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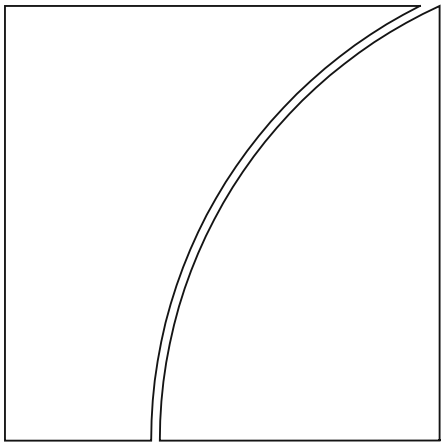

Liquidity stress testing: a survey of theory, empirics and current industry and supervisory practices

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List of abbreviations

ABCP	Asset-backed commercial paper
BCBS	Basel Committee on Banking Supervision
CCP	Central counterparty
CFP	Contingency Funding Plan
DVA	Debit Valuation Adjustment
ERMS	Enterprise risk management solution
FSAP	Financial Stability Assessment Program
FTP	Funds Transfer Pricing
GCF	General Collateral Finance
GFSR	Global Financial Stability Report
ISDA	International Swaps and Derivatives Association
LCR	Liquidity Coverage Ratio
MBS	Mortgage-backed security
MMF	Money market fund
Nibor	Norwegian Interbank Offered Rate
NSFR	Net Stable Funding Ratio
PFLOAT	Puttable Floating Option Tax Exempt Receipts
QIS	Quantitative Impact Study
RAMSI	Risk Assessment Model for Systemic Institutions
RMBS	Residential mortgage-backed securities
SPV	Special purpose vehicle

Liquidity stress testing: a survey of theory, empirics and current industry and supervisory practices

1. Introduction[1]

Stress testing is an important tool in developing a complete picture of an institution's liquidity risk profile. What constitutes a good stress test is, however, not universally clear. Practices still differ widely, not only in the supervisory community but also in the banking industry. The Workgroup on Liquidity Stress Testing of the Basel Committee's Research Task Force (RTF-LST) was mandated to draft a survey on current practices, identify gaps and – where possible – suggest ways forward.

The present discussion on liquidity focuses on the Liquidity Coverage Ratio (LCR) and, to a lesser extent, the Net Stable Funding Ratio (NSFR). The exact parameterisation of these measures has not been the Workgroup's prime concern. Rather, the group's focus has been to explore the potential usefulness and construction of more generalised measures of liquidity adequacy produced using stress-testing techniques. The group is explicitly not proposing to change any of the assumptions regarding inflows and outflows in the LCR.

Key messages

- Adequately designed and properly implemented liquidity stress tests can generate valuable information on a bank's liquidity profile that cannot be generated from a limited set of standardised liquidity metrics. An example of the added value of stress testing beyond reliance on a single metric can be found in the LCR's 30-day horizon, which does not preclude intra-30-day timing mismatches. In a stress test, shorter and longer horizons can be explored to assess whether a bank's outcomes are sensitive to this issue. The Workgroup has also identified other aspects relevant to a bank's liquidity that can have a material impact. These include the level of consolidation, the currency composition of exposures, and the buffer's composition.
- Among jurisdictions participating in the Workgroup, regulators differ in their conduct of liquidity stress testing. The Workgroup believes, however, that supervisors have a critical role to play in conducting system-wide liquidity stress tests as banks generally lack the data needed to calibrate a liquidity stress test and they often employ diverse assumptions and scenarios that can make it difficult for supervisors to assess the relative liquidity risk of different institutions. Banks also tend to develop stress tests that do not account for second-round or systemic effects, ie such tests assume that the bank's actions have no impact on the market and that there are no other banks seeking to undertake similar actions.
- While horizontal liquidity stress tests (ie a stress test for several banks using a common set of approaches, scenarios and assumptions) are desirable, a clear best practice for supervisors has yet to emerge. Based on its work to date, the Workgroup offers some observations for regulators to bear in mind in developing their own national liquidity stress tests. The Workgroup recommends that authorities apply both bottom-up and top-down approaches in

[1] Drafted by van Lelyveld (Netherlands Bank) with input from all Workgroup members. A special thanks to Kupiec (Federal Deposit Insurance Corporation), who provided detailed comments on all chapters.

conducting such horizontals to capture second-round and systemic effects. Furthermore, if applicable, authorities could consider evaluating (i) a bank's liquidity position on a currency-by-currency basis for those currencies in which it is most active; (ii) whether banks' interactions with elements of the shadow banking system (repo, secured funding, money market funds (MMFs)) that have no explicit lender of last resort should receive attention in authorities' stress testing; and (iii) banks' group structure (ie legal entities subject to different regulatory regimes vs consolidated).

- The Workgroup finds arguments both in favour and against factoring in the lender-of-last-resort function to supervisors' liquidity stress tests. On balance, the Workgroup concludes that liquidity stress-testing assumptions should limit assumptions regarding the central banks' support for the financial system in a crisis. Furthermore, there are practical questions about whether central bank lending, which requires collateral and thus subordinates a bank's unsecured creditors, might accelerate the run-off of a stressed bank's funding. Finally, as documented in one case study, institutions can run out of unencumbered central bank eligible collateral, thereby precluding official sector lending. All of these points argue for limiting the role of central bank monetary policy operations in designing liquidity stress tests. To assume more expansive central bank support in official stress tests runs the risk of encouraging excessive private sector risk-taking and overreliance on central bank liquidity.
- Liquidity and solvency risks are often interlinked but frequently treated separately in (supervisory) stress tests. For example, a capital stress test might only consider credit losses on a bank's securities holdings. A more integrated exercise might recognise that the bank could also incur capital losses from the liquidation of securities necessitated by wholesale funding run-off as the market observed the bank experiencing credit stress. Akin to assessing the liquidity of firms on a consolidated basis (ignoring possible regulatory or cross-border impediments to the transfer of liquidity within a firm), this separate treatment of capital and liquidity understates bank risk. The Workgroup recommends that this topic should be a focus of future (applied) work.
- While the Workgroup was encouraged that vendor models for evaluating liquidity risk generally appear able to support a more refined view of liquidity by currency, legal entity and jurisdiction, the current simple cash flow maturity approaches appear to have some limits in their usefulness. For example, the models of the vendors the Workgroup met with all lacked second-round or systemic effects. These models also focused on horizons similar to the LCR and ignored interactions between liquidity and solvency risk.
- The Workgroup believes it would be desirable to set clearer supervisory expectations regarding the integration of liquidity stress-testing results into banks' business practices. Even the best designed, most robust stress test will have no impact if its results are not used to set risk limits and inform the bank's operations.

Reading guide

The survey has been written with the broader supervisory community in mind. The Workgroup believes this would include a wide range of functions: for example, microprudential line supervisors, staff of supervisory institutions involved with liquidity stress tests, macroprudential regulators and supervisors. Many of the findings are, however, also relevant for risk managers in banks, given their role in measuring their institution's liquidity risk profile and enforcing risk limits. The key messages could also be helpful in future efforts to develop more guidance with regard to liquidity stress testing.

Each of the chapters in this survey could be of particular use to a specific segment of the intended audience. First, the overview of the academic literature and, in particular, the collection of case studies, can help to improve the design of stress tests. In addition, the examples of institutions

that experienced liquidity stress could aid line supervisors in challenging some firms' overly benign modelling assumptions. Second, the overview of the state of play in authorities' modelling efforts for liquidity stress tests could be helpful for those authorities that are looking to develop horizontal stress-testing methods for institutions in their jurisdiction. Third, the description of the capabilities of vendors' solutions and firms' modelling strategies might be helpful for line supervisors in assessing the efforts of their particular institution. Finally, the discussion of – adverse – external effects is important in the discussion of the interaction between a micro- and a macroprudential view on liquidity. The rest of the report is structured as follows.

Chapter 2 – Case studies

To outline what kind of scenarios are possible, we first discuss a wide range of case studies. These range from cases with a relatively local impact (eg Northern Rock) to firm defaults that had a global impact (eg Lehman Brothers). All in all, nine cases of individual bank failure or near-failure are discussed. We also discuss a number of country studies on the basis that it is sometimes useful to consider the experience of all institutions involved, rather than that of just a single institution.

Studying cases across the globe is helpful because individual cases of stressed or defaulted institutes represent too limited a sample. Obviously, the discussion of the literature review will touch on very similar experiences. The reader could see the separate outflow and counterbalancing capacity sections in the next chapter as elaborations on themes that come to the fore in the cases.

