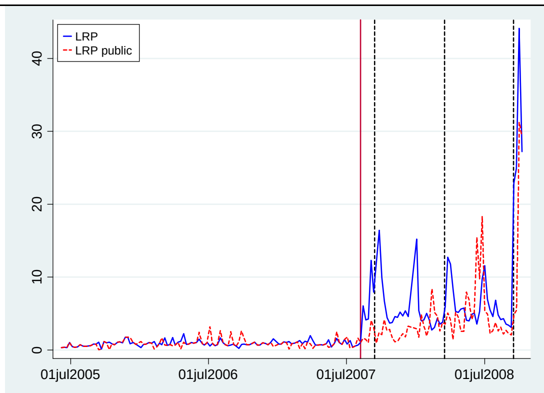
Graph 5

LRP measure based on public data

LRP and $LRP_{semi\text{-}public}$



LRP and LRP_{public}



Note: In basis points. The red horizontal line indicates the beginning of the crisis (7 August 2007).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).

9. Conclusion

In this paper we propose a measure of funding liquidity risk, using readily available information. As measurement without clear definitions is impossible, we also provide definitions of funding liquidity and funding liquidity risk. 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*. Ideally and in line with other risks, we would want to measure funding liquidity risk by the distribution summarising the stochastic nature of the underlying risk factors. Such distributions cannot be estimated because of a lack of data. However, we observe how much banks are willing to pay to obtain liquidity from the central bank. By submitting aggressive bids at the central bank auction, the bank can insure itself against becoming illiquid and thereby reveals its liquidity risk.

Using information from a data set of 170 main refinancing operations conducted by the ECB from June 2005 to October 2008, we find that funding liquidity risk increased rapidly after August 2007 and spiked after the rescue of Northern Rock. Following the failure of Bear Sterns liquidity risk rose sharply again, even though to less elevated levels. Unsurprisingly, our measure identifies record pressures in October 2008 after Lehman failed. More generally, we find that our measure has similar properties as market liquidity such as low levels, persistence and occasional spikes. We are able to find evidence that there is indeed an inverse relationship between funding liquidity risk and market liquidity.

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 horizons beyond one week or for different jurisdictions. This is certainly possible as the same auction design was also used for long term refinancing operations in the euro area prior to October 2008. It is also the case that a broad range of other countries such as the Canada, Mexico, or the UK have similar auction set-ups at least for some of their money market operations. Whilst daily OMOs in the United States are conducted with a narrow set of broker dealers, the auctions design of the newly introduced Term Auction Facility is similar to the one necessary to construct our measure.[27] 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.

It would also be interesting to strip out collateral effects, which may impact on banks' bidding behaviour. Conceptually, this is possible. However, we do not have access to the relevant information. Nonetheless, we argue that our approach provides a very useful tool not only because it opens up ways of further empirical research on liquidity, an area of research hindered by the unavailability of proxies, but also because it can be an efficient tool for policy analysis and monitoring.

[27] For further details see http://www.federalreserve.gov/monetarypolicy/taf.htm.

Bibliography

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

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

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.

Ayuso, 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.*

Biais, B., L. Glosten and C. Spatt (2005), "Market Microstructure: a Survey of Microfoundations, Empirical Results and Policy Implication", *Journal of Financial Markets,* 8, 217-264.

Bindseil, U., K. G. Nyborg and I. A. Strebulaev (2009): "Repo Auctions and the Market for Liquidity", *Journal of Money, Credit and Banking*, 41, 1391-1421.

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 (2009). "Market Liquidity and Funding Liquidity", *Review of Financial Studies,* 22, 2201-2238.

Brousseau, V., A. Chailloux and A. Durre (2009). "Inter-bank offered rate: Effects of the financial crisis on the information content of the fixing", *LEM,* 17.

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.

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 R. G. Rajan (2009). "Fear of firesales and the credit freeze", *NBER Working Paper* 14925.

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

ECB (2007), *Financial Stability Review,* June.

EURIBOR (2009), *The benchmark rate of the Euro money market, Technical Features, http://www.euribor.org/html/content/euribor_tech.html.*

Ewerhart, C., Cassola, N. and N. Valla (2010). "Declining valuations and equilibrium bidding in central bank refinancing operations", *International Journal of Industrial Organizations,* Vol. 28(1), 30-43.

Fecht, F., Nyborg, K. G. and Rocholl, J. (2009), "The price of liquidity: bank characteristics and market conditions", *Deutsche Bundesbank Working Paper*.

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.

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.

Heider, F., M. Hoerova and C. Holthausen (2009), "Liquidity hoarding and interbank market spreads: The role of counterparty risk", *ECB Working Paper*.

