Measuring Funding Liquidity and Funding Liquidity risk*

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Abstract

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1 Introduction

Funding liquidity is essential for the well functioning of the financial system. Policy makers have for example referred to it as the oil that greases the wheels of the financial machine (BIS)[1]. It is also widely acknowledge that liquidity risk played a key role during the recent sub-prime turmoil. However, and notwithstanding research efforts at least since Bagehot in the 1870s, so far remarkably little has been understood about funding liquidity risk. Indeed the drivers of funding liquidity and the exposure to funding liquidity risk still remains one of the main issues to explore with respect to the credit turmoil, stirring the interest of the research and policy practitioners (RFS, 2008).

Despite the much publicised role and the importance of funding liquidity for the financial system, both academic and policy analysis are still short of practical and simple measures of funding liquidity and funding liquidity risk. The available funding liquidity measures used by banks are based more on art than science. An additional problem from a research perspective is that they rely heavily on large volumes of private information, which are changing continuously and rapidly. A ray of light has been a recent attempt of Drehmann and Nikolaou (2008), who suggest to measure funding liquidity risk by using information from the central bank auctions. However, their measures are heavily influenced by factors unrelated to funding liquidity risk. In this paper, we therefore employ a panel regression analysis to identify normal bidding behaviour conditional on bank, auction, central bank policy and economy specific considerations. Our funding liquidity risk measure is based on the positive residuals of the regression analysis, i.e. funding liquidity risk is measured by abnormally high bids to obtain funding from the central bank.

Before exploring our measure of funding liquidity risk in depth, it is worth to clarify definitions. We follow Drehmann and Nikolaou (2008) in a general definition of funding liquidity and funding liquidity risk. They state that funding liquidity is the ability to satisfy the demand for high powered money, as transactions have to be either settled in either of its two components: cash and reserves[2]. Respectively, they define funding liquidity risk as the possibility that, over a specific horizon, the bank will be unable to satisfy the demand for high powered money.

Drehmann et al. (2007) suggest to view funding liquidity risk as a flow constraint. By doing so, two components of funding liquidity risk can be easily distinguished. The first is the net liquidity demand which is the difference between outflows and contractual inflows. This difference has to be funded by

[1] Speech by Mr Malcolm D Knight, General Manager of the BIS, at the Ninth Annual Risk Management Convention of the Global Association of Risk Professionals, 26-28 February 2008.

[2] A short discussion on the meaning of high powered money is presented in Section 2.

the bank, either from depositors, the interbank market, the central bank or by selling assets. Ultimately, funding – or more accurately high powered money – from different sources are perfect substitutes. So the choice of which funding source to use is determined by availability and more importantly the price, which is the second component of funding liquidity risk. The substitutability of funding sources allows us to use banks' bidding data in central bank auctions as a measure of funding liquidity risk. Following the theoretical literature of bidding behaviour in central bank auctions (e.g. see Ayusi and Repullo, 2003 or Ewerhart et al., 2007), Drehmann and Nikolaou show that banks' bids contain information about banks' own assessment about the future net-liquidity demand, different prices of liquidity and respective volatilities. Hence, liquidity risk can be proxied by banks' bids.

Indeed, they proxy funding liquidity risk by the area under the aggregate demand curve. Normalising by reserve requirements they take the integral under the aggregate demand curve for the successful bids minus the policy rate times the allotted volume. However, they explain that this proxy is rather crude and does not necessarily reveal funding pressure that is linked with funding liquidity risk scenarios. They, therefore, suggest looking at "exceptionally high bids" as a another proxy for funding liquidity risk. They introduce two alternative methods for this. One is to take into account only the bids above the marginal rate while constructing the measure and the second is to pool all bids across different auctions and select an extreme quantile, say the 99% percent quantile. In both cases, they finally sum the filtered "exceptionally high" bids across banks in each auction and derive a single aggregate risk measure for each auction.

We argue that these two measures do not efficiently and effectively alienate risky bids, for two reasons. First, their definitions of "exceptionally high bids" are ad-hoc, and second the spikes picked up may or may not indicate risk (i.e. they may pick up seasonal patterns but fail to pick up for example the higher liquidity risk during the recent market turmoil). All in all, we believe it is important to control for efficient bidding behaviour. We therefore filter out banks' "normal" bidding behaviour and use the remaining unexpected or "abnormally" high bids as our measure for funding liquidity risk.

Our analysis is based on a unique data set of 193 main refinancing operation (MRO) auctions conducted between March 2004 and December 2007. We effectively have information on the bidding schedules of each of the 877 participating banks in the relevant auctions. Our individual bank data allow us to reconstruct the liquidity demand measure of Drehmann and Nikolaou for each individual bank and control for the factors that may affect it under normal conditions, thereby revealing the cases of "abnormally" high liquidity demand. We filter out normal behaviour of banks by estimating a random effects panel regression with the liquidity demand of individual banks as dependent variable and explanatory variables drawn from previous literature on bidding behaviour (Graig and Fecth, 2007; Fecht et al.,2007; Linzert et al.,2007 and Eisenschmidt et al., 2008) as independent regressors. We also include the inverse Mills ratio to correct for sample selection bias (Heckman, 1979; Linzert et al., 2007).

The residuals from the above regression account for "abnormal" bids, i.e. bidding behaviour that cannot be explained based on standard assumptions about bank's liquidity demand under non-risky scenarios. Finally, we aggregate the residuals across all bids and banks at each time period t, (i.e. at each auction) to end up with our funding liquidity risk measure.

We find that this approach produces intuitive properties in our measure for risk. Namely, it effectively dampens the seasonal variations in the risk measures of Drehmann and Nikolaou, while revealing the important effects of the current turmoil in the funding liquidity risks of banks. Moreover, our series has the standard properties of persistence at a low level with occasional spikes that funding liquidity risk is supposed to have according to market practitioners (see Matz and Neu, 2007).

Overall, our paper addresses the issue of measuring funding liquidity, a notion that has been widely under-researched, despite the wide acceptance of its importance and its relevance for market practitioners and policy makers. This paper offers a significant improvement to previously suggested methods by Drehmann and Nikolaou (2008) both in terms of methodology and in terms of the properties of the final measure. Namely, we suggest a regression analysis which is in a position to efficiently and effectively filter out what is considered as abnormally high demand for liquidity, thereby providing a measure for liquidity risk that appears to be better able to withstand both empirical and theoretical criticism. In that sense, our paper provides an important contribution in this strand of literature.

