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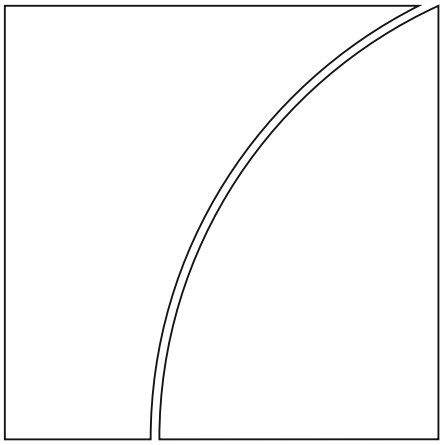

Literature review of factors relating to liquidity stress – extended version

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1. Introduction

The Basel Committee on Banking Supervision created the Research Task Force (RTF) to further the goals of the Committee through a variety of activities. One of these activities is to take on specific research projects addressing supervisory and financial stability issues.

Given the importance of stress testing as a tool in developing a complete picture of an institution's liquidity risk profile, the RTF's Workgroup on Liquidity Stress Testing (RTF-LST) was mandated to draft a survey on current practices, identify gaps and – where possible – suggest ways forward. The survey is written with the broader supervisory community in mind. Many of the findings are, however, also relevant for risk managers in banks as well, given their role in measuring their institution's liquidity risk profile and enforcing risk limits.

This note reviews the academic literature pertaining to liquidity stresses in more detail, compared to the review chapter in the survey (see Basel Committee Working Paper No 24). It is organised using the categories and concepts established in the Liquidity Coverage Ratio (LCR). In particular, the Workgroup reviewed the literature on: deposits, loan commitments, secured funding, wholesale funding, counterbalancing capacity, secured lending, and links with non-banks intermediaries. In addition to other parts of the abovementioned survey, this note can help to inform the design of stress tests.

2. Deposits

Both the empirical and theoretical discussions in the literature on deposits are broad and deep. This section examines the literature on various classifications of deposits while also keeping in mind those classifications established under the LCR.

2.1 Insured deposits

The literature does not agree on insured deposit[2] rates and runoffs in response to idiosyncratic institutional stress measures. While a few papers document some level of *both* increased rates and

[1] Drafted by Pogach (Federal Deposit Insurance Corporation) and Skander van den Heuvel (Board of Governors of the Federal Reserve System) based on literature reviews drafted by Arrambide (Board of Governors of the Federal Reserve System), Bevilacqua (Bank of Italy), Bonner (Netherlands Bank), Cetina (Office of the Comptroller of the Currency), Emmel (Board of Governors of the Federal Reserve System), Heider (European Central Bank), Holthausen (European Central Bank), Liu (UK Prudential Regulation Authority), Martin (Federal Reserve Bank of New York), Pogach (Federal Deposit Insurance Corporation), Schmitz (Austrian National Bank), Schmieder (Bank for International Settlements), Souissi (Bank of Canada) and van den Heuvel (Board of Governors of the Federal Reserve System).

[2] Insured deposits are generally difficult to measure in practice. Consequently, most studies, including those discussed in this report, use deposits with principal over a defined insurance limit as a proxy for insured deposits. The issue is complicated further by the multitude of deposit insurance schemes internationally and over time. Countries differ in the types of accounts

decreased quantities at struggling institutions, others fail to find such a result. The mixed results hold for both empirical studies and for case studies. However, the empirical evidence on insured bank runs generally focuses on developing countries.

Documentation of Hamilton Bank in Davenport and McDill (2006) shows that insured deposits dropped significantly in the three quarters prior to failure. It should be noted that this bank's failure did not occur during a market wide stress. In the months prior to failure, most insured account types (ie Individual, Joint, Individual Retirement Account (IRA), Trust, and Business) experienced a runoff in the 10 to 20% range.

Cook and Spellman (1994) and Park and Peristiani (1998) find statistically significant effects of banking institution risk taking (thrifts) on insured certificate of deposit rates. The former examine the question in the context of the savings and loan crisis and the insolvency of the deposit guarantor, the Federal Savings and Loan Insurance Corporation. They argue that restitution costs borne by the depositor and repudiation risk lead the market to risk price insured deposits. Park and Peristiani (1998) also study thrifts and find small, but statistically significant evidence of depositor discipline (decreased quantities, increased deposit rates) on insured time deposits. However, their result did not extend to negotiable orders of withdrawal (NOW) and interest-bearing checking accounts.

Similarly, Iyer and Puri (2008) find that deposit insurance does not completely eliminate a depositor's incentive to run. Using data from India, the authors show that insured depositors also participate in bank runs, albeit less than their uninsured counterparts. Moreover, account balances correlate with the likelihood of withdrawals even below the deposit limit. Martinez Peria and Schmukler (2001) use data from Argentina, Chile and Mexico to show that not only do insured depositors run, but they also do so at the same rate as other depositors. However, the extent to which these countries' experiences during the time period are comparable to those with more established deposit insurance systems is unclear. Like Cook and Spellman (1994), these results highlight the importance of credibility of the deposit insurer in providing stability to insured deposits.

On the other hand, some studies fail to find such an effect. Anecdotally, Feldberg (2008) shows that Wachovia was able to raise $15 billion in insured certificates of deposits (CDs) in one month a quarter prior to its acquisition by Wells Fargo and continued to raise CDs through the stresses of Lehman and Washington Mutual failures. This experience is also reflected in Jordan (2000) who shows that insured time deposits actually increase by 3% in the eight quarters leading up to failure in his sample even as overall deposits at the median decline by 11%. Transaction and savings accounts (which may include both insured and uninsured accounts), decrease by 13% and 1%, respectively.

Similarly, Ben-David et al (2011) do not find evidence of deposit market discipline of low capital banks during the crisis. Indeed, the relationship between insured deposit rates and deposit flows are statistically and economically equivalent for high capital and low capital banks. They attribute this finding to the fact that low capital banks were deleveraging during their period of study.