Chapter 3 – Literature review

The literature review seeks to provide an overview of the relevant literature although, in some areas, the coverage is patchy given the limited set of papers available. The structure of the chapter follows a widely used classification in outflow categories on the one hand and the counterbalancing capacity on the other. For each category, contributors have written more extensive literature reviews as collected in a standalone appendix. These reviews have consequently been condensed to make the chapter as accessible as possible. Although this has been done at the expense of strict academic rigour – as not each and every individual claim is referenced separately – the appendix provides a more in-depth discussion; there claims are attributed to the supporting source.

Chapter 4 – Authorities' approaches

In Chapter 4, the approaches taken by central banks and supervisors are described. They range from small parsimonious models to highly complex full-system models – whether particular models are useful in any particular jurisdictions depends on the available data and resources.

Chapter 5 – Banks and vendors

Based on available information in central banks and supervisors, Chapter 5 describes the state of play for liquidity stress testing in banks. In addition, a selection of leading vendors of balance sheet/liquidity risk models was contacted. Our motivation was that these vendors would be well placed to assess the technical capabilities of banks to compute stress-test exercises

Chapter 6 – Other considerations

Finally, a number of considerations have merited a separate discussion in Chapter 6 (the non-bank financial sector, the interaction between solvency and liquidity, and the role of the central bank etc).

Obviously, some aspects of these considerations have already come to the fore in earlier chapters. The common theme is that the mechanisms discussed would lead to a drain of liquidity from the banking system whereas in earlier discussions the focus was more on the transfer of liquidity within the banking system.

2. A set of global case studies[2]

2.1 Overview

2.1.1 Purpose of the case studies

One goal of the RTF's work on liquidity stress testing is to review and summarise the experiences of large institutions or banking sectors that have experienced severe liquidity stress. The aim is to gain a better understanding of the key drivers of liquidity stress and to identify issues that are important for sound liquidity stress-testing design. These case studies generate a number of insights that can be used to better evaluate banks' own internal liquidity stress tests or applied by supervisors in crafting horizontal liquidity stress tests. Such horizontal liquidity stress tests are a critical complement to quantitative liquidity standards as they require the evaluation of a broader range of scenarios and can be tailored to assess emerging risks.

2.1.2 Scope of case studies

The individual institutions covered in the case study review include: Dexia, Fortis, Hypo Real Estate Bank, Kaupthing Sverige AB (the Swedish subsidiary of an Icelandic bank), Icelandic banks' operations in Norway, the German Landesbanks, Lehman Brothers, Morgan Stanley, Northern Rock, RBS, Wachovia, and Washington Mutual. These cases include failed or near-failed European and US institutions from the 2007–09 financial crisis and span commercial, investment, specialty and universal banks.

In addition to individual institution case studies, this paper summarises case study papers that described sources of liquidity stress and lessons learned at the level of a national banking system. These papers addressed developments in the Brazilian, Japanese, Korean and Norwegian banking systems and, in most national banking system cases, also discuss liquidity crises that occurred as part of earlier financial crises.[3] As such, they are informative beyond just the last crisis.

It should be noted that all these case studies describe systemic stress events. This is due to the difficulty in identifying banks which experienced idiosyncratic liquidity stress. Unfortunately, there seems to be no literature on whether liquidity stresses are predominantly idiosyncratic or systemic – a topic for further research. Cases of idiosyncratic liquidity stress would be welcome additions to this work.

To prepare these case studies, Workgroup members drew on the growing body of publicly available data about these institutions' stress experiences that have arisen from legislative and/or legal inquiries into the circumstances surrounding these institutions' failure or near-failure. Some of the case study write-ups, however, are based on non-public supervisory data.

[2] Drafted by Cetina (Office of the Comptroller of the Currency) with input from Emmel (Board of Governors of the Federal Reserve System) and Nebhut (Office of the Comptroller of the Currency) based on case studies drafted by Alsadoun (Bank for International Settlements), Aronsen (Central Bank of Norway), Cetina (Office of the Comptroller of the Currency), Eliasson (Sveriges Riksbank), Emmel (Board of Governors of the Federal Reserve System), Guerra (Central Bank of Brazil), Ishizaki (Bank of Japan), Kim (Bank of Korea), Krebs (German Federal Financial Supervision Authority), Liu (UK Prudential Regulation Authority), Martin (Bank of France), Nguyen (National Bank of Belgium), Pausch (Deutsche Bundesbank), Pogach (Federal Deposit Insurance Corporation), Schmieder (Bank for International Settlements) and van Lelyveld (Netherlands Bank).

[3] The Brazilian case study contains an interesting discussion regarding the role of the deposit insurance and central bank policy actions during Brazil's period of macroeconomic stabilisation following hyper-inflation. There is insufficient data, however, to study problems related to liquidity sources.

2.1.3 Summary of case study findings

The case studies highlight many important sources of potential funding stress for banks. These include:

- loan pipeline back-ups;
- collateralisation of intraday credit and other exposures of payment and settlement banks to the stressed firm;
- uninsured deposits;
- liquidity commitments to ABCP conduits;
- prime brokerage balances;
- wholesale funding; and
- derivatives and foreign currency funding.

Each of these sources of funding stress will be discussed in more detail in Section 2.2.

With regard to banks' liquidity buffers and counterbalancing capacity, the case studies suggest six points of interest:

- Pre-crisis buffers were too small (as opposed to buffer assets being illiquid).
- Foreign currency securities issued by domestic entities may carry additional risks when held as a liquidity buffer.
- Counterparty arrangements can make unencumbered assets effectively unavailable to meet a bank's unexpected funding shortfalls.
- Transparent pricing must exist for buffer assets.
- Several stressed banks were able to obtain liquidity using repo eligible assets with a central counterparty (CCP).
- Banks often have to repay borrowings during a liquidity stress, but lending to non-banks tends to be rolled over (eg banks cannot count on maturing loans as a source of cash inflow).

Each of these findings will be discussed in more detail in Section 2.3.

Finally, the case studies also highlighted other considerations relevant to liquidity stress testing.

- Several case studies suggest that the transfer of liquidity among different legal entities within a firm cannot be assumed.
- Run-off rates for the liabilities of different legal entities within the same firm are very different. Rating agency commentary since the 2007–09 financial crisis has likely reinforced differences in run-off rates for banks in some countries.
- An investment-grade rating may not be sufficient to prevent firms from experiencing a liquidity shock.
- Superficially, the case studies suggest that contagion and network effects are a relevant consideration for liquidity stress testing.
- Several firms' assumptions and data used in liquidity stress testing were clearly inadequate in hindsight and the lack of integration of stress-test results into these firms' operating decisions was also a material source of their weakness.

Each of these points will be discussed in more detail in Section 2.4.

2.2 Sources and quantities of liquidity stress

2.2.1 Loan pipeline backups

Securitisation pipelines for residential mortgage and leveraged loans were a material source of liquidity risk. As credit markets froze, the backup in four banks' loan warehousing activities adversely affected both the capital adequacy and liquidity of these firms. Management generally did not consider the risk that they might be unable to distribute these assets and consequently did not have contingency plans for carrying them on the balance sheet in time of stress. Pipeline liquidity risks are correlated with deterioration in the credit quality of a bank's loan portfolio.

Banks' inability to execute planned sales of loans forced them to hold assets on balance sheet at a time when they already faced funding pressures and ideally would have liked to deleverage. Generally, this need to fund assets forced banks to increase their reliance on wholesale funding markets. Over-reliance on wholesale funding for several of the case studies was not the root problem; it is better understood as a symptom of lending pipeline issues.

Banks may have difficulties shutting down their mortgage pipelines. Agreements to extend funds on a mortgage can go out 90 days and sometimes even further, constraining firms' ability to reduce lending quickly. The use of third-party brokers as originators was another complicating factor in managing down loan pipelines as control was less centralised. Finally, several banks perceived that any cutback in originations would be interpreted by the market as signalling that they were in a distressed situation and, thus, would exacerbate funding pressures.

Banks' leveraged loan pipelines and loans to lower-credit quality borrowers should receive higher drawdown rates in liquidity stress tests. With regard to leveraged loans, evidence from two case studies suggests that banks' willingness to enter into "covenant-lite" deals increased both the credit and liquidity risks of these firms.[4] Competition was sufficiently intense that some institutions abandoned up-front syndications – leaving the lead bank with the risk of finding others willing to help fund loans to high-yield borrowers. One case study shows that the liquidity drains from the bank's leveraged loan pipeline and draws on its ABCP liquidity commitments were of comparable large magnitudes.

2.2.2 Collateralisation of intraday credit and other clearing bank funding

Unsecured intraday exposures arising from a financial institution's use of clearing and settlement services can contribute significantly to funding stress. Two US institutions' clearing and settlement banks sought collateral pledges and cash deposits to effectively secure their intraday credit risk.