The paper is structured as follows: Section 2 provides the definitions of funding liquidity and funding liquidity risk, the theoretical support and the measurements efforts of Drehman and Nikolaou (2008). It also introduces our criticism and our suggestions. Section 3 briefly describes the data used, while Section 4 comments on the methodology. Section 5 presents the regression results and discusses the final liquidity measure. Finally, Section 6 briefly concludes.

2 The funding liquidity information in the bidding data

2.1 Definition of funding liquidity and funding liquidity risk

Colloquially, a bank would be said to be liquid if it has “enough cash”. However, in a modern banking system cash plays only a minor role in settling transactions. The vast majority, and especially all transactions between banks themselves, between banks and the government and between banks and the central bank, are not settled in cash but via accounts held at the central bank. These accounts are also known as central bank reserves. Macroeconomists have long identified the sum of cash and central bank money as high powered money (e.g. see Friedman and Schwarz, 1963). Therefore, a more general definition states that funding liquidity is the ability to satisfy the demand for high powered money. Respectively, a bank is illiquid if it cannot satisfy the demand for high powered money. In this case the bank fails[3].

It is worth to point out that illiquidity is only a result of imperfect information and imperfect capital markets. In a world with perfect information and perfect capital markets, a solvent bank can always satisfy the demand for high powered money with immediacy by selling assets (at their fair value). Putting it differently, funding liquidity (ie the ability to satisfy the demand for high powered money with immediacy) depends on market liquidity (ie whether assets can be sold at their fair value with immediacy)[4]. And funding liquidity also depends on central bank liquidity, which is the term often used for the aggregate provision of high powered money. This short discussion already hints at important interrelations between funding, market and central bank liquidity, something we explore in greater depth below.

Given a definition of funding liquidity it is easy to proceed to a definition of funding liquidity risk. According to the Oxford English Dictionary risk is "the possibility that something unpleasant will happen". In case of funding liquidity risk, the unpleasant event is that the bank will not be able to satisfy the demand for high powered money. Clearly, as any other risk, the risk also depends on the time horizon considered. In this paper we measure funding liquidity risk over a one week horizon for reasons that will become apparent later. However, the conceptual discussion is general enough to consider any other time frame. To sum up, we define funding liquidity risk as the possibility that, over a one week horizon, the bank will be unable to satisfy the demand for high powered money.

As pointed out by Drehmann, Elliot and Kapadia (2007) funding liquidity risk is not determined by flows rather than by stocks. A bank is able to satisfy the demand for high powered money, and hence is liquid, as long as outflows are smaller or equal to inflows at each point t in time. Therefore, funding liquidity risk is the possibility that outflows are larger than inflows over a specific time horizon.

[3] Alternatively, the central bank can act as a lender of last resort for an emergency loan.

[4] That funding liquidity depends on market liquidity can be seen from the theoretical literature. Take for example the seminal work by Diamond and Dybvig (1983). In their model, depositors which want to consume early or late cannot be distinguished by the bank, and deposits of both are contractually due in early period. Cash or short-term assets held by the bank are used to payout early depositors. If there is no bank run, late depositors roll over their deposits. But if there is a run, the bank is forced to sell assets to satisfy the demand for cash. As the markets for these assets are not perfect – ie this asset market is illiquid –the bank is only able to realise heavily discounted prices for their assets and not enough cash can be raised and the bank fails (for further discussion of the theoretical literature and the definition of funding liquidity see Drehmann and Nikolaou, 2008, and Drehmann et al, 2007).

Following this reasoning, a flow constraint provides an easy and straightforward way of representing funding liquidity and funding liquidity risk:

$$Outflows_t \leq Inflows_t. \tag{1}$$

Or in more detail as:

$$(L^D_{due} + LI^D_{due} + A^D_{new}) + (L^{IB}_{due} + LI^{IB}_{due} + A^{IB}_{new}) + (L^{CB}_{due} + LI^{CB}_{due} + A^{CB}_{new}) + (A_{bought} + OB_{out}) \leq$$

$$(L^D_{new} + AI^D_{due} + A^D_{due}) + (L^{IB}_{new} + AI^{IB}_{due} + A^{IB}_{due}) + (L^{CB}_{new} + AI^{CB}_{due} + A^{CB}_{due}) + (A_{sold} + OB_{in} + NetIncome),$$

where:

- L/A are liabilities and assets of the bank[5] ;
- LI/AI are interest paid by the bank on liabilities and received on assets;
- $IB/CB/D$ stands for interbank, central bank and other depositors, where the latter includes corporates and households;
- OB are off-balance sheet items where *out/in* indicates whether they are a demand/supply on liquidity;
- *due* stands for assets and liabilities which are contractually due in the period;
- *new* stands for assets and liabilities newly issued (in the case of liabilities and assets) or bought (in case of assets). New can also include liabilities or assets which are rolled over;
- *Assets* can also be *sold/bought* on the secondary market [6];
- *NetIncome* are cash flows which are due to other income, e.g. fees and commissions, minus costs.

(Note that in order to keep sub-indices to a minimum, t was drop in the detailed representation. But the reader should keep in mind that time plays an important role for funding liquidity.)

Drehmann and Nikolaou (2008) introduce this constraint and discuss it in depth. For the needs of this paper we are only highlighting the important properties of this constraint.

First, this constraint is expressed in such a way as to clearly show the inflows and outflows of a bank vis-a-vis depositors, other banks (the interbank market), the central bank and financial markets. In that sense, this constraint shows the inter-relations between the various agents of the financial system in greater detail and offers a broad idea of the various liquidity sources of banks. Importantly, this

[5] These included assets and liabilities in both the banking and trading book.

[6] This includes assets sales from the trading book such as bonds and equities as well as assets sales in the banking book, e.g. via securitization.

exposition reveals the substitutability of obtaining liquidity from the central bank or other sources. This motivates the intuition behind the use of the CB auction data as proxies for a measure of liquidity risk.

Second, ex-ante inflows and outflows are uncertain. Clearly, contractual obligations (assets and liabilities *due*) and their maturities are known, even though defaulting counterparties can lead to some randomness. Other components, such as the inflow of new retail deposits (part of L^{D}_{new}), are relatively easy to predict under most circumstances. However, off-balance sheet items (OB_{out}) or the re-investment behaviour of large and sophisticated investors (part of L^{D}_{new}) as well as other banks (L^{IB}_{new}), are more difficult to predict. As seen during the sub-prime turmoil, these components can induce large swings in cash flows. Note, that outflows are partly endogenously determined. Under severe stress the bank may decide to cut back on new lending (A_{new}) or reduce asset purchases (A_{bought}).