Holmström, B. and J. Tirole (1998): "Private and Public Supply of Liquidity", *Journal of Political Economy,* 106, 1-40.

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

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

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

Kapadia, S., M. Drehmann, J. Elliot and G. Stern (2010): "Liquidity riks, cash flow constraints and systemic feedbacks.", *mimeo*.

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.

Milgrom, P. R. and R. J. Weber (1982): "A Theory of Auctions and Competitive Bidding", *Econometrica,* 50, 1089-1122.

Nikolaou, K. (2009): "Liquidity (risk) concepts: definitions and interactions", *ECB Working Paper Series* 1008.

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.

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 funding liquidity can be captured by a cash flow constraint:

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

Table A1.1

Components and sources of in- and outflows of money

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

Where:

- *L/A* are liabilities and assets of the bank;[28]
- *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.[29]

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 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

[28] These include assets and liabilities in both the banking and trading book.

[29] In the Eurosystem reserves are also remunerated which constitute are part of CB_{in}^{other}.

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_{ne}w). 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 *X* 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 which is a real time gross settlement system (RTGS), ie 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).[30] Whilst assets held in the banking book are sold and purchased for example via securitisation programmes "over the counter". This requires more 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). Essentially, are 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

[30] 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.

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*.

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}.[31]

[31] 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 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 is the euro area is less pronounced.

Annex 2: Additional table

A2.1

Regression results of LRP on different market liquidity measures

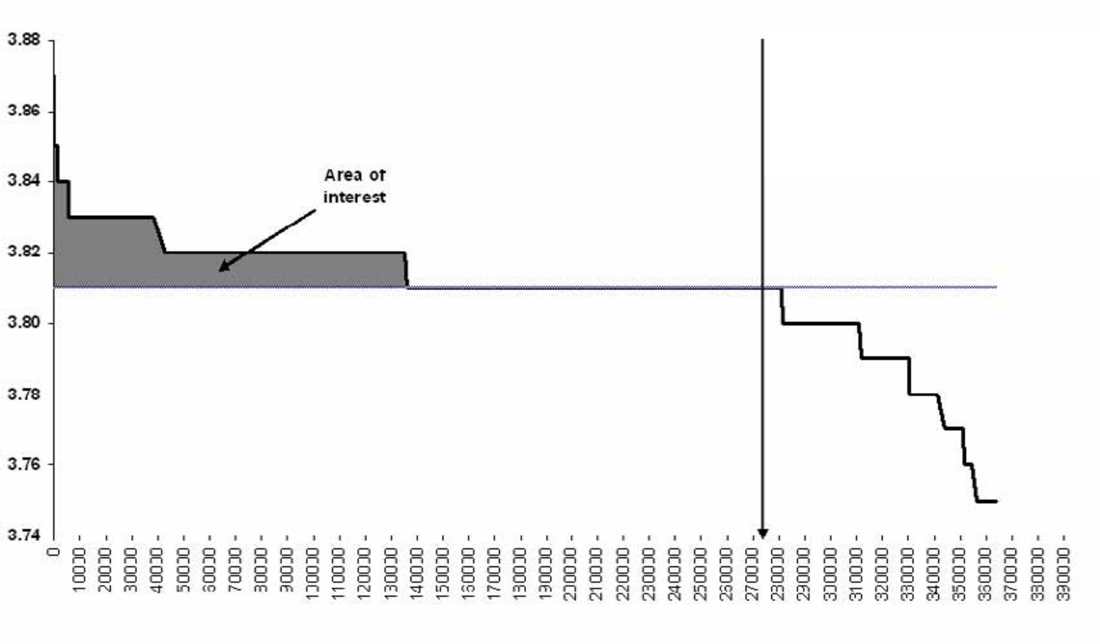
	LRP on money market liquidity		**LRP on FX, equity and bond market liquidity**	
	Coef	**R-squared**	**Coef**	**R-squared**
Full sample				
Market liquidity	-5.8***	0.45	-37.0***	0.23
constant	0.4		16.3***	
Normal				
Market liquidity	-1.3*	0.03	2.1**	0.04
constant	0.7***		0.1	
Crisis				
Market liquidity	-4.6***	0.13	-23.1**	0.081
constant	2.1		14.7	

The independent variable is LRP for all regressions. Normal indicates the period from June 2005 until 7 August 2007. Crisis is the remaining period until 7 October 2008. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Annex 3: Additional graphs

Graph A3.1

A central bank auction and the funding liquidity risk measures.