Clearing and settlement banks may use their unique relationship to obtain security on their other exposures to a stressed bank. Some of the clearing and settlement banks of one of the institutions also sought to secure other exposures to the firm unrelated to clearing and settlement services. That is, they aimed to fully collateralise their derivative and other exposures while negotiating the firm's continued access to daylight overdraft facilities. None of those demands had been contemplated as part of the firm's internal liquidity stress test, but are estimated to have amounted to roughly one third of the firm's reported liquidity buffer.

"Deposit requests" were also a material source of outflow during the crisis. For the institutions in question, these "deposit requests" were effectively a veiled demand for the firm to post

[4] Some commentators have observed that the annualised rates of covenant-lite loan issuance in Q4 2012 in some countries are comparable to highs from 2007 (see Stein (2013)).

assets to its clearing bank sufficient to cover its use of intraday credit. By requesting deposits, the request did not appear to impose any additional encumbrances on the firm's collateral and yet these deposit requests clearly reduced the firm's liquidity position. The firms who made these deposit requests maintained that the assets were available to withdraw at any time, even though to have done so would have affected their ability to conduct normal operations. In the case of one institution, "deposit requests" necessitated the transfer of $20 billion in cash in a single week, about one third of its liquidity buffer. These "deposit requests" extended beyond the firm's use of intraday credit and also included requests for the firm to effectively deposit cash to collateralise derivatives payable, securities lending, securities borrowed, and other unsecured positions with its clearing and settlement banks.

Collateral demands from clearing and settlement arrangements can drain a bank's buffer assets. Documentation from one of a firm's clearing banks indicates that during the fall of 2008 this clearing bank sought additional collateral, as well as broader guarantees and pledge agreements, from other investment banks too. This suggests that liquidity stress related to the use of clearing and settlement services during the recent crisis was not unique to these two US firms and, in fact, was quite broadly based. It is also noteworthy that the clearing and settlement banks making these collateral demands included firms domiciled not just in the United States but also in Europe and Asia.

2.2.3 Deposit run-off

For commercial banks, deposit run-off was an important source of funding stress. Unsurprisingly, the insurance status of deposits was critical to deposit run-off rates. The LCR assumes that the deposit insurance status and "operational" versus "non-operational" classification are important determinants of deposit run-off rates.

In the two cases of US commercial banks, deposit outflows, largely driven by uninsured deposits, were one of the top drivers of liquidity stress. Institutions' definitions of "core" deposits proved to have little bearing on actual deposit run-off. In the case of one of these institutions, insured deposit run-off remained consistent with historical trends during non-stress periods, while sweep accounts experienced run-off and premature redemptions of certificates of deposit occurred in amounts greater than anticipated by the firm. The latter indicates that term funding can be unstable absent material penalties for early withdrawal.

The US case studies show substantial deposit run-off, but still materially less than assumed under the LCR, even inclusive of recently agreed recalibrations. The two US depository institutions averaged 9% one-month deposit run-off during their respective peak stresses. This compares with an aggregate deposit related outflow assumed under the LCR as a percentage of total deposits for the median US QIS reporting bank of 24%.[5]

The case studies provide additional evidence for the importance of deposit insurance and guarantees in determining run-off rates. In the case of one European institution, a foreign government's decision to fully backstop the deposits of its domestic banks but not those of foreign banking organisations was a significant source of liquidity pressure on the parent bank. In the case of another European bank, the domestic co-insurance scheme proved destabilising for the bank's retail deposit base. Non-traditional retail deposits, such as postal accounts, offshore, telephone and internet deposits, all fell sharply, particularly following the announcement of official sector support. In contrast, another European institution experienced deposit run-off that varied little for operations in different jurisdictions despite somewhat different national deposit guarantee regimes.

[5] This calculation aggregates deposit-related outflows under the LCR assumed run-off rates across all deposit categories and compares those assumed one-month outflows to each QIS reporting banks' total deposits. It is inclusive of changes made to the LCR in January 2013 (see BCBS (2013)).

Government injections of bank capital may not attenuate depositor runs. In the weeks following Lehman's failure, government injections of capital into one European institution caused deposit outflows to accelerate rather than attenuate, amounting to €36 billion over four days as uncertainty around the fate of the institution was high.

Foreign subsidiary operations may experience runs even when they are well capitalised. Finally, two European bank case studies illustrate that a subsidiary of a foreign bank operating in a host country can experience severe deposit run-off as a result of the parent institution's stress even when the subsidiary itself seems well capitalised. Assuming that all public and corporate deposits were uninsured and deposit run-off was proportional on a monthly basis over the first quarter of 2008, data for one of these institutions suggest a monthly run-off of uninsured deposits of roughly 23%.

2.2.4 The role of off-balance sheet commitments in liquidity stress

The evidence regarding lending commitments is mixed. The case studies suggest substantial variation with regard to whether commitments were a material source of liquidity stress to banks, the key differentiator being the type of commitment. Liquidity stress tests should thus differentiate on this point. The LCR assumes drawdown rates for credit (and liquidity) commitments of 10% (30%) for non-financial institutions, 40% (40%) for supervised banks, and 40% (100%) for other non-bank financial institutions.

Commitments to corporate borrowers do not appear to have been a material source of stress. One US commercial bank case study suggests that increases in line utilisation were largely the result of a reduction in the commitment amount as opposed to drawdowns. Data from one US investment bank case study also indicate that loan commitment drawdowns were one of the smallest sources of liquidity stress during the peak of the 2007–09 financial crisis.

Commitments to ABCP conduits and other capital market instruments, by contrast, materially affected banks' liquidity positions. One European bank, for example, was active in issuing Puttable Floating Options Tax-Exempt Receipts (PFLOATs).[6] The volume of PFLOATs put back to the bank experienced a significant surge upward starting in October 2008 (due to the combination of an increase in municipal bond spreads and negative news about the firm). Similarly, many investors exercised put options on municipal variable rate demand notes amid the financial crisis. Consequently, one US commercial bank saw its inventory of municipal variable rate demand notes and tender option bonds increase from $1 billion to $9 billion during this period.

It is difficult to know the size of conduit commitments, but the variety and volume of conduit exposures was considerable. A US commercial bank's commitments to its conduit materialised precisely at the peak stress of that institution, forcing the bank to fund $635 million of commercial paper on an overnight basis. Several European institutions' provision of liquidity commitments to ABCP conduits were also material sources of liquidity stress and, in some cases, materialised in a foreign currency. Some tentative estimates from one of the case studies suggest that for one European bank

[6] The bank purchased mostly fixed-rate, tax-exempt US municipal bonds and sold them to an SPV, which, in turn, issued tax-exempt paper to finance the bond purchase. A liquidity facility (provided to the SPV by the bank) allowed the PFLOAT investor to tender the PFLOAT at par plus accrued interest with five business days' notice. This liquidity facility was provided to allow investors with regulatory constraints on investing in long-term securities to buy the PFLOAT. The liquidity facility took the form of a standby bond purchase agreement where the bank guaranteed the liquidity.

these lines amounted to at least £65 billion of which £10 billion was drawn.[7] Another European institution faced a material funding gap as a result of its need to fund €20 billion for its ABCP conduits.

2.2.5 Prime brokerage

The run-off in prime brokerage balances was the single largest factor adversely impacting one firm's liquidity position. Prime brokerage arrangements arise between large dealer banks and hedge fund clients. Hedge fund clients borrow from their prime broker against the collateral held at the broker. Long positions are financed with the underlying securities purchased, less a margin, while the broker uses the cash from a short sale to fund a securities borrowing transaction to cover the short position. Both short positions and net free credit in clients' accounts give rise to customer payables at dealer banks. Data from one of the US investment banks showed that the run-off in prime brokerage balances was the single largest factor adversely impacting the firm's liquidity position. For the firm in question, prime brokerage run-off amounted to $46.7 billion during the two-week period at the height of the 2007–09 financial crisis.

As customers took payables away from prime brokerage firms, the "lock up" did not unwind quickly enough reduce liquidity risk. Depending on national laws, customer payables are to be offset by a "lock up" of an equivalent amount of cash that is in place to protect brokerage customers should the firm fail. Customer withdrawals should have resulted in the release of this "locked-up" cash, thereby offsetting or at least reducing liquidity risk. As customers delivered and moved business away from the prime broker, locked up funds were released, but not in a timely manner. The timing difference between the pure outflows and receiving the locked up funds created two significant liquidity risks for prime brokers: (i) as firms were only calculating the lock up on a weekly basis, there was a significant timing mismatch with the actual outflows (sometimes up to a week); and (ii) prime brokerage funding, which depending on the jurisdiction is allowed to a varying degree, might also be withdrawn during stress. The LCR attempts to address many of the shortcomings including running customer cash balances off at 100%, assuming margin lending rolls at 50%, treating customer short positions as securities lending transactions between the bank and the customer, and treating margin loans as a financial commitment. The treatment does allow for inflows freed up from the lock-up requirement to be recognised. Banks completed a Basel III monitoring exercise reflecting the changes earlier in 2013.