In order to measure directly the needs for high powered money over a one week horizon, we define a new variable that we call net-liquidity demand (NLD). We construct this variable by reworking the flow constraint, namely we take the difference between all Outflows ($Outflows$) and contractual Inflows, including inflows from off-balance see items ($Inflows_{due}$).

$$NLD = Outflows - Inflows_{due} \quad (2)$$

$$= L^{D}_{new} + L^{IB}_{new} + L^{CB}_{new} + A_{sold}). \quad (3)$$

Given banks borrow short and lend long, NLD is positive. Even when there are unusual situations where contractual outflows are smaller than contractual inflows, banks would adjust new lending (A_{new}) or asset purchases (A_{bought}) and hence increase (expected) outflows[7]. To avoid illiquidity, NLD has to be funded by the bank through *new* Inflows. These can be derived from depositors, other banks, the central bank or by selling assets. Therefore this measure presents the volume of liquidity needs of the bank and its choice of potential funding sources.

From the perspective of the individual bank, the choice of funding source will be determined by the price of obtaining liquidity. This is the third important point. As discussed above, in a world with perfect information and perfect capital markets, a bank would always be able to satisfy the demand for high powered money, as long as it would be solvent. Hence, from a funding liquidity risk management perspective the price of A_{sold} is determined by the (market) liquidity of market the asset is sold in[8], while

[7] Ex-post inflows always equal outflows as long as the bank does not fail. High inflows are always absorbed by asset purchases A_{bought} or new lending. If at the end of the day, banks have excess inflows they will deposit them with the marginal deposit facility at the central bank (A^{CB}_{new}).

[8] Note that A_{sold} is used in a very broad sense as banks do not only sell (and buy) items in the trading book such as

(market) liquidity across different markets differs widely and is not constant over time. In contrast to investment banks commercial banks rely, however, mostly on deposits , i.e. the three other sources of funding (L^{D}_{new},L^{IB}_{new} and L^{CB}_{new}), with each one also involving different (stochastic) prices.

Taken together the flow constraint shows that funding liquidity risk from the perspective of an individual bank is driven by stochastic in- and outflows as well as by stochastic prices for liquidity, which in turn are the key determinants in deciding which funding source banks want to access. For our measure it is particularly important that banks can rely on central banks directly to obtain funding. This allows us to derive a proxy for funding liquidity risk, even though it cannot be directly observed[9].We follow Drehmann and Nikolaou (2008) and use information from banks' bidding behaviour in main refinancing operations. During these operations banks basically submit a demand schedule for one week loans from the central bank (L^{CB}_{new}), which can give information about expected volume of liquidity needed and the banks' willingness to pay over this horizon. In Section 2.3 we show how this information can be used to proxy bank specific liquidity risk. Before doing so it is however necessary to provide some institutional background about open market operations in the euro area.

2.2 Open Market Operations and the banking system

The CB is the sole originator and the monopolist provider of high powered money. Given the substitutability of different liquidity sources this underlines the importance of central banks in a modern banking system. Central bank liquidity is mainly provided via open market operations (OMOs). Typically, the central bank provides the "benchmark" amount of liquidity, which comprises changes in reserve requirements and autonomous factors[10].

For readers unfamiliar with the language of OMOs, the latter two terms may require further explanations. The two largest components of autonomous factors are banknotes in circulation, i.e. cash which is part of high powered money, and government deposits. Other autonomous factors are balance sheet items of the ECB that are neither monetary policy operations nor current account holdings of counterparties with the ECB, such as interbank payments which are not settled in time[11].

We now turn to the reserve requirements, which are the other component of high powered money.

equities, bonds or more complex products. More generally, they also sell assets from the banking book, e.g. via outright sales or securitization programs.

[9] Drehmann and Nikolaou provide a discussion on alternative measures of liquidity risk (related to balance sheet analysis and stress testing techniques) from a market practitioner's point of views.

[10] The benchmark amount of liquidity can also contain other corrections, which are typically small (see ECB, 2004).

[11] Interbank payments which are not settled in time are generally referred to as float. Bindseil (2005) shows that this is a small and stable component in the euro area.

Central bank balances – or reserves – are necessary for individual banks to being able to settle transactions with other banks, the central bank or the government. In addition, individual banks have to fulfil reserve requirement. In the euro area banks are allowed to hold positive or negative balances with the CB within a specified period, as long as on average across the maintenance period, the reserve requirements are fulfilled. The maintenance period lasts approximately a month. At the start of the maintenance period, the reserve requirements are determined for each bank and remain fixed during the period. The start of it coincides with the settlement day of the first MRO in the maintenance period. In addition, this is the day on which interest rate decisions of the Governing Council become effective (after April 2004).

As monopolistic provider of (central bank) liquidity the central bank determines the aggregate liquidity conditions in the market except for changes in autonomous factors. This is important to stress. Aggregate liquidity conditions can only change because of *a*) active involvement by the central bank for example when conducting OMOs and *b*) changes in autonomous factors, which were not expected by the CB. The latter is due to the fact that all transactions between private banks are settled with reserves held at the CB. As liquidity outflow of one institution is the liquidity inflow of another the total sum of reserves does not change, just the distribution within the system. This holds even during extreme liquidity stress scenarios such as a bank run. In this case depositors withdrawal all their (matured) funds from the bank. If they deposit it with another bank, then this is an inflow at another institution and hence the aggregate volume of reserves does not change. If depositors take the cash and "stuff it under the mattress" then this implies a change in the volume of bank notes and hence a change in autonomous factors[12].

As mentioned above, the most important sources of central bank liquidity are main refinancing operations (MROs). In the case of the euro area, they amount to an average of 75 percent of all OMOs. With about 24 percent, longer term refinancing operations (LTROs) are the second largest source of liquidity. Besides, fine tuning operations (FTOs) are conducted if the ECB sees the need for an additional and extraordinary injection or absorption of liquidity. Furthermore, banks can also access the marginal lending facility in case of large funding needs which cannot be satisfied from other sources. To access the marginal lending facility, banks have to pay 100bp above the policy rate. Similarly, in case of excess liquidity banks can deposit it with the ECB at the marginal deposit facility, which pays the policy rate minus 100bp. Rates of the marginal lending and deposit facility effectively put a floor and cap to rates in the interbank market.