2.2 Uninsured deposits

A common result in the literature is that uninsured depositors exert "market discipline" (ie impose higher interest rates for a fixed quantity or runoff quantities for a fixed deposit rate) on riskier banking

insured (ie consumer/business, transaction/savings), the presence of supplemental private insurance systems (eg Germany), the presence of coinsurance (eg United Kingdom prior to 1 October 2007), and insurance limits. Unless otherwise indicated, this paper uses the term insured deposits to interchangeably imply the theoretical measure of deposits that are insured 100% by a public deposit insurer and deposits below the 100% insurance threshold. For links to governing statutes on current deposit insurance practices see www.iadi.org/di.aspx?id=69.

institutions and to a greater extent than insured depositors. This result holds both in developing and developed economies and is supported by both case studies and empirical evidence.

While Davenport and McDill (2006) document significant runoffs of insured deposits, the runoff rates of uninsured depositors are generally much greater. Uninsured Individual, Joint, Trust, and Business accounts run off at approximately three times the rates of the insured counterparts. Empirical evidence of this can be found in Acharya and Mora (2012) who show increased deposit rates and decreased deposit flows at failing banks and banks with liquidity exposures. Furthermore, Park and Peristiani (1998) show large and statistically significant correlations in the expected directions between thrift failure probabilities (estimated using a failure logit model) and uninsured deposit growth rates and deposit rates. Similar results on bank risk taking and uninsured deposit rates are found in Hannan and Hanweck (1988).

Furthermore, Imai and Takarabe (2011) find similar evidence of uninsured deposit outflows in Japan in 2002 as the government removed a blanket guarantee in favour of a cap. Following the removal of the guarantee, weak banks' uninsured time deposits fell and these banks were unable to compensate with increases in insured deposits, leading to a contraction in credit supply.

Iyer and Puri (2008) and Martinez Peria and Schmukler (2001) find that uninsured deposits run during stress events using data from India and three Latin American countries, respectively. The first is consistent with the other literature finding that these outflows are significantly greater for uninsured depositors, while the second differs in its finding that the two classes behave similarly.

Without any systematic insurance system, asset-backed commercial paper (ABCP) programs operated like banks, transforming long term assets into short term liquid debt. Thus, the experience of ABCP programs may provide further insight into uninsured deposits, with the caveat that investors and institutions are not entirely comparable. Under this premise, Covitz et al (forthcoming) find that one third of ABCP programs were in the midst of a run at the height of the financial crisis. As might be expected with uninsured deposits, credit and liquidity exposures were related to runs in ABCP.

2.3 Retail/core versus wholesale deposits

Core deposits are not consistently defined in the literature, but are generally contrasted with wholesale deposits. Generally speaking, in studies using US data, core deposits consist of some subset of demand deposits, NOW and automatic transfer service (ATS) accounts, money market deposit accounts (MMDAs), other savings accounts, and insured CDs, though vary on their inclusion of insured brokered deposits.

Due to their long realised durations and behaviour relative to macro-interest rates, core deposits are thought to be beneficial to a bank's health. Although many components of core deposits have no explicit maturity, a number of studies have found that their realised maturities are quite long. Using a small proprietary sample of financial institutions, Sheehan (2013) finds maturities of 10 to 20 years for checking (business and retail) and NOW accounts and maturities of 5 to 20 years for money market and savings accounts. Kiser (2002) finds similar durations for consumer checking and savings accounts from survey data. Furthermore, the literature generally shows (see Hannan and Berger (1991), Neumark and Sharpe (1992)) that core deposit rates fall with macroeconomic interest rates, but sluggishly adjust to increases in macroeconomic interest rates. Thus, core deposits serve as a source of bank franchise value. Hutchinson and Pennacchi (1996) use this concept and estimate deposit durations to quantify bank franchise value of retail deposits. They obtain lower estimates of durations for NOW

accounts and MMDAs (seven years and less than one year, respectively), but show that bank charter value deriving from retail deposit accounts amounts to 3.8% on average of total deposits.

At least in the US, statutes[3] limit the extent to which undercapitalised banks may raise brokered deposits. Thus, any analysis on the behaviour of brokered deposits during a stress event would need to disentangle this effect from the behaviour of brokered deposits.

Nevertheless, a number of studies examine the relationship between bank stresses and core (variously defined) or brokered deposits. The FDIC (2011) study on core and brokered deposits reviews the literature on core versus brokered deposits and provides additional analysis. Among the findings are: core deposits decrease a bank's probability of failure, decrease a bank's loss-given-default (Bennett and Unal (2011)), decrease resolution costs (Osterberg and Thomson (1995)), and increase the premium paid for failed institutions (James (1991)). Furthermore, core deposits are associated with continued lending during periods of external stresses (Cornett et al (2011) and Berlin and Mester (1999)). FDIC (2011) goes on to show that these results are driven by a definition of core that excludes insured brokered deposits. Indeed, the deleterious effects of non-core deposits are experienced equally when insured brokered funds substitute for other forms of wholesale funding.

Although Shin (2009) argues that the run on Northern Rock was not primarily *driven* by a classic retail bank run, the data he presents suggest that retail deposits run at significant rates, even if they lag other creditors' run on the bank. Wholesale funding and retail funding drop by a similar percentage from June 2007 to December 2007. Meanwhile, Figure 7 in the article suggests that offshore accounts ran off at the highest rate among retail deposits. However, traditional branch accounts ran at a comparable rate to internet and telephone accounts (46% and 38% runoffs, respectively). No distinction was made in the article between insured and uninsured accounts, though at that time deposits in the United Kingdom were entirely insured only up to £2,000 with 90% coinsurance up to an additional £33,000.