Secured lending

Prior to the crisis, secured lending was seen as a very safe funding strategy. Insurer AIG, for example, engaged in approximately $90 billion in secured lending transactions using corporate bonds and other securities as collateral. AIG then used the cash it received from these secured lending arrangements to invest in subprime RMBS. AIG had assumed that these securities would remain liquid. When AIG's secured lending counterparties requested their funds back, the insurer had difficulty coming up with the cash and ultimately required official assistance to meet its obligations in late 2008.

2.2.6 Over-reliance on wholesale funding

Wholesale funding concentrations were clearly a primary source of liquidity stress. Some European banks lacked adequate retail deposit funding (especially in US dollars) and sought wholesale funding on the interbank market, in secured funding markets via repo and covered bonds, and from the commercial paper market.

[7] The firm may also have purchased some ABCP as opposed to allowing its line to be drawn down. This would effectively imply an even higher drawdown amount.

Several institutions had sizeable maturity mismatches prior to the onset of liquidity stress – suggesting that a root cause of their difficulty was initial over-reliance on short-term non-deposit funding. As noted in the discussion of banks' loan pipelines, stress generally caused these institutions' wholesale funding dependencies to increase further. Wholesale funding receives a conservative treatment under the LCR.

2.2.7 Derivatives and foreign currency funding

While derivatives were a contributing source of liquidity stress, their contribution was of secondary importance for most institutions discussed here.[8] For example, in the case of one European bank, while margin calls and pre-funding of foreign currency (FX) swaps reduced the bank's liquidity position, data suggest that these factors amounted to about 8% of the bank's liquidity gap. Similarly, data for a US investment bank suggest that collateral movements due to derivative assignments and unwinds amounted to $8.1 billion over a two-week period, or about 10% of the firm's outflows over this timeframe. Still, disruptions in the FX swap market affected one European bank's ability to continue to fund its US dollar activities.

FX derivatives positions were problematic in some cases. In the Korean case, despite efforts to regulate banks' foreign currency liquidity after the 1997 crisis, a mismatch between off-balance sheet FX derivative assets and liabilities, not included in Korea's domestic liquidity regulation, created material rollover problems for Korean banks in 2008–09. A reduction in US dollar funding available to Korean banks and the shortening of its tenor spurred the appreciation of the US dollar relative to the Korean won. This created an adverse feedback loop between the exchange rate and banking system funding. Given that Korean banks' derivatives positions were net short US dollars, the appreciation of the US dollar gave rise to a large mark-to-market loss on FX derivatives and forced Korean banks to deposit additional margin (roughly $6 billion over the course of 10 months) with their counterparties at a time when they already faced a severe US dollar funding shortfall. Finally, the Icelandic case study revealed similar issues related to FX exposures. In the (failed) 2007/08 stress test of Landsbanki, neither the bank's off-balance sheet positions nor its currency mismatches were included in the stress test.

Liquidity problems in one market segment or country can spread to other countries or markets, and become systemic of nature, even if there is no solvency problem. Norwegian banks did not encounter solvency problems during the 2007–09 financial crisis as they had only minimal exposure to US subprime real estate. However, the Norwegian money market has for a long time been closely linked to the US dollar money market and the problems in the US dollar market in 2008 quickly affected Norwegian banks' funding. First, as Norwegian banks fund some of their activities using foreign currency swapped to Norwegian kroner, they were confronted with the same shortage of US dollars as banks in other countries. Second, Norwegian interbank rates (Nibor) were derived from the rates of interbank loans in US dollars swapped to Norwegian kroner in the FX swap market. Conditions in the US money market following Lehman's failure therefore had a direct impact on Nibor. The liquidity strains at Norwegian banks necessitated non-standard liquidity provision by the Central Bank of Norway.

2.3 Liquidity buffers

While the case study review has so far raised some valuable findings with respect to drivers of outflows, findings that relate to liquidity buffers are far fewer, due mostly to data limitations. We will discuss these

[8] Arguably, AIG is a clear exception that is not covered in our survey, although its derivative issues were centred on its CDS positions, which have payoffs that are more asymmetrical than those of some other derivatives, such as interest rate or FX swaps.

findings below. The lesson learned related to repo with CCPs could arguably be grouped here or in the outflow discussion (Section 2.2) as it relates to the run-off of secured funding.

2.3.1 Pre-crisis buffers were too small

Banks' liquidity buffers were just too small relative to the stress they experienced during the crisis. In four of the case studies, it is clear that banks' liquidity buffers were just too small relative to the stress they experienced during the crisis (as distinct from banks building large buffers, but experiencing difficulty in liquidating those assets). One of the European institutions, which carried a liquidity buffer of a mere €2.1 billion, faced ABCP-related outflows that were 10 times larger. A US investment bank had a liquidity buffer of approximately $70 billion of liquid collateral, including cash, government bonds, agency debentures and MBS as of late August 2008. However, September "deposit requests" from clearing and settlement banks totalled roughly one third of this amount and prime brokerage-related outflows about half of the value of its buffer, suggesting that its buffer was too small, rather than that the types of asset included in its buffer were inappropriate. In another case, management shrunk the firm's investment portfolio to a mere $19 billion of unencumbered securities, roughly half of which was private label RMBS. Management continued to aggressively increase the share of higher-yielding assets on the balance sheet, specifically, mortgage loans that they believed to be liquid, at the expense of maintaining a lower-yielding liquidity buffer of high-quality securities. The firm's one-month peak deposit run-off totalled $19 billion, ie deposit run-off alone was equivalent to its buffer ignoring other wholesale funding and loan pipeline challenges faced by the firm.

2.3.2 Heightened risk in foreign currency-denominated securities

Foreign currency securities issued by domestic entities may be an unreliable buffer asset when solvency risks are heightened by exchange rate depreciation. The Korean case study indicates that matching the currency of buffer assets to outflows may not mitigate liquidity/funding stress. Due to the implementation of foreign currency liquidity regulations after the Asian crisis, Korean banks had acquired US dollar-denominated bonds issued by Korean corporates. However, when faced with reduced access to US dollar funding in 2008–09, Korean banks found that they faced a large discount when selling their holdings of these bonds, as Korean assets were shunned given the uncertainty surrounding the exchange rate. Thus, these assets, issued in US dollars but by domestic firms, failed to serve their intended function of providing US dollar liquidity to Korean banks at a time of stress.[9]

2.3.3 Definition of "freely available" assets in banks' buffers

Strategies that substitute for pledging collateral may generate liquidity stress. One US firm developed a number of creative approaches to allow it to include assets provided to clearing and settlement banks in its liquidity buffer. The strategies pursued by the firm included placing deposits with its clearing and settlement banks in lieu of pledging collateral and/or revising master account agreements to provide its agent banks with offset rights against its accounts. In some instances, these approaches fell short of outright pledging, but ultimately had the net effect of making these assets unavailable to Lehman at a time of liquidity stress.

"Creative" clearing and settlement arrangements and liquidity accounting may become problematic. Some firms include deposits in other institutions in their measure of "freely available" funds even when these funds cannot be easily accessed. As a firm's perceived health deteriorates, its clearing and settlement banks may demand cash collateral. One firm included these amounts provided

[9] The LCR allows eligible buffer assets to be denominated in the same currency as the outflow, regardless of the issuer's domicile.

to its clearing and settlement banks in its liquidity pool, even though these counterparties encumbered these assets intraday, on the basis that the collateral was "freely" available to the firm at the end of the day. In reality it was functionally impossible for the firm to move these funds in the evening after the close of Fedwire, and almost all of the funds in these accounts were required each morning to unwind the previous day's tri-party repo trades. The firm's inclusion of these deposits as "freely available" cash in its liquidity buffer was aided by several of its clearing and settlement banks, including one that allowed the firm to briefly withdraw its deposit over a quarterly reporting period.

Important issues are raised by encumbrance tests with respect to the availability of a given asset to meet a bank's unexpected funding shortfalls. The operational definition of the liquidity buffer for the purpose of stress testing is clearly important. Deposits are not included in the LCR's buffer, but rather in the LCR's denominator as an inflow. However, a bank's own operational deposits, such as those related to clearing and settlement, receive no inflow credit under the standard. Had the LCR been in place during the 2007–08 crisis, banks' ratios would have dropped substantially once the clearing and settlement banks requested firms "deposit" funds sufficient to collateralise their use of intraday credit and any other unsecured exposures.