To understand our measure of funding liquidity risk, further explanations of institutional details of

[12] For a more detailed discussion see Drehmann and Nikolaou (2008).

MROs are necessary. In the euro area they are executed through standard, flexible rate tenders, conducted on a weekly basis against eligible collateral. They are always repo arrangements with a maturity of one week. Therefore, we are only able to measure funding liquidity risk at a one week horizon. At the outset of the MRO, the minimum bid rate is known to the market and equals the policy rate set by the Governing Council. The ECB also publishes the benchmark allotment. For each MRO auction, each eligible bank can submit bids (volume and price) at up to ten different bid rates at the precision of one basis point (0.01%). The auction is price-discriminating, i.e. every successful bidder has to pay its bid. At the marginal rate, bids are rationed, so that everyone takes the same pro rata amount of the remaining liquidity. Bids at rates lower than the marginal rate are not satisfied (for a full discussion of the timing and details of MROs see Annex 1).

2.3 Bidding behaviour and funding liquidity risk

The theoretical literature on bidding behaviour for price discriminating open market operations is so far very limited. Analytical models are based on highly stylised set ups and rely on several important assumptions, such as that IB markets are efficient and banks can always access them. The essence of these models is the following: As discussed, from a system wide perspective, aggregate net liquidity demand is purely driven by reserve requirements and the fluctuations in autonomous factors. From the perspective of an individual bank, the choice of funding source is only between bidding in the initial period for CB funds directly or accessing the IB market later. No other components of the flow constraint are considered. Prices in the interbank market reflect possible cost differences between funding from the central bank and the interbank market. Prices also react to deviations of autonomous factors which were not foreseen (and hence provided for) by the central bank. Even though the market in aggregate can be short or long, efficient trading in the interbank market implies that random shocks to autonomous factors across institutions are smoothed out.

More specifically, Ayusi and Repullo (2003) devise a set up where banks optimally bid only at the expected secondary market rate, even though the authors acknowledge that this is not what can be observed empirically. This happens because in their setting, collateral used to obtain central bank money directly is costless, but banks incur costs if their bid volume allotted exceeds available collateral. Ewerhart et al (2007) consider more realistic assumptions about collateral (collateral in the IB market is costly). In line with empirical observations, their model implies downward sloping demand schedules which are shifting outwards. Therefore, in their set-up, bids during MROs would be the perfect proxy for banks' own assessment of funding liquidity risk. In their model banks' bid schedules are closely linked to their marginal valuations of liquidity over a one week horizon and, hence, reflect expectations about NLD, the price of liquidity as well as their possible fluctuations during this period[13].

However, in practice their assumptions are quite stringent. For example, the fully efficient and accessible IB markets hypothesis may not be realistic. It is well known, that banks cannot always rely fully on interbank markets as some banks may be rationed out of the market in extreme circumstances (e.g. see Furfine, 2002, or Flannery, 1996). As has been seen in the turmoil in August 2007 the whole interbank markets may also break down at some points. These episodes are certainly important for funding liquidity risk management as it is more likely during these times that the flow constraint is binding because IB funding is unavailable. Further, during these episodes it is also more likely that (market) liquidity across markets is drying up, which was for example a reason for the LTCM intervention in 1998 (see Drehmann et al., 2007).

Therefore, Drehmann and Nikolaou conjecture that when banks fear that the IB market is not accessible and that market liquidity is likely to dry up, they would be willing to pay a higher price (i.e. the bid rate) in order to obtain liquidity from the CB. Banks would also be likely to bid higher volumes to ensure that that the flow constraint is non-binding when interbank markets turn out to be not accessible. Furthermore, in stressed situations expected outflows could also be higher, because e.g. of the draw-down of committed credit lines (see Gatev and Strahan, 2006). Therefore, stressed conditions are likely to shift the submitted demand schedules outwards, i.e. prices and volumes are likely to increase. This has been indeed observed during the recent sub-prime turmoil.

Based on this analysis, Drehmann and Nikolaou (2008) suggest to measure funding liquidity risk by the area under the aggregate demand curve. Normalising by reserve requirements they take the integral under the aggregate demand curve for the successful bids minus the policy rate times the allotted volume. This formulation accounts for changes in reserve requirements and changes in the monetary policy stance. Both are unrelated to funding liquidity risk.

It should be pointed out that the area under the aggregate demand curve is only a proxy for funding liquidity risk as banks generally do not bid their full marginal valuations. However, individual bids reflect banks specific funding liquidity risk as they incorporate the bank's expectations about NLD, the price of liquidity as well as their possible fluctuations over the coming week. By summing across the bids of all banks, the aggregate demand curve therefore provides a rough approximation of aggregate funding

[13] In the model, bids shading occurs and bids do not fully reflect the marginal value.

pressures.

Drehmann and Nikolaou (2008) explain that this proxy is rather crude. For example, the aggregation may mask important differences between banks. It may be the case that the area under the bid curve is the same if all banks bid normally or if one bank has exceptionally high liquidity demands whilst all others bid lower. However, liquidity risk can be detrimental if the flow constraint is binding, i.e. given a focus on downside risks. Furthermore, it may be that the area chosen is too broad and therefore includes valuations which do not directly relate to risky situations but for example include bids which are undertaken for speculative purposes[14]. They argue that it is exceptionally high bids which should reveal threatening risky situations, for example if banks expect break downs in the IB market or system wide drying up of market liquidity, i.e. scenarios which are key for liquidity risk management.

Drehmann and Nikolaou (2008), therefore suggest looking at "exceptionally high bids" as another proxy for funding liquidity risk and propose two ways to do that. First, they pool all bids across different auctions and select an extreme quantile, say the 99% percent quantile. As a second way, they consider the integral under the aggregate demand curve for the successful bids minus the marginal rate times the allotted volume (normalised by the reserve requirements). In both cases, they sum all extreme valuations across banks in each auction to derive a single aggregate risk measure for each auction.