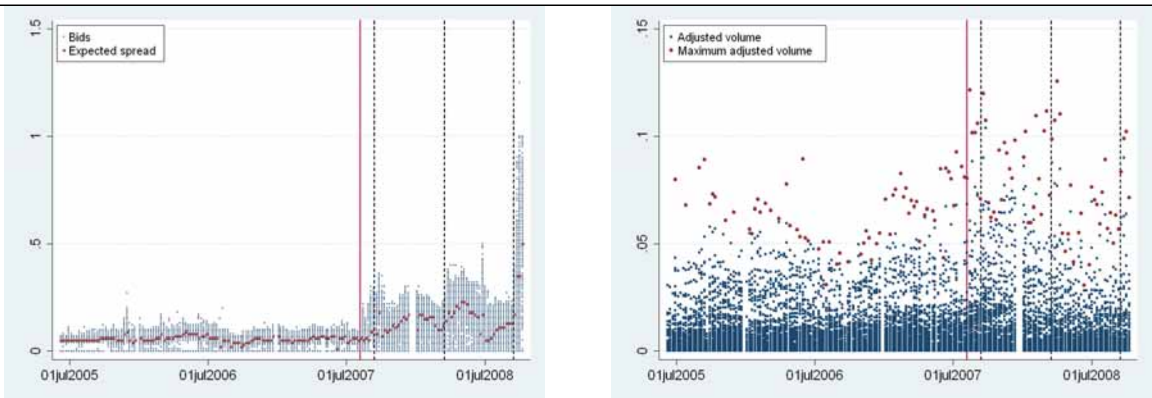


Note: Horizontal line is expected marginal rate and vertical line indicates expected total allotment

Graph A3.2

Components of the individual bids

Spreads[1] | Volumes[2]

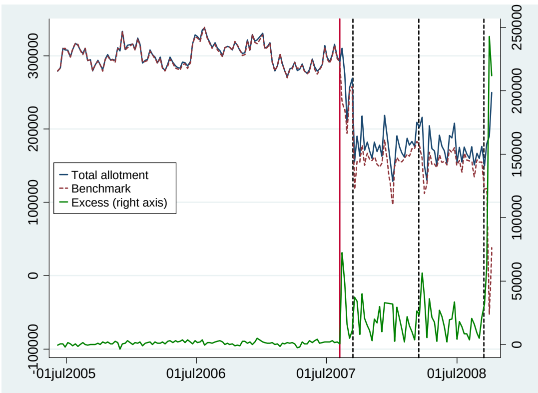


[1] The expected spread is the expected marginal rate minus the policy rate. [2] Volumes bid are normalised by the expected total allotment. Only bids above the expected marginal rate are shown.

The red horizontal line indicates the beginning of the crisis (7August 2007).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).

Graph A3.3

The total allotment and the benchmark at announcement

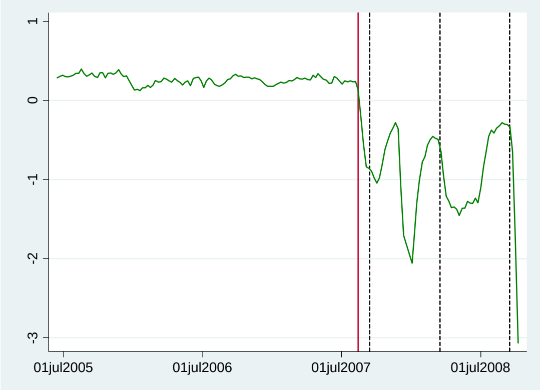
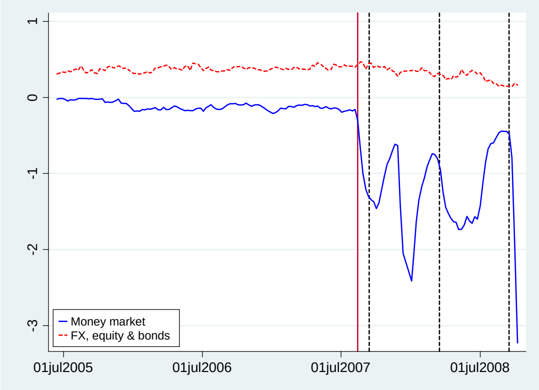


Note: Benchmark is the benchmark at announcement. Excess is the difference between the total allotment and the benchmark at announcement.

The red horizontal line indicates the beginning of the crisis (7August 2007).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).

Graph A3.4

ECB financial market liquidity indicators

Aggregate index	Money market and FX, equity and bond market index
	

Note: The red horizontal line indicates the beginning of the crisis (7August 2007).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).