2.3.4 Lemons problem

Difficult-to-value, complex securities are likely to suffer from a "lemons discount" problem in a liquidity crisis and thus are undesirable assets for inclusion in banks' buffers.[10] Some firms' experiences suggest that buffer assets need to be those for which active markets and transparent pricing exist. The LCR defines buffer-eligible assets largely on the basis of risk weights and ratings from recognised external credit assessment institutions. One US firm's experience of trying to meet collateral demands with collateralised debt obligations suggests that, ideally, buffer assets should be those for which transparent pricing models exist. Another US firm was unable to liquidate its buffer holdings of private label RMBS to manage its liquidity stress (which, unfortunately, was also positively correlated with the source of its banking book stress), although a separate finding also appears to be that this firm's buffer was too small.

2.3.5 Repoability of assets with central counterparties

Some institutions seem to have been able to raise funds reliably through the crisis using repo through CCPs against eligible collateral. Some of the case studies provide insight with respect to the viability of continued repo market access when firms experience liquidity stress. While there are reasons to doubt firms' continued access to the bilateral repo and, to a lesser extent, the tri-party repo markets under such conditions, several firms seem to have been able to raise funds through repo with CCPs against eligible collateral during the crisis. For one European institution, bilateral repo was not a reliable source of funding even against collateral of the highest quality, while repo intermediated by a CCP against eligible collateral was. The blind-brokered nature of repo via a CCP, as well as the mitigation of credit risk as a result of transacting through a CCP, is thought to be critical in influencing the greater "repoability" of firms' buffer assets. This may argue for consideration of the repoability of an asset with a

[10] Bolton et al (forthcoming) develop a model in which they show that, under asymmetric information, banks have an immediate incentive to sell assets to obtain liquidity and, under some states of the world, they have 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 complex assets, adverse selection or a "lemons discount" problem arises.

CCP as a criterion for buffer assets. The LCR assumes firms can always fully roll over repurchase agreements collateralised by Level 1 assets such as government securities.[11]

Investors prefer to engage in repo with the insured depository institution instead of the uninsured holding company. With regard to repoability of assets, one of the US case studies suggests there may have been discrimination by repo investors between legal entities with investors preferring to engage in repo with the insured depository institution instead of with the uninsured holding company parent. Additionally, at least at the insured depository level, Treasury and agency repo intermediated by a CCP served as a material source of funding even during the most significant period of stress for this entity. Despite severe stress, the firm´s insured depository subsidiary was able to raise $24 billion through GCF repo during its peak liquidity stress period.[12]

There is some evidence that tri-party repo remained a reliable source of funding. One failed US institution experienced no material change in tri-party repo haircuts or financing volumes until one week prior to failure. Most of the change in the haircuts applied to the firm's collateral in the days before bankruptcy is explained by the deterioration in the quality of the collateral pledged by the firm. With regard to tri-party repo volumes, there was a sharp decline in the amount of collateral posted by the firm in tri-party repo in the week prior to failure – ranging from –20% to –40% per day in the week before failure. That said, CCP disclosures suggest that the firm obtained liquidity via repo with a CCP in the period immediately preceding its failure.

2.3.6 Banks cannot always count on maturing loans as a source of liquidity

Maturing loans may need to be refunded. The Korean case study suggests that a flaw in the foreign currency liquidity regulation promulgated after the Asian crisis was to count maturing US dollar denominated loans as counterbalancing capacity available to banks to mitigate funding stress. During the 2007–09 crisis, Korean banks generally found that they needed to roll over maturing loans to existing borrowers who faced a lack of FX availability even as the banks' own US dollar funding ceased to roll over. The LCR allows banks to count 50% of maturing loans as inflows, thereby reducing the need to hold buffer assets.

2.4 Other considerations

2.4.1 The legal entity view

Liquidity may not flow freely among the separate legal entities in a consolidated institution.[13] Two European case studies strongly suggest that looking at firms on a consolidated basis is insufficient for assessing liquidity, as different regulatory regimes across varying types of legal entities (ie banks, broker-dealers and insurers) or jurisdictions can restrict the free flow of liquidity. In the case of one institution, one of its affiliates included a regulated insurance entity that incurred substantial liquidity risk. Similarly,

[11] The standard also assumes that 85% of repurchase agreements backed by Level 2 assets, such as covered bonds, agency MBS and corporate bonds, can be rolled over and 0% of repurchase agreements backed by other assets as collateral can be rolled over.

[12] GCF repo is the General Collateral Finance repo service of the Fixed Income Clearing Corporation, a subsidiary of the Depository Trust & Clearing Corporation. Eligible collateral for GCF repo includes: US Treasuries, agency debentures and agency MBS.

[13] The Joint Forum (2012) report on intragroup support measures notes that 10 of the 25 global financial institutions that participated in its survey indicated that they did not manage their liquidity on a centralised basis. While these firms did note higher costs, they observed benefits in terms of a clearer picture of units' profitability, easier separation of units from the rest of the group if sold, and limiting contagion.

the Section 23a waiver of the Federal Reserve Act during the crisis (which governs the provision of loans by a depository to its parent and non-bank legal entities within the firm), suggests that legal entity restrictions were also an important liquidity issue in the United States. In the US case, this waiver was provided to facilitate the provision of liquidity to banks' broker-dealer subsidiaries. The LCR requires that assets which have legal restrictions on being transferred to the parent not be recognised in the consolidated buffer, but the requirement is silent on the issue of inflows in the LCR's denominator. Other regulatory restrictions on, for instance, a bank's inflows supporting non-bank affiliates' outflows can also have material implications for the calculation of the consolidated LCR under the standard.[14] In sum, while looking at liquidity purely on a consolidated basis, as the LCR does, is less complex, it risks overstating firms' liquidity. Finally, the case studies suggested that focusing only on banking activities in stress tests may fail to identify intragroup links that can have important liquidity implications for the banking entities.

Run-off rates may differ among legal entities in a consolidated institution. One US case study revealed strong investor preferences to extend credit to the insured depository rather than other entities within the holding company parent even months before the firm reached peak stress.[15] Rating agency commentary since the crisis has likely reinforced this perception, at least in the United States. With respect to US banks, Moody's stated that they "believe government support for creditors of bank holding companies is becoming less certain and predictable, whereas support for creditors of the operating entities of large and complex groups remains sufficiently likely and predictable to warrant stable outlooks."[16] This suggests differentiation of run-off rates by legal entity should be considered when developing stress tests. It is unclear whether the LCR is intended to be calibrated to operating entities, such as banks, or to holding companies. Finally, two of the case studies also suggested that it is possible for jurisdictional borders to impede the flow of liquidity from one part of an entity to another.

2.4.2 Ratings and ratings-based triggers

Ratings triggers can be a material source of liquidity risk. One case study found that ratings-based triggers in a non-bank entity were a material source of liquidity stress. In this specific case, depositors were allowed to withdraw their deposits if the rating of the entity fell below a certain threshold. The combination of rating triggers with internal guarantees contributed to a specific problem that spread through the whole group. Finally, even though explicit rating triggers can be a substantial source of stress, the absence of formal rating triggers or even a good rating per se do not constitute guarantees against liquidity shocks. For instance, one of the European banks featured in the case studies experienced a loss of interbank funding while still maintaining an investment-grade rating.

2.4.3 Network effects

Liquidity stress tests may need to recognise the importance of network linkages and contagion. While the clustering of bank stress and failure during the 2007–09 crisis is well known, Japan's financial crisis in 1997 had a similar pattern of successive failures. As in the 2007–09 crisis, the rapid failure of a broker-dealer in November 1997 sent shockwaves throughout the Japanese financial system. Specifically,

[14] For example, a firm's insured depositories could be the primary source of gross inflows or hold the bulk of Level 1 assets while its non-bank subsidiaries hold a disproportionate share of Level 2 assets and/or outflows. The consolidated LCR calculation implies that the insured depositories' liquidity would be available to assist non-bank subsidiaries even if the other regulatory restrictions meant to limit the scope of the deposit insurance safety net could impede such transactions.

[15] This occurred prior to the failure of Washington Mutual, where creditors of the bank holding company experienced losses while creditors of the bank received full value for their claims.

[16] Moody's (2012, p 14).

a small default ($104 million) in the interbank market of a mid-size broker-dealer, Sanyo Securities, critically impaired the functioning of the unsecured funding market in Japan and required the Bank of Japan to inject substantial liquidity volumes ($275 billion at peak). Yamaichi Securities, at the time Japan's fourth largest broker-dealer, followed Sanyo into bankruptcy three weeks later. As in the case of Lehman, it is clear that these events had systemic repercussions on funding availability. Furthermore, the Icelandic case study, which reviews the lessons learned from the inadequate 2007/08 stress test of Landsbanki, finds that contagion risk was an important, but missing, element.