Whilst the focus on "exceptionally high" bids to measure funding liquidity risk is correct, we argue that the measure used by Drehmann and Nikolaou is too crude. To start with, their definition of extremely high bid is ad-hoc as quantiles are arbitrarily chosen. Furthermore, the spikes picked up do not necessarily indicate risk. Examples are the seasonal patterns in liquidity. For example, Bindseil et al (2003) have shown that banks engage in window dressing activities before the year end, which typically increases their demand for liquidity. Such actions are nevertheless seen as normal behaviour and would not suggest liquidity risk in the sense that banks expect it to be more likely that they will not be able to satisfy the demand for high powered money. The existence of such extreme, yet normal valuations would bias our measure upwards and crowd our other instances, where smaller, yet meaningful peaks are recorded. The empirical literature on bidding behaviour has also highlighted other factors that affect the biding behaviour of the banks, related to perhaps inefficient bidding behaviour of banks, auction-specific characteristics, and general market conditions. A detailed list can be found below (section XX) together with explanation about the way they influence it. Certainly, these factors are not related to funding liquidity risk, even though they can be controlled for.

[14] Central bank balances are re-numerated at the marginal rate. Hence, obtaining funding at this rate is therefore essentially costless.

Using regression analysis we derive expected or "normal" bids conditional on exogenous factors. The "exceptionally high" component of a bid is simply the positive residual, which reflects bank specific funding liquidity risk. Our proxy is therefore the sum of positive residuals for each auction. Unfortunately this proxy contains statistical noise from the estimation. However, it improves significantly on the measure by Drehmann and Nikolaou.

3 Data

Our analysis is based on a unique data set of 193 main refinancing operation (MRO) auctions conducted by the ECB. Because of changes in operational framework we start our analysis in March 2004. Our sample ends in December 2007. ECB data for ECB MRO auctions allow us to follow the bidding behavior of each of the 877 banks over time. 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. Further data on the policy rate (minimum bid rate), the marginal rate, the maintenance periods, the settlement dates of the auctions, the liquidity provided from each type of OMO and the list of the EONIA panel banks are taken from the ECB's internet site. All financial markets data are taken from Bloomberg. Variables are explained below and include the spot EONIA rate, 1 month forward EONIA rates, US repo rates for treasury bonds and mortgage backed securities (ABS). All quantities are transformed by taking logs.

4 Empirical Methodology

Even though banks are allowed to submit up to ten bids per MRO, the average number of bids prior to the turmoil was below 1.5. Even during the turmoil the average number did only increase to around 2 (see Eisenschmidt et al., 2008). Hence, we do not observe a full demand curve but just points along it. Nonetheless, as argued above, these bids reflect funding liquidity risk. Therefore, following Drehmann and Nikolaou (2008) we define the *Liquidity Risk Proxy1* (LPR_1_i) per bank i at auction t as

$$LPR\_1_{i,t} = \sum_{b=1}^{B} \left(\frac{spread_{t,i,b} * volume_{t,i,b}}{reserve\_requirements_{t,i}} \right) \tag{4}$$

LPR_1_i is a normalised summary variable of the bid price ($spread_{t,i,b}$) times the bid volume ($volume_{t,i,b}$) of bank i, submitting from b=1 up to B bids at time (auction) t. As discussed above, the normalization of bids is necessary to remove changes in the monetary policy stance. Even for unchanged liquidity risk, bid rates would increase with an increase in the policy rate. Hence we use the $spread_{t,i,b}$ which equals the $bid\_rate_{t,i,b}$ minus the $policy\_rate_t$. We also normalise by $reserve\_requirements_{t,i}$ to ensure consistency across banks. The actual reserve requirements are not known, so we approximate them with the sum of the allotted volume within the same maintenance period. Therefore, as our first proxy for aggregate liquidity risk we take the normalised area under the aggregate demand curve, i.e. we sum the $LPR\_1_{i,t}$ across all banks from i=1 to N whithin each time (auction) t. This can be written as

$$LPR\_1_t = \sum_{i=1}^{N} LPR\_1_{i,t} \tag{5}$$

Following our discussion in Section 2.3, it is clear that this measure is a first but crude proxy for funding liquidity risk as it is influence by many factors unrelated to funding liquidity risk. Therefore the analysis in this paper aims to identify normal bidding behaviour conditional on observable factors. Building on the literature on bidding behaviour (e.g. Graig and Fecht, 2007, Fecht et al. 2007, Linzert, et al. (2007) and Eisenschmidt et al., 2008), we construct a large number of variables to explain the bidding behaviour of the banks. Some of these variables have been used as such in the past, and some are newly introduced in this paper. Details are discussed in the next section. Furthermore, we add one more variable to correct for sample selection bias (Heckman, 1979). Since a bank's bid amount or its average bid rate can only be observed if the bank actually participated in the MRO, estimation may be subject to a selection bias. Accounting for banks' participation decision, we employ panel sample selection estimation techniques, which extend the cross sectional Heckman approach to the panel case (Linzert et al., 2007). We then estimate a random effects panel regression with $LPR\_1_{i,t}$ as dependent variable and a long list of explanatory variables as independent regressors, in which we include the inverse Mills ratio to correct for selection bias.

Our second step collects the residuals from the above regression, which account for "abnormal" bidding, i.e. bidding behaviour that based on observables cannot be explained using standard assumptions about bank's liquidity demand. Certainly, errors are partly a result of statistical uncertainty. However, positive errors indicate cases where the bank is faced with very high liquidity risk, over and above its normal level. These are the cases when the flow constraint is most likely to bind. This series, therefore, is a cleaner proxy for the funding liquidity risk of the banks.

In order to construct a time series, we again aggregate the residuals across all bids and banks at each time period t (i.e. at each auction). Note that we only pick up positive residuals, given that we are interested at the cases when the constraint is more likely to bind. Our second proxy for funding liquidity risk LRP_2_t , is therefore:

$$LRP\_2_t = \sum_{i=1}^{N} residuals_{t,i}^{+} \tag{4.1}$$

4.1 Explanatory variables

Focusing on the list of regressors, they fall into five main categories, which control different aspects of bidding behaviour. The first one relates to bank specific variables, such as size and the bidding characteristics of the individual bank. These variables aim to partly account for potential dependency patterns in the bidding behaviour of banks. The second aims to control for the differences between the CB auctions and the interbank market. Variables in this category include a comparison between the risks and costs undertaken in each market. The third one controls for auction specific characteristics, such as maintenance end and the year end. These variables control for the seasonality patterns in the bidding behaviour and effectively complement the auction-market side of the previous category. The fourth category comprises general economic variables, such as the future volatility of interest rates and the turmoil dummy. The last category includes variables which are controlled by the central bank and therefore significantly impact on aggregate (central bank) liquidity. We are now going to analyse each one of these variables, by category.