2.4 Transactional deposits

Some theoretical and empirical literature (eg Gatev et al (2009), Kashyap et al (2002)) suggests that transactional accounts in particular mitigate liquidity stress from loan commitments. The underlying premise of these papers is that holding liquidity to meet demand deposits or commitments is costly. That banks provide both these services is efficient because commitment takedowns and depositor withdrawals are not perfectly correlated, allowing them to use the held liquidity to meet either need. To examine this claim, Gatev et al (2009) show that stock return volatility is positively correlated with unused commitments, but that this association is dampened in the presence of transaction deposits. Furthermore, they show that this deposit-lending risk management synergy is strengthened during times of tightened liquidity. They argue that this arises because the correlation between commitment takedowns and deposit withdrawals is negative during such time periods, with higher commitments associated with transactional deposit inflows. However, Pennacchi (2006) and Santos (2012) demonstrate that such a result does not necessarily hold for uninsured deposits. Rather, the correlation runs the wrong way between commitments and uninsured deposits during stress.

2.5 Bank-depositor relationships

Another finding in the literature is the role that bank-depositor relationships play in the reliability of deposits.

[3] See 12 U.S.C. § 1831f and 12 C.F.R. § 337.6.

Iyer and Puri (2008) find that both the duration and breadth of the bank-depositor relationship decrease the probability of a withdrawal of funds during a crisis, where duration is measured on the deposit account and breadth is measured by the presence of a loan linkage. A previous loan linkage is associated with a lower withdrawal probability even if the loan was no longer outstanding at the time of bank stress.

One mechanism through which relationships may operate is that upon failure, uninsured depositors can apply the full balance of outstanding loans to offset their losses. Davenport and McDill (2006) find that uninsured deposits unprotected by this offset dropped by nearly two-thirds while uninsured deposits overall dropped by half.

3. Commitments

By extending loan commitments to their clients, banks expose themselves to contingent liquidity outflows, where the risk materialises when the borrower decides to draw down the line of credit. Loan commitments are valued by firms as insurance against unexpected cash flow shortages. Similarly, entities that issue asset-backed securities (such as ABCP) usually rely on similar liquidity facilities structured to cover the face value – principal and interest – of the assets, which protects buyers from a sponsor's inability to "roll" on its debt.

As argued by Diamond and Rajan (2001) and Kashyap et al (2002) banks reap economies of scope by combining lending and deposit taking. Specifically, Kashyap et al argue that outflows of funds due to lending – in particular from loan commitments – and outflows from deposits are imperfectly correlated, so that both activities can share the cost of a common liquid asset stockpile. In fact, Gatev and Strahan (2006) present evidence that deposit inflows into the banking system tend to increase when there are liquidity disruptions or higher spreads in the commercial paper market. Thus, banks are in a unique position to offer relatively inexpensive insurance against such disruptions by extending credit lines to commercial paper programs or their sponsor, which are in fact drawn down during such episodes. In effect, banks can have a natural hedge against such market-wide liquidity shocks, as deposit inflows from institutional investors counterbalance unexpected strains on liquidity from credit line drawdowns.

That said the experience of the recent financial crisis casts doubt on the notion that deposit taking and commitment lending are always a natural hedge. First, borrowers drew down on their credit lines to hold cash on their balance sheets as a precautionary measure against turbulent credit markets, or because other funding options were simply less attractive (Ivashina and Scharfstein (2010), Berrospide et al (2012), Irani (2011), Santos (2012)). Even prior to the recent crisis, Pennacchi (2006) shows using pre-FDIC data that flows on uninsured funds may exacerbate, rather than hedge against, flows on commitments during stress.

Second, and arguably quantitatively more important, the ABCP market froze, resulting in funding pressures for financial institutions, either because they sponsored ABCP programs or had extended liquidity support to such programs (Acharya et al (2013), Covitz et al (forthcoming), Kacperczyk and Schnabl (2010)). Notably, the balance sheet disruptions from these ABCP liquidity and/or credit guarantees were of potentially greater magnitude than those resulting from draw-downs on "plain vanilla" credit lines to nonfinancial firms. However, it is difficult to precisely quantify the effect of ABCP market freeze on banks' balance sheets due to data limitations; see Acharya et al (2013) for a discussion and an "upper bound" estimate of the balance sheet effects. Berrospide et al (2012) quantify the – comparatively modest – increase in drawdown rates on credit lines of nonfinancial firms during the crisis. Meanwhile, Bord and Santos (2011) demonstrate that increased funding costs through ABCP stress were also passed on to corporate customers via higher credit line fees.

Third, even as firms and issuers of ABCP drew down their backup lines, deposit inflows appear to have been tempered as the crisis unfolded and concerns about the financial health of banks put into question the safe haven status of banks. Together, these events somewhat negated the natural hedge thought to be inherent in the combination of deposit taking and lending (Acharya and Mora (2012)).

As access to the short term credit markets stalled or collapsed, firms became increasingly dependent on banks for liquidity (Chava and Purnanandam (2009)).[4] Consequently, banks became inundated with liquidity demands resulting in an unmanageable level of outflows. With no access to previously cheap short term funding and demand inflows used heavily by banks to counterbalance market disruptions, the liquidity risk crisis spread across industries and markets. Concerns over market uncertainty and bank solvency continued to stall inflows from institutional investors or other sources. Only after the provision of more extensive extraordinary government support in the fall of 2008 were banks able to attract deposit inflows to counterbalance the funding pressures.

4. Secured funding

With a total market volume of several trillion US dollars, secured funding constitutes a large and important source of short-term bank funding, particularly in the United States and Europe. The following reviews literature and available case studies on secured funding in the relevant market segments in the most recent crisis.

4.1 Procyclicality

While initially secured funding might be perceived as making banks less subject to liquidity risk by reassuring a bank's creditors as to the bankruptcy remoteness of their funding, the theoretical literature identifies secured funding as creating procyclical leverage in banks and other financial institutions through distinct four channels. These procyclical channels include: (1) securities' valuation, (2) repo haircuts, (3) collateral velocity, and (4) changes in counterparty credit risk limits (due to changes in perceived counterparty creditworthiness) in an economic downturn.