2.4.4 Liquidity risk management

Liquidity stress tests will have little benefit unless their results are used to inform business practices. In the case of three firms, liquidity stress tests were in place prior to the crisis. While some case studies revealed methodological flaws in firms' stress-testing approaches – such as a failure to consider some of the above highlighted sources of stress or incorporate necessary data – the efficacy of stress tests was also limited by firms' use of results. Specifically, several firms did not use their liquidity stress tests to set or enforce internal risk limits, make decisions about balance sheet adjustments, adjust transfer pricing or govern banks' liquidity risk-taking. Stress test results, therefore, had a very limited impact.

3. Literature review of factors relating to liquidity stress[17]

3.1 Overview

Liquidity stress testing requires financial institutions to weigh potential liquidity outflow exposures under stressed scenarios against the available counterbalancing capacity. However, it is difficult to accurately determine the potential outflows during a period of liquidity stress or the counterbalancing capacity. Ideally, this determination would be made using robust findings across a number of systematic empirical approaches. In practice, data limitations hinder researchers when they seek to draw precise conclusions for stress testing at a sufficiently granular level for practitioners. Nevertheless, academic research provides some important insights relevant to sources of liquidity stress and their magnitudes.

In this section, the academic literature relevant for liquidity stress testing is presented in a review organised according to the categories and concepts established in the LCR. In particular, the Workgroup reviewed the literature on deposits, loan commitments, secured funding, wholesale funding, counterbalancing capacity, secured lending and links with non-bank intermediaries. In some cases, concepts defined in the LCR are too granular for publicly available data and the literature is therefore silent on these issues.

The literature review contains decades of research including papers that focus on the recent financial crisis across multiple jurisdictions. As with any study, the conclusions from the literature depend on the context. Thus, decision-makers should take care to understand how their own environment compares with that described in the studies when considering how far any conclusions or prescriptions may be appropriate to their own situation. The conclusions drawn from the literature should also be considered alongside conclusions drawn elsewhere in this survey, such as in the case studies.

To improve readability, direct references are not included in the text. In the annex, selected references are included, grouped by section. For a more elaborate discussion and explicit links between claims and papers, see the extended literature review that is available separately.

3.2 Deposits

A prominent finding in the literature is that a deposit's insurance status is the most important characteristic in determining the sensitivity of deposits to risk or stress.[18] The literature examines the stability of deposits across a variety of characteristics. Among the heuristics considered in the literature are a deposit's insurance status, core deposits versus wholesale deposits, and bank-depositor relationships. There is some evidence in the literature that even fully insured depositors discipline risky banks through higher rates and positive run-offs. However, there is a consensus in the literature that the

[17] Drafted by Pogach (Federal Deposit Insurance Corporation) and 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 (Central Bank of the Republic of Austria), Schmieder (Bank for International Settlements), Souissi (Bank of Canada) and van den Heuvel (Board of Governors of the Federal Reserve System).

[18] In practice, insurance status is difficult to observe directly. In this paper and the literature, it is used interchangeably with deposits whose principal falls below a fully insured limit.

magnitudes of the run-offs and presence of risk pricing are much greater when deposits are not fully insured.

Core deposits are associated with greater funding stability, allowing a bank to lend more, or decrease lending by less, during stress periods. However, the definition of "core" varies across studies and one paper shows that deposits commonly labelled as core do not exhibit these tendencies uniformly. This suggests that liquidity stress tests should avoid coarse definitions when possible.

Bank-depositor relationships have a significant effect on the stability of a deposit. Longer-lasting relationships and relationships that span multiple bank products are both associated with lower outflows during stress. The literature suggests that the latter may in part be the consequence of the right to offset, in which a depositor's loss in a bank failure can be used to offset the depositor's debt to the bank.

3.3 Commitments

There is no clear evidence that loan commitment liquidity outflows are naturally hedged by deposit inflows during a severe event. The literature on loan commitments is largely centred on the hypothesis that banks reap economies of scope through their dual role as deposit-takers and commitment lenders. The argument is that outflows of funds due to lending – in particular from loan commitments – and outflows from deposits are imperfectly correlated, allowing them to share a common stockpile of liquid assets. From a stress-testing perspective, the relevant question is how far these two aspects of liquidity provision serve as a natural hedge during periods of liquidity stress. Prior to the recent crisis, the literature suggests that deposit outflows and commitment drawdowns in the United States exhibited the desirable negative correlation, given that banks appear to have benefited from a flight to safety during periods of liquidity stress. However, in the context of the financial crisis, findings suggest that this effect was somewhat blunted, perhaps because banks temporarily lost some of their safe haven status and that this status was restored only after the extension of extraordinary public sector support to the banking sector. Furthermore, some of the literature suggests that the correlation runs in the wrong direction at stressed institutions as commitment drawdowns exacerbate uninsured deposit withdrawals.

Liquidity support to ABCP programmes is potentially a much greater and more acute source of liquidity stress than loan commitments. Another strand of literature suggests that liquidity support to ABCP programmes was a significant source of stress for sponsoring financial institutions during the recent crisis and may have had a potentially much larger impact on banks' balance sheets than traditional lines of credit to non-financial firms. The literature shows that much of the funding for ABCP came from MMFs that were relatively risk averse and sensitive to asset ratings.

3.4 Secured funding

A general theme in both the theoretical and empirical literature is that access to secured funding is procyclical. Secured funding is procyclical with regard to haircuts, securities valuation, collateral velocity, shortened tenors and changes in counterparty credit risk limits. During the crisis, capital-constrained speculators cut their positions, reducing liquidity and increasing haircuts. In addition, the literature shows that tenors shorten as MMFs shorten their maturity profile. Furthermore, the empirical literature shows decreased collateral velocity during the crisis and positive correlation between perceived creditworthiness and counterparty credit limits.

Collateral does not shield against an idiosyncratic shut-out of an otherwise rather resilient market. Secured funding may not be an entirely reliable source of funding during a stress event despite the bankruptcy remoteness of potential creditors' claims. Such findings of procyclicality

are also consistent with evidence from interviews with market participants after the crisis. These issues need to be taken into account in liquidity stress tests.

The reliability of the secured funding market is highly variable during stress periods, with notable differences found on two fronts: market segmentation and collateral quality. The literature shows that secured funding with high-quality collateral exhibited stable haircuts and volumes in the tri-party repo market. This result is contrasted to bilateral repo markets, in which haircuts and funding changed dramatically during the same time period. Furthermore, some authors characterise the experience in the bilateral inter-dealer repo market as a "run on repo", akin to a traditional bank run. Unfortunately, no empirical literature examines the stability of centrally cleared repo transactions.

Even for the relatively stable tri-party repo market, asset credit quality is important. The findings of tri-party funding repo stability are shown to hold for US Treasuries and agency MBS, but not for non-agency ABS and MBS. Furthermore, evidence from Europe during the crisis suggests the expected correlations between haircut increases during a crisis and counterparty credit quality (negative correlation), collateral credit quality (negative), and repo term (positive).

Equity haircuts resemble those of corporate bonds, but adverse equity price movements may have a particularly large effect on secured funding that use equities during a stress period. The haircuts for equity increased substantially during stress, but the asset class remained acceptable as collateral. However, large price shocks can imply that the profit and loss impact of a (forced) asset sale on the solvency of the bank is larger.

A reduction in the extent and speed of rehypothecation during the crisis contributed to a liquidity shortfall. The literature suggests that rehypothecation – where an institution uses collateral received from one secured funding transaction to pledge as collateral in a second secured funding transaction – plays an important role in some financial institutions' liquidity management. Because it increases or reduces the total amount of lending from a given pool of collateral, the velocity of rehypothecation – the frequency at which financial collateral is re-used – and its stability are important measures of the liquidity in the secured funding market.

3.5 Wholesale funding

The wholesale interbank market allows banks to engage in maturity transformation but this advantage may come at the expense of banks' underinvesting in liquid assets. Even prior to the crisis, the literature presented conflicting viewpoints on the efficiency of the wholesale interbank market. On the one hand, the ability to rely on insurance against liquidity shocks through the wholesale funding market let banks engage in more maturity transformation by investing more funds into less liquid and more profitable investment projects. On the other hand, this mechanism may have provided incentives for banks to underinvest in liquid assets due to misaligned incentives as a result of externalities associated with the possibility of asset fire sales in the event of liquidity stress, or other distortions.

While wholesale funding did not entirely dry up during the financial crisis, tenors shortened and rates became more sensitive to borrower characteristics. The literature points to three factors that may cause wholesale funding to dry up during a financial crisis: borrower solvency problems, lender liquidity problems, and a market freeze driven by informational frictions such as adverse selection. Empirically, the literature finds that, while features of the wholesale funding markets changed during the crisis, funding did not altogether evaporate. Rather, the tenor of interbank market loans shortened, and interbank market rates became more sensitive to borrower characteristics. In contrast, money market freezes are driven by lender liquidity hoarding.