4.1.1 Banks specific variables

Size: Several empirical studies document that the size of the bank determines its liquidity needs. Bigger banks, due to their diversified portfolio of activities might need more liquidity (Graig and Fecth, 2007), which should be easier and cheaper to get either in the interbank market or directly from the central bank (Fecht et al., 2007; Linzert et al, 2006). The size of each bank should be proportional to its reserve requirements. We use data on the reserve requirements of banks in 2002, assuming that the basic structure has not changed much to this date. The few banks that were not reported in 2002, but enter our current sample were assigned zero values. This might be reconciled by the assumption that big banks should already be contained in the sample.

Success at previous biddings: The intuition behind this variable is that banks who have not acquired the necessary liquidity in the previous auction, will try to make up for it in the next auction. In order to control for this, we divide the actual obtained funding by the desired funding (cover to bid ratio) for each bank from the previous auction.

Regular bidders: It is possible that the bidding behaviour and liquidity demand patterns of a regular bidder might be different from these of an irregular one. Linzert et al. (2006) mention that regular bidders seem to be well informed about conditions in the money market. They bid closer to the marginal rate than non-regular bidders and receive their allotment cheaper. They also have a higher cover to bid ratio than non-regular bidders. We count the times each bank participated in the auctions available divided by the total number of auctions to measure the regularity of its bids.

4.1.2 Relative costs of central bank auctions versus inter-bank lending

Opportunity cost: It is possible for a bank to hedge against the interest rate risk, but not the auction risk (unless we assume a cost inefficient bidding behaviour). This is possible by using a one-week Eonia swap, i.e. a contract that exchanges a payment based on the fixed swap rate at the end of one week (which we capture with Swap) for one based on the arithmetic average of daily Eonia rates during the same period. Thus, the Eonia swap rate is the risk-free rate at which a bank could receive liquidity for one weeks without incurring the auction risk.

Collateral premium: This variable should reflect the relative attractiveness of the ECB tender operations vis-a-vis the interbank market. This is because the ECB accepts and prices a broad range of collateral in its operations almost regardless of underlying market conditions for these collateral assets. This variable is defined as the spread of (US) one week repo rates for treasury bonds to those for mortgage backed securities (Eisenschmidt et al., 2008)[15].

4.1.3 Auction specific characteristics

Maintenance end: It is very likely that the last auction of the maintenance period be very different than the previous ones, given that it is in that one that the reserve requirement becomes binding. The maintenance period spans approximately a month, within which banks need to fulfil the binding reserve requirements that they need to hold with the CB. Banks are allowed to hold positive or negative balances with the CB across the period, as long as on average, across the month, the reserve requirement condition holds. This can consequently result to increased or decreased liquidity demands towards the end of the maintenance period, when banks will need to close up any gaps. We therefore need to control for excessive liquidity demand by introducing a variable taking the value of one at the last auction of the maintenance period and zero otherwise.

Year end: Similarly, the end of the year is a period where a lot of banks have increased liquidity

[15] US data has to be used as not European data are available.

demand, before closing their financial accounts, without this behaviour necessarily suggesting funding liquidity risk. We therefore control for this effect using a dummy variable which is one at the end of the year auction and zero otherwise.

4.1.4 General economic variables

Volatility of interest rates: Interest rate uncertainty might affect the bidding behaviour of banks. Regarding the impact of uncertainty, auction theory predicts the winner's curse effect which implies that banks bid more cautiously when interest rate uncertainty increases. With increasing uncertainty, banks should mitigate the exposure to winner's curse by bidding at lower rates, reducing the quantity demanded and increasing the bid rate dispersion, see Nyborg, Rydqvist and Sundaresan (2002). In fact, this effect is well documented for Treasury bill auctions, see e.g. Nyborg, Rydqvist and Sundaresan (2002) and Bjonnes (2001). Yet, Nyborg, Bindseil and Strebulaev (2002) found only mixed evidence in favor of the winner's curse effect in the ECB's MROs. In our context interest rate uncertainty is proxied by the variable volatility, measured as the spread between the 1 month forward rate one month ahead minus the policy rate.

Turmoil dummy: The recent credit market turmoil unavoidably spurred a great increase in CB money, given the break down of the interbank market. The turmoil is likely to introduce a structural change in the bidding behaviour of the banks and therefore its effects is controlled for with a dummy that takes the value of zero before the turmoil period and 1 after.

Eonia volume: Higher volumes in the interbank market indicate that flows of high powered money between banks increase. If this is expected, NDL is also increasing, increasing liquidity risk and hence should lead to higher LRP_1. We measure this variables as the logged turnover of EONIA panel banks the day before the MRO allotment.

Volume in TARGET payments: Payments between banks are settled with central banks reserves, via a settlement system which is called TARGET in the euro area. If payments, increase, liquidity management becomes more complex and time critical. Therefore, it appears natural that an increase in payment volumes adds to the demand pressure for liquidity and hence leads to higher bid rates in the MROs. This we measure by the logged four week moving average of TARGET system payment volumes (Eisenschmidt et al. 2008).

4.1.5 Central bank policy variables

Liquidity policy: The CB's liquidity policy (allotting substantially above the benchmark) can potentially alleviate the demand pressure for liquidity and therefore the overall increase in banks' bid rates, by increasing the allotment amount, i.e. allotting above the benchmark amount. Given well functioning interbank markets, the benchmark allotment equals the expected aggregate liquidity needs of the banking system vis-a-vis the CB (i.e. changes in reserve requirements and changes in autonomous factors). If banks expect the CB to provide more (central bank) liquidity than necessary to fulfil aggregate liquidity demands, banks bids should be lower. We construct this variable by calculating the ex-post deviation of the allotted amount from the benchmark (Eisenschmidt et al. 2008).

Auction size: Higher MRO volumes can be perceived to be associated with increased operational risks and increased costs of foregone allotment which induces banks to bid at higher rates to secure their funds. We measure this variable by the log of the benchmark amount.

Share of MRO: MRO are an important liquidity providing operation, however, a large amount of liquidity is also provided by regular and occasionally irregular LTROs and to a much lesser extent via FTOs fine-tuning operations. It appears that increasing the volume of the LTROs at the expense of MRO volume can increase the competition among banks for the weekly liquidity resulting in higher bid rates. Following Eisenschmidt et al. (2008) we measure this variable by the ratio of MROs over total refinancing operations (MRO+LTRO+FTO).