Many theoretical papers have shown that secured funding transactions, such as repos, are subject to procyclical changes in the valuation of and haircuts on collateral. This strand of literature can be traced back to a paper by Geanakoplos (1997) which studies leverage, collateral and their impact on the financial system in a general equilibrium model. More recently, Brunnermeier and Pedersen (2009) show that, in crisis times, speculators that are subject to capital constraints will reduce their positions and market liquidity declines, which will then lead to higher haircuts (which are increasing in illiquidity) and a so-called liquidity spiral. In addition, Gai et al (2011) develop a model of an interbank network in which contagion arises from liquidity hoarding and changes in repo haircuts. Other papers on this topic include Jurek and Stafford (2010), Valderrama (2010), Rytchkov (2009), Geanakoplos (2010), Acharya et al (forthcoming), Heider and Hoerova (2009) and Biais et al (2012).

A number of papers also point out that collateral velocity is another procyclical factor that is relevant to firms' liquidity management. Singh and Aitken (2009, 2010) estimate that the size of collateral rehypothecation in the United States declined from $4.5 trillion at the end of 2007 to $2.1 trillion at the end of 2009, and that the churning factor of collateral (the extent to which the collateral has been

[4] As discussed by Sufi (2009) and Huang (2010), outflows can be limited due to covenants in the contract, which place certain restrictions on the borrower, eg based on cash flow or leverage restrictions, in order to use the line of credit.

reused) is around 4. Singh (2011) discusses the "velocity" of collateral (the frequency at which financial collateral is re-used) and its role in the financial market, and documents significant declines in both source collateral and collateral velocity after the collapse of Lehman Brothers. Poznar and Singh (2011) look at "collateral mining" (banks receive funding through the re-use of pledged collateral "mined" from asset managers) and "reverse maturity transformation" (long-term savings are invested by asset managers into short-term liquid assets). Singh and Stella (2012) show that the reduction in the pool of assets considered acceptable as collateral resulted in a liquidity shortage and argue that relevant regulatory proposals need to bring the velocity-like characteristics into scope.

Finally, recent FSB work (2012) also identifies changes in counterparty credit limits in response to changes in the perceived creditworthiness of financial institutions as a fourth possible procyclical factor affecting the stability of repo funding.

Several empirical papers have confirmed the procyclical effects for segments of the repo market. Adrian and Shin (2010) showed that repo transactions have accounted for most of the procyclical adjustment of the leverage of US investment banks, ie growth in repo liabilities explains most of the growth in leverage. Gorton and Metrick (2010, 2012) found that inter-dealer bilateral repo haircuts increased dramatically as the financial crisis unfolded.

4.2 Empirical findings of relevance for liquidity stress testing

According to FSB (2012), the global repo market can be split into two segments: (1) a repo-financing segment, consisting of both bilateral and tri-party transactions; and (2) an inter-dealer repo segment which consists of mostly centrally cleared transactions though also includes some bilateral transactions. In addition, (3) collateral swaps and (4) rehypothecation by prime brokers are aspects in the securities lending market that may also play important roles in the secured funding market and are therefore of relevance for liquidity stress testing.

The FSB survey also finds that the United States and the euro area have by far the largest repo markets in the world. Japan and Canada also have sizable repo markets. Separate estimates of the size of these different segments are available only in the United States where it is estimated that tri-party repo accounts for between 65% and 80% of the total US repo market. All of the empirical literature discussed is based on developments in the United States during the most recent crisis.

The empirical literature on the repo market generally agrees that repurchase agreements against more risky/less liquid types of collateral was a source of liquidity stress on the dealer banks during the crisis. The empirical literature also suggests that secured funding transactions against more safe/liquid assets – in the case of the United States, Treasuries, agency debentures and agency mortgage-backed securities (MBS) – generally remained in place even for institutions under stress. Based on limited data it appears that the withdrawal of prime brokerage fund balances was also a substantial source of outflows during the crisis. Duffie (2012) provides some helpful empirical context on the relative importance of repo haircut widening on liquidity losses to US banks following Lehman's failure. He shows that repo haircut widening resulted in a $4 billion loss to Morgan Stanley's liquidity pool over a two week timeframe around Lehman's failure relative to a $56.4 billion loss relating to prime brokerage outflows and $85.3 billion liquidity loss at Morgan Stanley overall. Unfortunately, a lack of research in these areas hampers our ability to draw meaningful conclusions about how best to address these business activities in designing and evaluating liquidity stress tests.

4.3 Repo financing – tri-party repo

The repo financing market segment was historically used by dealers to borrow from retail banks to finance their inventories, but there is currently increasing participation from retail banks on the borrowing side (mainly European commercial banks due to funding pressures) and corporates, funds

(non-leveraged asset managers, not including hedge funds) and insurers on the lending side. The market provides the cash lenders a safe way to invest and the cash borrowers a cheap and stable source of funding. Trades can either be on a bilateral or a tri-party basis.

In the tri-party repo market, a third party is responsible for the management of the collateral during the life of the transaction. Unlike central counterparties (CCPs), tri-party agents do not act as the counterparty to the parties involved in the trade. A tri-party agent provides a number of services including trade matching, collateral selection, settlement, collateral valuation, custody and reporting.

Based on US data, Copeland et al (2012) find that haircuts and funding changed dramatically in the bilateral repo market, but stayed fairly stable in the tri-party repo market, the largest segment of the US repo market, controlling for differences in types of collateral. For the largest asset classes in tri-party repo, the data indicate that haircuts on US Treasuries, agency debentures and agency MBS minimally moved during the crisis. Copeland et al (2012) also find using their roughly $2 trillion tri-party repo dataset during the crisis that offering Treasuries, agencies or agency MBS as collateral does not impact the haircut a dealer faces. With the notable exception of Lehman Brothers, the study finds that four other stressed dealers were able to maintain stable amounts of tri-party repo funding and haircuts even when hit with adverse events like the announcement of government assistance or poor earnings releases. In the case of Lehman, the authors find that haircuts faced by Lehman on low risk collateral were little changed. Overall haircuts barely moved until the week prior to failure and changes were largely driven by the deterioration in Lehman's tri-party repo book towards lower quality collateral. Lehman's volume of tri-party repo financing declined significantly but the authors note that causes for this decline in tri-party funding are unclear. Possible explanations include: a pull-back by tri-party repo investors, collateral calls unrelated to tri-party repo, a run-off in Lehman's prime brokerage accounts, a wind-down in Lehman's matched book repo, and/or asset sales. These findings suggest that inclusion of an assumption of a material disruption in a bank's tri-party repo funding against high quality collateral (government securities and agencies) in a liquidity stress test is a quite severe assumption.