3.6 Intraday liquidity

Banks have an incentive to delay intraday outgoing payments while waiting for others to pay first. The literature on intraday borrowing focuses on banks' trade-offs between the costs of delaying payment (eg reputation) against the costs of borrowing reserves to make timely payments. Because the former does not incorporate all social costs associated with delay (ie costs imposed on the recipients of payments), banks will free-ride on other banks' liquidity, increasing the risk of gridlock. Note that these incentives are likely to be magnified during a stress event.

Stress tests should take into account that system-wide liquidity is a function of the supply of reserves and the nature of the payment system. The risk of gridlock can be mitigated with a large supply of reserves and liquidity-saving mechanisms.[19] Liquidity-saving mechanisms reduce the probability of gridlock by creating incentives for early submission of payments, thereby increasing the endogenous liquidity generated from banks' recirculation of their reserves. Meanwhile, increases of excess reserves through central bank policy (eg paying interest on reserves) reduce a bank's opportunity cost for holding reserves that facilitate earlier payment and lessen the risk of gridlock.

3.7 Counterbalancing capacity

The empirical literature provides little guidance on the appropriate counterbalancing capacity for stress-testing purposes. The need for counterbalancing capacity is discussed in the literature through the theoretical underpinnings of liquidity spirals resulting from liquidity or solvency shocks, which lead to asset sales, declining asset prices, and escalating liquidity needs. The literature suggests that requirements for larger stocks of liquid assets could in some circumstances be more effective in stemming systemic crises than capital requirements. However, the discussion of counterbalancing capacity is conducted at a fairly high level, as a result of data limitations that prevent us from providing specific guidance on which asset classes might be appropriate for inclusion in the stock of liquid assets.

Opaque assets are generally poor candidates for inclusion in a stock of liquid assets. Theoretical models demonstrate that holding of opaque assets may exacerbate liquidity or solvency problems at a bank. In particular, a bank that delays selling its complex assets at a discount may be subject to adverse selection. Thus, holding complex assets may be a signal of low asset quality, thereby increasing the market participants' incentives to sell and accelerating a decline in bank asset prices.

3.8 Securities lending (including liquidity swaps)

Liquidity stress tests need to take into account security flows and not only cash flows. In a securities lending transaction the institution that holds securities lends them to a party that wants to short-sell the securities or needs securities to settle other transactions. Meanwhile, in a liquidity swap, a bank exchanges a less liquid asset for a more liquid asset with a counterparty (eg an insurance company or pension fund). A liquidity swap can be seen as a combination of securities lending transactions. While data are limited on this topic, the literature shows that securities lending contract volumes fell by 60% in Europe after the Lehman failure.

Stress tests should factor in daily margining and large haircuts. Banks acting as agent lenders in the securities lending market typically provide indemnification to their clients – the beneficial

[19] For example, a system that matches payment instructions bilaterally or multilaterally and only settles in the presence of offsetting payments.

owners of the securities – against borrower default. That is, when the securities borrower defaults, the agent lender is obliged to pay compensation for 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, especially in times of crisis.

3.9 Money market funds

Run-off rate and haircut assumptions on borrowings from MMFs should reflect shortened maturity profiles. The literature shows that MMFs constitute an important source of funding for both US and European financial institutions. Thus, changes in MMF behaviour can have a dramatic effect on banks' liquidity. After the Reserve Primary Fund "broke the buck", investors withdrew from MMFs, which responded by shortening their tenors and reducing their holdings of unsecured financial commercial paper and other exposures to financial institutions.

The composition of MMF investors, in particular along the domestic/international dimension, affects behaviour during stress. MMF behaviour was not uniform during the crisis. The literature shows that more informed, professional investors were more likely to seek MMF redemptions during the crisis than retail investors. Furthermore, the literature shows that the MMF location is an important factor in evaluating the stability of a financial institution's funding – a consideration that also highlights a mechanism that transmits liquidity shocks across jurisdictions. In particular, the literature shows that MMF redemptions were greater for exposures to foreign banks than to domestic ones.

4. Authorities' stress-testing methods for liquidity risk[20]

4.1 Introduction

Macro stress tests, the topic of this chapter, are part of the macroprudential toolkit that authorities may use to detect system-wide liquidity risks. Macro stress tests can be conducted either bottom-up or top-down. Bottom-up stress tests are conducted by financial institutions, based on their own assumptions or on common scenarios designed by the central bank or supervisor for a horizontal review. Top-down stress tests are conducted by the authorities or by the IMF, usually based on in-house models and common assumptions across firms and supervisory and/or publicly available data. The classification holds for all types of risk that are subject to stress testing, although the various methods have been mainly applied to credit risk. For liquidity risk, the methods are currently not as advanced. In practice, most authorities conduct both top-down and bottom-up stress tests, as these are complementary and allow for valuable cross-checks.

4.2 Bottom-up macro stress tests for liquidity risk

Bottom-up macro stress tests are usually an important part of IMF Financial Sector Assessment Programs (FSAP). Over the past decade, FSAP stress tests show how frameworks have evolved in the context of the financial crisis. Before 2007 (and until the early phase of the crisis), most FSAP liquidity stress tests consisted of simplified bank run-type scenarios based on implied cash flow tests that were often limited to on-balance sheet positions. These tests rarely paid much attention to off-balance sheet exposures, other contingent cash flows (such as margin calls etc) and the liquidity profile by currency. But precisely these issues turned out to be a challenge during the crisis. Likewise, the scenarios with respect to both market and funding liquidity were often too benign and thus did not uncover the potential risks. A case study by Ong and Čihák (2010) for Iceland shows ex post why risks were not detected, pointing to the severity of the scenario on the one hand and the scope of the tests on the other.

In more recent FSAPs, liquidity stress tests have been extended in scope and draw upon more sophisticated methods used by the authorities involved and, importantly, more comprehensive data. In most cases, the scenarios are based on a combination of macroeconomic scenario modelling and expert judgment, taking into account the particular system and constraints on the data available. In terms of scope, recent stress tests comprised bank run-type implied cash flow tests and, to some degree, analysis of maturity mismatches, including through proxies of Basel III ratios. An explicit link between solvency and liquidity has been established for funding costs – with their evolution being simulated as part of multi-year scenario analyses (Schmieder et al (2012)).

4.2.1 Examples of bottom-up macro stress tests for liquidity risk

Bottom-up stress tests conducted by authorities comprise both regular liquidity risk reports and occasional horizontal exercises based on common stress assumptions, often in the context of an IMF FSAP. For liquidity tests, in contrast to solvency tests, authorities tend to rely more on banks and adopt bottom-up approaches because liquidity tests usually require more granular data than afforded by typical supervisory data, and results depend on an in-depth knowledge of banks' liquidity strategies

[20] Drafted by van den End (Netherlands Bank) based on members' contributions.

(Oura and Schumacher (2012)).To illustrate how authorities apply such liquidity stress tests, this section presents the practices of the Bank of Italy, the China Banking Regulatory Commission (CBRC) and the European Banking Authority (EBA).

Bank of Italy

The Bank of Italy has conducted several bottom-up liquidity stress tests focusing on potential weaknesses arising from the drying-up of wholesale funding. Starting from a baseline set by its regular weekly liquidity assessment methodology, banks have been asked to assess additional stress hypotheses. In the weekly liquidity risk monitoring framework, wholesale funds and maturing term deposits from large corporate counterparties enter into the maturity ladder with a 0% rollover rate. The weekly liquidity monitoring metrics represent a baseline "stress" scenario in which wholesale markets freeze up completely and the bank has to survive the shock using its available central bank eligible securities. On several occasions, Italian banks have been asked to simulate additional contingent liquidity needs that might arise from adverse developments in the credit markets. In particular, banks were asked to consider the effects of rating downgrades, for both banks and sovereign exposures, widening credit spreads, increased collateralisation requirements, loss of funding due to large investor deposit withdrawals, loss of funding due to margin calls, and loss of eligibility or increased haircuts for their collateral buffer assets. Banks have also been asked to model the reaction of retail depositors to swings in sovereign spreads and to estimate their bank's capacity to generate central bank eligible collateral in the event of a systemic crisis.