5 Results

The regression results are presented in the Tables of Results (Panel A and B). The tables present the estimated coefficients of each variable, arranged in their respect five categories. We see that almost all variables appear to be statistically significant at the 1% level and have the expected signs. The inverse Mills ratio is also statistically significant at the 5% level (not presented in the table) although its inclusion does not affect the statistical significance of the other variables. Overall, the results validate our choice of variables and increase the credibility of our funding liquidity risk measure.

Both of our measures indicate that liquidity risk is generally time low and stable (stationary), with occasional spikes (see Chart 1). This seems intuitive. Under normal market conditions (prior to August 2007 in our sample), the risk that NLD cannot be founded from any of the four sources (depositors, interbank markets, the central bank or selling assets) is virtually 0. Hence, changes in funding liquidity risk are driven by expectations about the different prices of obtaining funding from different sources. The empirical research on market liquidity measures indicates for example that (market) liquidity risk is time varying and persistent (Amihud, 2002; Chordia et al., 2005,2002,2001; Pastor and Staumbaugh, 2003). And our measures seem to have the same properties.

In stressed conditions after August 2007, not only did the price risk of obtaining funding from different sources increase, but also the risk that e.g. interbank markets would not be accessible either because of asymmetric information or because of liquidity hoarding of other counterparties. Furthermore, NDL also increased for most players because of a re-intermediation of off-balance sheet vehicles. Indeed the biggest spikes of our measures are at the end of our sample, when we observe the reaction of the banking system to the credit market turmoil (in August and December 2007). And most practitioners would certainly agree that the recent months have been the most risky event in our sample. Moreover, comparing LRP_1 and LRP_2 it is obvious that LRP_2 controls much better for the seasonal spikes, especially the ones at the end of the year which have been the most pronounced ones.

Finally, comparing LRP_2 to the measure of Drehmann and Nikolaou LRP_DN (Chart 2) based on the excessively high values of the integral under the aggregate demand curve[16], we observe that our measure of risk lies broadly on the same level as the LRP_DN, thereby suggesting that we indeed pick up exceptionally high bids. Nevertheless, we see that our refinement can successfully deal with seasonal patterns, while maintaining the spike during the turmoil period. The fact that this spike is omitted from the DN measure suggests that during the turmoil the marginal rate also rose, as a large number of banks were bidding at higher rates. These results validates our relevant conjecture about the ad-hocness of such liquidity risk measures.

6 Conclusion

[To follow]

[16] This is the integral under the aggregate demand curve for the successful bids minus the marginal rate times the allotted volume (normalised by the reserve requirements).

Annex 1: The main refinancing operations

Main refinancing operations are conducted at weekly frequency and have a tender period of one week. The implementation procedure of an MRO spans three days. On Monday morning, the auction is announced. The announcement includes the publication of the benchmark allotment and an estimate of autonomous factors that are assumed to prevail until the subsequent MRO. A (possibly) up-dated benchmark allotment is published on Tuesday. On Tuesday, the ECB decides about total allotment and individual allotments. Banks have time to submit their bids until ~9:30 am. At ~11:20 am the result of the tender operation is announced. Finally, on Wednesday, the operation is settled.

Benchmark allotment, autonomous factors and reserve requirements

For every MRO, the ECB calculates a so-called benchmark allotment. The benchmark allotment is the allotment which ensures neutral liquidity conditions in the market given that there are no liquidity shocks. The benchmark allotment takes into consideration forecasts of autonomous factors until the next MRO, reserve requirements and liquidity imbalances that have accumulated during the maintenance period. Autonomous factors comprise banknotes in circulation, government deposits and other balance sheet items of the ECB that are neither monetary policy operations nor current account holdings of counterparties with the ECB. Autonomous factors are one source of liquidity needs of counterparties. The other source of liquidity needs is the obligation to meet reserve requirements. Whereas autonomous factors vary during the course of a maintenance period, reserve requirements are constant.

Longer term refinancing operations

LTROs take place on the last Wednesday of every month and have a maturity of 3 months. They are an additional source of liquidity. The advantage of this period is that banks can cover basic liquidity needs by the liquidity they obtained in LTROs for a longer time horizon. However, short-run and ad hoc liquidity needs cannot be covered. Since the ECB does not aim to send signals to the market by LTROs, it acts as a price taker.

Reserve maintenance period

The start of a reserve maintenance period coincides with the settlement day of the first MRO in the maintenance period. In addition, this is the day on which interest rate decisions become effective. Thus, within a maintenance period, no interest rate changes become effective.

Liquidity policy

In addition, since the introduction of the new framework, the ECB has used the supply of liquidity in a more structural way as policy option. That means, since the second half of 2005, the ECB has deliberately pursued a loose liquidity policy to prevent the spread from rising. Liquidity policy is measured as the difference between actual allotment and benchmark allotment. Since the benchmark allotment takes into account accumulated liquidity imbalances and thus "reverses" liquidity policy in the previous MROs, only the liquidity policy in the last MRO of a maintenance period decides about the liquidity character of all MROs within a maintenance period. I.e. only if the actual allotment in the last MRO is higher than benchmark allotment, total liquidity supply in the period has been higher than necessary for neutral liquidity conditions.