Krishnamurthy et al (2012) use data from a large sub-set of tri-party repo investors, money market mutual funds and securities lenders, which is effectively a sub-set of Copeland et al (2012) though extends back further in time. This paper finds that financing was mostly stable in the tri-party repo market although it provides evidence of a sharp reduction in the amount of non-agency ABS and MBS financed.

4.4 Inter-dealer repo

The inter-dealer repo market segment includes mainly repo transactions between dealers. Transactions are either for funding purposes against general collateral, or to borrow specific securities against cash. The interdealer repo market is of key importance to the liquidity of the cash market.

In the United States, Europe and Japan, the inter-dealer repo market is typically cleared by central counterparties and transactions are generally at an overnight maturity against government securities, which in the United States includes agency debentures and agency MBS. A 2012 FSB survey finds that the inter-dealer repo market has almost replaced unsecured money markets as the marginal source and use of overnight funds for global banks.

Centrally cleared: Unfortunately, there is no empirical literature that examines the use of centrally cleared repo transactions as a source of funding during the crisis or to institutions experiencing stress. An advantage to central clearing is that trades are conducted on a blind basis and intermediated by a central counterparty. For example, the US Fixed Income Clearing Corporation (FICC)'s own announcements make clear that FICC continued to transact on behalf of Lehman in the days following its failure, suggesting that holding collateral eligible for centrally cleared repo services can help institutions facing very significant pressures on liquidity. In this regard, Copeland et al (2012) notes that some of the decline in Lehman's tri-party repo volume may have been funded through FICC's GCF repo service, for

which US Treasuries, agency debentures and agency MBS constitute eligible collateral. Nevertheless, absent additional data it is unclear whether CCP-intermediated repo constitutes a stable source of liquidity for banks experiencing liquidity stress against eligible, high quality collateral. With regards to stability of CCP haircuts against differing types of collateral, the FSB report (2012) indicates that in the euro area CCPs have increased haircuts significantly on the repo of government bonds issued by peripheral euro area sovereigns in response to widening yielding differentials in the secondary cash market.

Bilaterally cleared: With regards to the smaller bilateral inter-dealer market, Gorton and Metrick (2010, 2012) use data from one US broker-dealer to show that repo haircuts increased dramatically as the financial crisis unfolded, and that the increases in haircuts are correlated with proxies for counterparty risk and collateral quality. The authors argue that the recent financial crisis can be characterised as a "run on repo", ie short-term repo liabilities backed by "information insensitive" securities can be considered as safe and liquid instruments, but may be subject to "loss of confidence" and liquidity spirals as the collateral becomes "information sensitive" following a large enough economic shock.

4.5 Collateral swaps

Collateral swaps are a type of securities lending transaction that involves borrowing high-quality and liquid securities, such as gilts, in return for pledging relatively less liquid securities, such as RMBS. The bank may use the high-quality securities they have borrowed to raise cash in the repo market or as collateral for swap and derivative transactions. More recently, there has been increasing demand from banks to undertake collateral swaps to meet regulatory liquidity requirements (swapping risky assets for high-quality ones eligible for inclusion within the liquidity buffer).

As a form of secured funding subject to margining, collateral swaps could add to procyclicality in the funding markets (see Bank of England (2011)). The FSB report (2012) also notes that banks are increasingly pledging less liquid collateral to asset managers and other counterparties in exchange for high quality securities. More data about the volume and term of these arrangements would be helpful to understand the nature and scale of the underlying risks.

4.6 Rehypothecation by prime brokers

Prime brokers are typically large investment banks or securities firms that offer financing and securities lending services to their clients, most of which are hedge funds. When providing financing to the hedge fund, the prime broker usually obtains the cash by borrowing from other market participants, collateralised by the collateral posted by the hedge fund to the prime broker. This is possible as the prime brokerage agreement gives the prime broker the right to use the assets it holds on behalf of the client. Therefore the right to re-use clients' collateral is essential to the business model of prime brokerage, a practice known as rehypothecation.

In some circumstances, rehypothecation may also be used by the prime broker to fund its own business. If the prime broker becomes insolvent before the securities are returned, the client is treated as an unsecured creditor for the value of the rehypothecated securities in the prime broker's insolvency. The failure of Lehman Brothers International (Europe) (LBIE), the main Lehman Brothers UK subsidiary, highlighted the impact the failure of a major prime broker can have on clients' cash and non-cash assets. To the extent that a prime broker relies on rehypothecation to obtain funding, the impact of hedge fund withdrawals should be carefully considered in the firm's liquidity stress testing.

In addition, rehypothecation can also refer more broadly to the reuse of collateral (including collateral received in repo and securities lending transactions). A number of papers (discussed earlier in Section 4.1) point out that this is key to the liquidity management by firms and our understanding of the

financial system. However, it is still unclear how the decline in the velocity of collateral and the ability of firms to rehypothecate them should or can be explicitly incorporated in liquidity stress tests.

4.7 Evidence from institution interviews

The typical haircuts summarised in CGFS (2010) generally confirm the findings of the empirical literature; haircuts increase during stress periods. In addition, the increases differ substantially across asset classes, credit quality levels of both collateral and counterparty, and the term of the repo. G7 government bonds constitute the most stable collateral class, followed by US Agencies and Pfandbriefe. Corporate bonds rank third behind G7 government bonds and Agency debt/Pfandbriefe. Even high yield corporate bonds are more liquid than all securitisations but AAA-rated MBS. Their haircuts are roughly comparable to that of equity. However, as haircuts in liquidity stress tests do not only reflect changes in actual repo haircuts, but also adverse price movements in the stress scenario, it is important to put the equity haircuts in perspective. G7 equity indices dropped significantly over the period June 2007 to June 2009 (EURO STOXX 50 -46%, Dow Jones Industrial Average -38%), so that the liquidity generated by pledging, say, the EURO STOXX 50 index portfolio drops by more than 50% for non-prime counterparties, considerably more than the increase in haircuts from 12% to 20%.

ICMA (2012a) presents data on the total volume of the euro repo market from June 2001 and to December 2011 (gross figures, surveyed at the end of the business day). The market grew steadily from €1.9 trillion to reach a peak of €6.7 trillion before the onset of the crisis in mid-2007.[5] Over the following year, market volume decreased slightly to €6.5 trillion. After the Lehman failure the market experienced a sharp contraction by about 30% to €4.5 trillion (December 2008). In June 2010 volume reached a new peak (€6.9 trillion); after that it contracted sharply again (-15%) until December 2010. More recent data shows a slow recovery to €6.2 trillion (December 2011).

ICMA (2012b) argues that haircuts were uncommon in European repos before the crisis for interdealer repo, government bond repos, short-term repo and voice broker repo. Immediately after the onset of the crisis in August 2007 the first reaction consisted of shortening tenors, a jump to 100% haircuts for MBS and structured products, and a reduction of the size of repos with individual counterparties. For collateral that faced haircuts before the onset of the crisis, the haircuts roughly tripled under stress. Haircuts on the tri-partite repo market segment are reported to remain more stable during stress. After the Lehman failure haircuts became much more common.

5. Wholesale funding

The traditional (pre-financial crisis) literature on banking argues that an interbank market improves economic efficiency: banks can use it to insure each other against unexpected liquidity shocks, thereby to economise on liquid asset holdings and enable them to invest their funds into more profitable, but less liquid (long-term) investment projects (see Allen and Gale (2000), Holmström and Tirole (1998)). However, Bhattacharya and Gale (1987) and Huang and Ratnovski (2011) point out that there may be incentives for banks to over-rely on this type of insurance, so that underinvestment in the liquid asset occurs.

Another strand of literature notes that unsecured funding can play a role as disciplinary device; this argument is especially valid for short-term debt (Huberman and Repullo (2011)).

[5] This data is subject to double counting while the US tri-partite figures are not.

However, the experience of the financial crisis shows that the positive features of unsecured funding also has downsides. Unsecured funding can evaporate extremely quickly. This can happen because of borrower characteristics, but also because of general market developments. The following distinguishes between three different reasons for why a bank might not be able to tap unsecured wholesale funding in a crisis: borrower solvency problems, lender liquidity problems, and market freeze.

Borrower solvency problems: Allen and Gale (2000), Freixas and Holthausen (2005), and also Bruche and Suarez (2010) argue that a high level of counterparty risk would lead to high interbank interest rates for a particular bank. If these rates become too high to be sustainable, the bank would no longer be able to obtain loans, but be cut off from the interbank market. Taking into account the maturity structure of wholesale funding, Brunnermeiner and Oehmke (2013) argue that if solvency of a borrower is considered problematic, creditors have incentives to shorten the maturity of their loans (in order to be the first in line if counterparty risk becomes unsustainable).

Lender liquidity problems: In times of high market distress, the lenders' characteristics may also play a role in a reduction of wholesale funding: Eisenschmidt and Tapking (2009) model a lender's decision to provide interbank loans and show that lenders who face funding problems themselves or who wish to hold precautionary liquidity buffers may refrain from lending to other financial institutions.

Market freeze: Heider et al (2009) model adverse selection in the interbank market: potential lenders are uncertain about the credit quality of the potential borrowers. Here, the adverse selection problem could lead to break-down of interbank market activity, especially when either the average level of counterparty credit risk is very high, and/or when the degree of asymmetric information is particularly pronounced. In this case, even high quality borrowers may be unable to obtain wholesale funding. Allen et al (2009) also find that a high degree of volatility of money market interest rates, possibly due to a high uncertainty about aggregate liquidity needs of the banking sector, may lead to a breakdown of the interbank market. Both studies mentioned here find that a central bank has a role in providing liquidity to markets in order to increase efficiency, similar to Holmström and Tirole (1998).

Several empirical studies analyse the availability of wholesale funding during the recent financial crisis. Generally, it is found that the market did not entirely dry up, but rather that several features changed.

For the euro area, Angelini et al (2011) show that the maturity of interbank market loans significantly shortened. Volumes in the overnight segments remained roughly speaking constant over time, while longer-term loans significantly declined in volumes. Moreover, the authors find that borrower characteristics started playing a much larger role in the sense that they influence both the quantities as well as the interest rates of interbank market loans.

Similarly, Afonso et al (2010) find that also in the Fed Funds market in the US, the interbank market was not frozen, but that lower-quality borrowers now have to pay higher rates than borrowers of higher credit quality.

Regarding the UK, Acharya and Merrouche (2013) find that precautionary motive for hoarding liquidity seemed to have played a major role in money market freezes on the worst crisis days.

6. Intraday liquidity

The theoretical literature on payments suggests that a key driver of banks' payment decision is the trade-off between the cost of delay and the cost of borrowing reserves from the central bank (Bech and Garratt (2003)). The cost of delay provides banks with an incentive to make their payments earlier while the cost of borrowing gives banks an incentive to delay payments.

Delay has several private and social costs associated with it. First, time is money (even intraday) and hence delay of settlement may displease customers and counterparties, which are left with higher

costs and greater uncertainty. Second, delayed settlement increases operational risk insofar as the time span during which an incident may disrupt the settlement process increases and the time to recover after an incident decreases. Third, the process of delaying can be costly, and the resources devoted to managing intraday positions are a cost. Fourth, delay increases the length of time participants may be faced with credit risk exposures vis-à-vis each other (Bech (2008)).

On real-time gross settlement (RTGS) systems, the type of system currently used by most central banks,[6] a payment can only be settled if the sending bank has sufficient reserves in its reserve account, or the ability to borrow reserves. The lack of available reserves can be a reason for a bank to delay payments, as it can be costly to obtain additional reserves. For example, the central bank may charge a fee for the credit it provides, or it may require the borrowing bank to post collateral, which has a cost because the assets serving as collateral could be put to another use.