Fine Tuning Operations

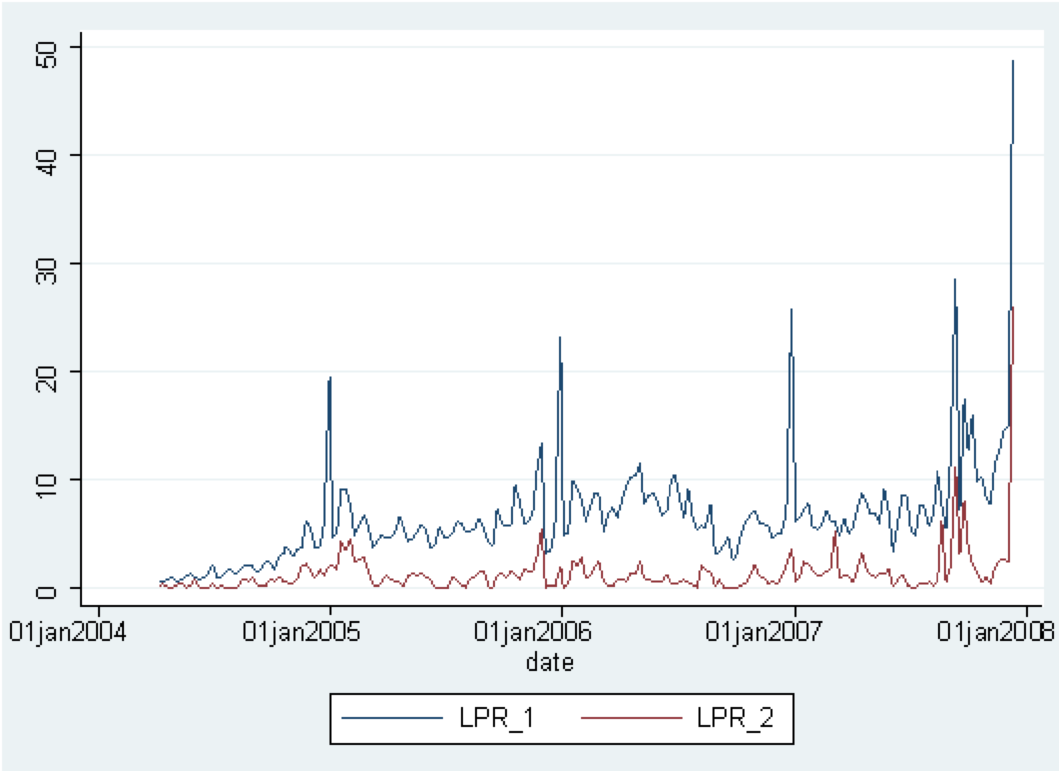
FTOs have been used increasingly in a structural and foreseeable way in the new framework. The ECB has mainly implemented them on the last day of the reserve maintenance period to neutralize liquidity conditions. Fine tuning operations have no regular schedule and no pre-specified tender period. FTOs are implemented on an ad-hoc basis if unexpected liquidity situations occur in the market. FTOs can be implemented as quick tenders if the ECB intends to have a rapid impact on the liquidity situation. Quick tenders are conducted within one hour and are restricted to a very limited number of counterparties.

Table of Results

Panel A

Category / Variable	Coefficient	Category / Variable	Coefficient
Bank specific		**Central Bank policy**	
Bank size	0.001 (0.001)	Liquidity Policy	−0.036 (0.001)
Success at previous biddings	−0.567 (0.029)	Auction Size	3.369 (0.079)
Regular bidder	−1.381 (0.146)	Share of MRO	−11.978 (0.280)
Central Bank vs inter-bank		**General/ Economic variables**	
Opportunity cost	−0.579 (0.019)	Volatility of interest rates	0.162 (0.0.067)
Collateral Premium	3.564 (0.088)	Turmoil dummy	2.267 (0.053)
Auction Specific		Eonia volume	0.320 (0.031)
Maintenance end dummy	−0.048 (0.015)	Volume of Target Payments	0.9725 (0.078)
Year end dummy	2.684 (0.054)	constant	−21.888 (0.972)

Notes: The table presents the results of the panel regressions, as explained in Section 4. The tables displays the estimated coefficient and the standard errors (in parethesis) for each of the regressors (see Section 4.1 for list of regressors).



Charts

Chart 1. Funding liquidity risk LPR_1 and LPR_2

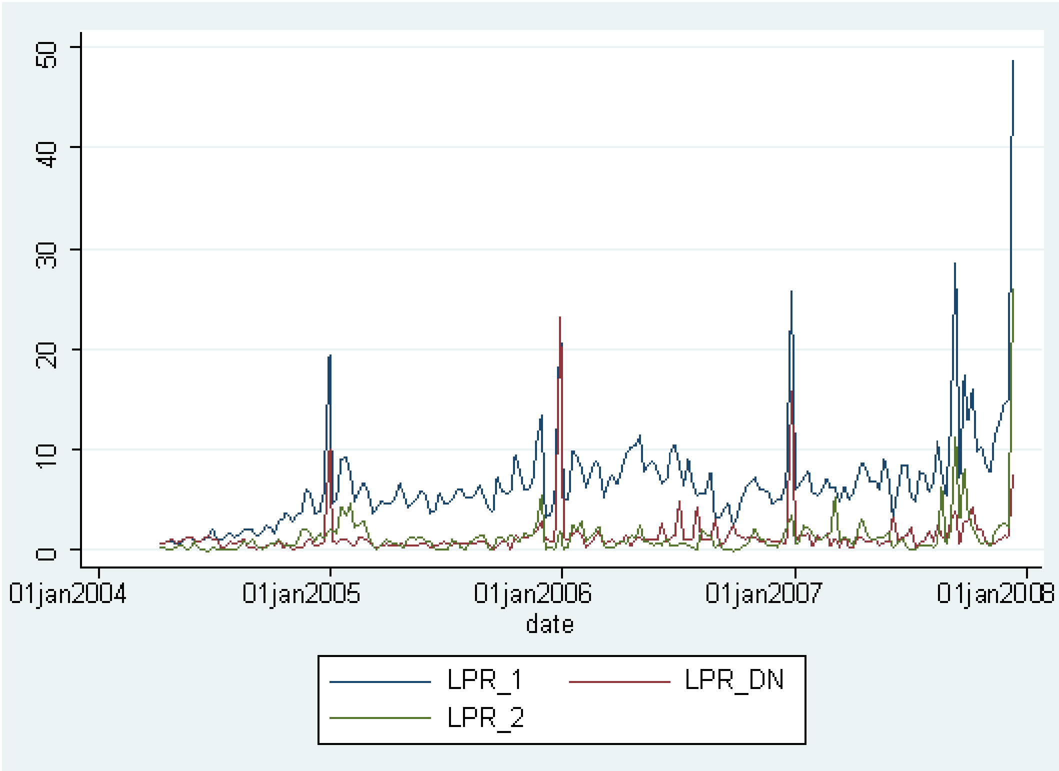


Chart 2. Funding liquidity risk LPR_1, LPR_2 and LPR_1 and LPR_DN

Notes: The charts present the measures of the aggregate funding liquidity risk. Chart 1 refers to the methodology and results of the current paper. The measure for demand pressure is given by formula 5 in Section 4, and the measure for liquidity risk is the positive residuals of the regressions analysis (formula 6 in same section). Chart 2 compares the liquidity risk measures of this paper to the risk measure LPR_DN of Drehmann and Nikolaou (2008), as explained in the Results (see Section 5).

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