To summarise, when reserves are costly, banks have an incentive to delay payments because it allows them to free-ride on the reserves provided by other banks when they make payments. While an individual bank will weigh this benefit against the cost of delay, the system as a whole experiences no benefit from delay since it only redistributes reserves between banks. Hence, from the perspective of the system, there is excessive delay.

The excessive delays can contribute to systemic risk as they increase operational risk. Moreover, the incentives to delay payment are likely to become particularly strong during periods of high uncertainty or financial stress. Payment systems' participants are expected to be reluctant to send payments to any institution that is perceived to be unlikely to make its own payments, either because of operational difficulties or because it may default. But institutions that do not receive the payments they expect will have incentives to delay, propagating the problem further. Such situations can result in significant delays relative to a "normal" day and, potentially, to "gridlock" in the payment system (McAndrews and Potter (2002)).

6.1 Determinants of the liquidity of the system

Since the amount of available reserves influences the incentives to send payments promptly, it is important to consider the sources of reserves. In general, the level of overnight balances is determined by a combination of reserve requirements, the desire of banks to hold additional buffers of readily available funds, and the degree to which the central bank manages the supply of reserves day-to-day, for example to offset the reserves impact of so-called autonomous factors.[7]

When holding overnight balances at the central bank implies that banks must forego higher (risk adjusted) returns elsewhere, banks will tend to operate with only small buffers of reserves on top of the required minima. However, as uncertainty mounts, as it did during the financial crisis, banks may seek to expand their buffers of readily available funds. Moreover, as seen with the unconventional monetary policies enacted in several countries (or currency areas) during the crisis, central banks can

[6] See Bech and Hobijn (2007).

[7] The central bank is usually the banker of the government and the payments activity of the public sector vis-à-vis the private sector is typically the most prominent of the autonomous factors. Another important autonomous factor is credit extensions arising from the central banks role as lender of last resort.

impose additional reserve holdings on the banking systems by buying assets, such as government bonds, from the private sector (see Keister and McAndrews (2009)).[8]

In contrast, intraday credit extensions or daylight overdrafts are, in general, used to accommodate residual demand for funds for payments purposes. As is the case with most central banks, the Federal Reserve provides intraday overdrafts to banks at no fee against collateral. The Fed also provides intraday overdrafts on an uncollateralised basis at a fee.

The stock of funds available from the settlement institution (typically the central bank) is not the entire picture in terms of settlement liquidity. One way to classify the different sources of funds for settlement is inside and outside liquidity where the former represents liquidity generated within the system itself and the latter represents funds supplied from the outside. Inside liquidity is determined by the speed by which the settlement asset (ie reserves) is being circulated by participants as well as the degree to which credit is extended among participants. In other words, for an individual institution there are, in addition to overnight balances and intraday credit, two other sources of funds in an RTGS system: interbank loans and incoming payments from other banks (see McAndrews and Rajan (2000) for a discussion of the funding sources for Fedwire transfers). These two sources do not add reserves to the system but rather serve to redistribute them among participants. Consequently, the liquidity of a payment system depends importantly on the actions of participants. For example, strategic payment delays, as discussed above, can reduce the liquidity and thus the efficiency of a system.

The monetary policy implementation framework used by most central banks before the crisis relied on excess reserves having an opportunity cost (see Keister et al (2008)). This provides a strong incentive for banks to economise on such reserves. With few overnight reserves available, daylight overdrafts are the main source of reserves for the system as a whole. Since the crisis, however, many central banks have increased the amount of excess reserves considerably. Since these central banks pay interest on these reserves, the opportunity cost of reserves has declined. This has led to a dramatic reduction in daylight overdrafts and earlier settlement of payments in a number of systems (Bech et al (2012)).[9]

6.2 Liquidity-saving mechanisms

Several RTGS systems use liquidity-saving mechanisms (LSMs) to reduce the incentives to delay. Liquidity saving mechanisms match payment instructions bilaterally or multilaterally and settle these instructions simultaneously, reducing the need for reserves. A key role played by LSMs is to allow payment systems participants to make sure that payments are released only when an offsetting payment is received (Martin and McAndrews (2008)).

A simplified description of an LSM's operation is as follows. A bank wishes to make a payment and has a choice of when to submit it to the payments system. Upon submitting the payment, the bank has a second choice to make: It can either submit the payment to a central queue (the LSM part of the payments system), or attempt to settle the payment at the time of submission (the RTGS part of the payments system). If the bank submits the payment to the LSM channel, that payment will settle only

[8] Reserves are commonly classified into required and excess reserves where the latter is simply any reserves in excess of the former. A further distinction can be made as to whether reserve holdings beyond a certain level of excess reserves no longer serve a precautionary demand, but, instead their demand is based solely on the remuneration they receive.

[9] It is important to observe that as most central banks guarantee the finality of payments transferred across RTGS systems (once a payment is made it is not possible to claw back the amount) an increase in intraday credit extensions adds to these central banks' credit risk exposure. Hence, the decrease in intraday credit that has accompanied the increase in reserves has reduced central bank risk.

when certain conditions have been met. If the bank attempts to settle via the RTGS channel and it has sufficient funds available, the payment will settle immediately. One condition that might trigger the settlement of a payment (and is common to LSMs) occurs when the request in the LSM channel is made in the presence of an offsetting payment in the queue of the bank to which the payment is to be made. If the two payments offset, then both can be released by the LSM.

By economising on liquidity, LSMs reduce the incentive to delay and can lead to a more efficient payment system. This is likely to be particularly important in times of high uncertainty and financial stress. Indeed, the concern, noted above, that participants would be reluctant to send payments to an institution that is perceived to be unlikely to make its own payments is reduced by the fact that a payment to that institution would not be settled unless an offsetting payment is received.

LSMs could reduce stress in the payment system when central banks operate with a small amount of overnight reserves and must extend large quantities of intraday credit. However, this method of implementing monetary policy, even when an LSM is available, would not do as much to reduce stress as a system with a large quantity of reserves. Indeed, the latter system, by eliminating the opportunity cost of reserves, essentially eliminates the incentive to delay and the risk of gridlock.

7. Counterbalancing capacity

Starting with Fisher (1933), the literature has identified strong links between asset sales and banks' health. The basic idea is that given a liquidity or solvency shock, banks start to sell assets, excess supply in the asset market lowers asset prices, falling asset prices, in turn; imply further asset sales to meet liquidity needs and so on.

Cifuentes et al (2005) suggest that liquidity buffer requirements may be more effective than capital buffers in forestalling systemic crises. During periods of major financial distress, even a large capital buffer may be insufficient to prevent contagion as assets can only be sold at a discount. Requirements to maintain a stock of liquid assets can internalise some of the negative externalities that are generated by the price impact of selling less liquid assets.

Wagner (2008a,b) explores the implication of a lack of market liquidity in times of stress. On the one hand, a lack of market liquidity implies that asset sales to meet liquidity demands lower asset prices even further, which can lead to the failure of other institutions. On the other hand, low market liquidity increases the cost of failure for individual firms, the more so, the larger the number of banks that fail. Hence, a bank's returns, as well as the negative externalities arising when it fails, will depend on the entire return distribution of other banks' portfolios. An optimal regulatory regime would have banks which are more correlated with each other face higher capital and/or liquidity requirements.

Shim and von Peter (2007) provide a helpful survey of the literature on asset market feedbacks and distressed selling. The authors note that distress selling can be triggered by either a liquidity or solvency shock which requires the bank to dispose of assets it had not otherwise planned to in order to meet its financial commitments. Distress selling occurs when the asset disposal would constitute excess supply at the current price, ie the demand curve for the asset is downward sloping. Thus, Shim and von Peter note that the liquidity characteristics of an asset are key from the perspective of identifying assets which are less likely to experience distress selling.[10] Additionally, Shim and von Peter cite other research

[10] This is relevant as the Basel liquidity standard uses risk weights as the primary criteria for determining buffer eligible assets. While there is generally an inverse relationship between the credit risk of an instrument and its liquidity within an asset class,

suggesting that the number of firms and diversity of types of firms which participate in the market for an asset are relevant in determining whether an asset will trade near its fundamental value.

Bolton et al (2011) develop a model in which they show that under asymmetric information banks face an immediate incentive to sell assets to obtain liquidity and, under some states of the world, incentives both to sell assets immediately and to try to ride out the crisis and only sell assets as a last resort. An important insight from the paper is that when banks hold assets which are complex, adverse selection or a "lemons' discount" problem arises. On the one hand, banks would prefer to wait to liquidate assets until they are certain they have a persistent funding need so as to avoid liquidating at a discount. On the other hand, waiting to liquidate assets causes potential investors in those assets to perceive an adverse selection problem which increases the discount if in fact the bank requires liquidity. Thus, an insight is that the difficulty of the risk assessment and valuation process for a given asset plays a significant role in the size of a discount faced by banks trying to liquidate assets in a liquidity crisis.

8. Securities lending

This section focuses on the securities lending side of the chain of transactions that is related to securities lending: the institution that holds securities lends them to a party that wants to short-sell it or needs to settle another securities transaction. If the security lender requires cash collateral for the transaction, he would then invest this cash in another collateralised transaction (eg tri-partite repo market). If non-cash collateral is required, it might be re-used in further security lending or repo transactions. There are a number of purposes of securities lending, such as borrowing the security to sell it short or to cover a security delivery obligation.

Securities lending contracted sharply in Europe after the Lehman failure, dropping from 21.7% of total business on repo desks to 12.5% from June to December 2008 (ICMA (2009)). Given that total business contracted from €6.5 trillion to €4.6 trillion, securities lending contracted by about 60% within six months.

Banks, when acting as agent lenders in the securities lending market, typically provide indemnification to their clients (ie beneficial owners of the securities) against borrower default.[11] That is, when the securities borrower defaults, the agent lender is obliged to compensate the difference between the value of the securities lent and the liquidation proceeds of the collateral. Such off-balance sheet obligations may negatively impact the bank's liquidity condition, especially in crisis times. During the recent crisis, the amount of indemnification provided by agent lenders was relatively small, because the collateral was sufficient to cover the losses in most cases. However, given its increasing popularity in the market, indemnification should still be considered in liquidity stress tests of banks with large-scale agent lending activities.

across markets and across asset classes, it is noteworthy that the credit quality of an instrument is not equivalent to its liquidity.

[11] See FSB (2012) for a description of the securities lending market practices.

9. Money market funds

Based on the various reports on the impact of the crisis on EU money market funds (MMFs) Ansidei et al (2012) conjecture that more informed, professional investors are more likely to pull out of MMFs earlier during the financial crisis: Between 9 and 23 September 2008 institutional investors decreased their investments in prime MMFs from $1,330 billion to $948 billion (about 30% in two weeks) shifting funds primarily to Treasury MMFs (ICI (2012)), while retail investors reduced theirs by only $28 billion to $727 billion (about 4%). MMFs reduced their exposure and also shortened their maturity profile substantially. The following disruption of the funding markets motivated the Federal Reserve to provide two emergence liquidity facilities for MMFs and the US Treasury to provide a guarantee program for participating MMFs. No claims were made against the guarantee and the US Treasury received a fee income of $1.2 billion (ICI (2012)). In Europe enhanced MMFs (ie more risky MMFs) were at the centre of the crisis; first in Q3 2007 and again in Q4 2008. Some of the funds suspended redemptions and/or received sponsor support from banks, but the authorities do not intervene directly.

The large share of external assets of MMFs constituted a channel of interaction across financial systems. Ansidei et al (2012) present Fitch data covering a sample of US prime MMFs holding total assets about €600 billion (about 45% of the total market of prime MMFs of €1.5 trillion). In May 2011 their exposure to European banks amounts to 51.5% of total assets (CD 28.3%, CP 10.7%, repo 9.4%). Within only six months aggregate exposure decreased by 40% and that to French banks dropped from 15.1% of US MMF total assets to just 1.1%.

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