China Banking Regulatory Commission

Chinese banks report the outcomes of a standardised liquidity stress test on a quarterly basis. The CBRC requires banks to take account of the following stress scenarios: unexpected deposit withdrawals, shocks to liquid assets, drying-up of wholesale funding markets, increasing funding cost, and higher margin requirements by counterparties. In practice, banks usually add some specific stress events to the tests based on their own risk judgment, such as an increase of the required reserves ratio. Banks have to consider mild, medium and severe levels of stress. Most banks measure the outcomes of liquidity stress test by the cash flow gap for each time horizon and by the shortest survival period. The CBRC regularly discusses with the banks the scope and severity of stress scenarios and the stress-test results. Overall, large banks in China are better than small and medium-sized banks in terms of data collection, modelling and management use. Nevertheless, the effectiveness and robustness of banks' stress tests are generally constrained by data limitations.

European Banking Authority

The European Banking Authority has conducted several EU-wide stress tests in the crisis, based on common scenarios and implemented by local supervisors for a number of large cross-border European banks. The banks conducted stress tests and the supervisors aggregated country results. Liquidity risk was taken into account through changes in spreads on retail and wholesale funding. These shocks had an impact on bank capital through net interest income. A separate liquidity risk assessment was conducted using a cash flow approach, focusing on the net counterbalancing capacity of banks. Multiple scenarios were run, combining market-wide and idiosyncratic shocks.

4.3 Top-down liquidity stress-testing methods

Some national authorities perform routine liquidity stress tests on banks' balance sheet data. In many instances, scenario shocks, such as haircuts on assets and liability run-off assumptions are applied to balance sheet positions. Some authorities use in-house models to test the resilience of single banks or a financial system in a top-down manner.

While there has been significant progress in testing bank solvency, certainly in relation to credit risk, liquidity risk modelling still remains in its infancy, especially in macro stress tests. A range of modelling approaches has been developed over the last decade, gradually evolving to (i) fully fledged macro stress tests with the explicit aim of establishing macrofinancial linkages, ie to assess resilience under specific macroeconomic scenarios, and (ii) integrated frameworks to model dynamic and systemic effects. A limited set of stress-testing models do include liquidity risk and feedback effects within the financial sector and – hence – systemic liquidity effects. They draw on theoretical work on modelling systemic financial crises (eg on Allen and Gale (2000) for interbank contagion and on Cifuentes et al (2005) for fire sales).

The most advanced liquidity stress-testing models are part of integrated frameworks that combine modules for credit, market and liquidity risk. Scenarios are usually constructed as simulated shocks to bank credit portfolios that spill over into market and funding liquidity risk. In most models, the responses of banks to the shocks affect market liquidity (haircuts on assets through fire sales) or funding liquidity (liquidity run-offs, in some cases through interbank network effects).

4.3.1 Examples of balance sheet-based approaches

Balance sheet-based approaches are liquidity stress tests conducted by scenario shocks that generate haircuts on assets and liability run-off rates that are applied to banks' balance sheet data. This can be implemented using either supervisory or public data. The tests assess banks' capacity to counterbalance these shocks. Balance sheet-based approaches can identify the source of individual vulnerabilities in the balance sheet, but are backward-looking, static and limited to the first-round effects of liquidity stress. These exercises are usually part of regular financial stability assessments, as for instance in the cases of the Bank of Japan, Sveriges Riksbank, Bank of Italy and Central Bank of Brazil discussed below.

Bank of Japan

The Bank of Japan approach to stress testing of system-wide liquidity risk looks at the actual portfolios of Japanese banks and assesses whether and to what extent these banks can withstand a severe shock assumed by the Bank of Japan. To assess funding liquidity risk, the Bank of Japan assumes that market funding comes to a halt for an extended period and assesses the impact of a scenario by looking at estimated changes in liquidity ratios and buffers of the banks. Such macro stress testing is conducted separately for funding in yen and in foreign currencies. The results are published in the semiannual *Financial System Report*.

Sveriges Riksbank

For some time, Sveriges Riksbank has computed liquidity metrics similar to the Basel Committee's LCR and NSFR. The metrics are published in the Financial Stability Report. Sveriges Riksbank does not specify a bespoke quantitative macroeconomic scenario, nor does it use empirical data to calibrate run-off rates in its liquidity stress tests. Sveriges Riksbank is working on adjustments to the stress test to incorporate increased loan losses and will soon start to include increased funding costs in the stress scenario.

Bank of Italy

Top-down stress tests have been employed repeatedly by the Bank of Italy as part of the ongoing supervisory analysis on liquidity risk, with a particular focus on wholesale and retail medium-term funding needs. While the tests initially relied solely on extensive supervisory information, this has more recently been augmented by ad hoc information requests to cover phenomena such as the behaviour of retail debt investors and wholesale counterparties for certificates of deposit and commercial paper. In the market operations area, liquidity risk analysis is focused on top-down stress tests performed on the interbank network analysis.

Central Bank of Brazil

The liquidity stress test conducted by the Central Bank of Brazil compares the amount of liquid resources with the estimated outflow in stress scenarios. From these data, a liquidity index is derived, which is similar to the LCR. The liquidity stress test considers, for each individual financial institution, the different asset classes and funding, but does not take into account the actual linkages among institutions.[21]

4.3.2 Examples of top-down models

Many supervisory authorities currently employ top-down stress-testing methods. This section presents models used by central banks, supervisory authorities and the IMF to stress-test liquidity risk in a top-down manner. It covers a large variety of modelling approaches, ranging from basic simulation techniques to more complex integrated frameworks. This diversity of approaches shows that the field is developing rapidly and that a common framework has yet to emerge. Some of the models are still at a developmental stage and few of them are actually used for monitoring risks in the financial system. Occasionally the models have been used in IMF FSAPs. The models detect the systemic effects of funding and market liquidity shocks that can arise through various channels of contagion (eg fire sales or network effects).

Central Bank of the Republic of Austria, Systemic Risk Monitor

One of the earliest integrated stress-testing models is the Systemic Risk Monitor of the Central Bank of the Republic of Austria (OeNB, Boss et al (2006)), which integrates satellite models of credit and market risk with a network model to evaluate the probability of bank default. In the Systemic Risk Monitor, shocks to credit and market risk exposures may trigger bank defaults, leading to interbank contagion effects in a network model that is built on a matrix of bilateral interbank exposures. Systemic Risk Monitor combines bank exposure data and market data. Scenarios are based on stochastic simulations of market prices and macroeconomic variables, taking into account the dependency structure. There are currently no efforts to augment the Systemic Risk Monitor with liquidity risk channels. The Central Bank of the Republic of Austria does incorporate liquidity risk in EBA macro-stress tests according to EBA requirements. They also incorporate funding costs in their own macro top-down stress tests.

Bank of England, RAMSI model

The Bank of England's RAMSI model (Alessandri et al (2009)) uses a suite of models to estimate resilience in a stress scenario. The component models include: a Bayesian vector autoregression model to simulate macroeconomic scenarios, satellite models for credit and market risk and net interest income, an interbank network model and an asset price function to simulate fire sales of assets (market liquidity risk). RAMSI has been extended to include feedback effects resulting from liquidity risk (Aikman et al (2009)). RAMSI is based on bank-level data and market prices and uses stochastic simulation to estimate stress scenario outcomes. A bank's funding cost is in part determined by a bank's credit rating. Baseline funding costs are endogenously stressed when the bank's capital ratio declines as the bank loses its funding sources, representing stressed times. Once funding sources are restricted, banks must rely on asset sales, which have a negative spillover effect by depressing asset prices. This spillover could, in turn, raise the bank's funding costs and trigger additional asset sales. This is the interaction mechanism between market liquidity shock and funding liquidity shock within RAMSI.

[21] Tabak et al (2013).

Bank of Canada, Macro-Financial Risk Assessment Framework

The Bank of Canada's Macro-Financial Risk Assessment Framework (MFRAF) identifies systemic risks by estimating interbank spillover effects at major Canadian banks under a stress scenario (Gauthier et al (2010, 2012)). The framework links solvency, market, and funding liquidity risks. Funding liquidity risk is generated by banks' solvency risk and the potential for asset fire sales. Uncertainty about a bank's asset quality gives rise to solvency risk concerns and lenders may stop rolling over their short-term deposits. This can force illiquid asset sales at a large discount (ie asset fire sales), generate losses and reinforce funding liquidity risk. This approach requires detailed data on banks' funding maturity, sources (insured deposits, secured and unsecured (wholesale) funding), and asset quality (liquid and illiquid assets). Work is under way to extend the framework to include (i) the impact of higher funding costs on banks' earnings; (ii) contagion effects among banks short-term funding; and (iii) a model for asset fire sale discounts.

In addition to MFRAF, the Bank of Canada has plans to adopt a top-down quantitative liquidity stress test to assess the capacity of banks to withstand a stress situation characterised by a (wholesale and retail) bank run with deteriorating market liquidity conditions for asset sales. The method will account for banks' asset-liability maturity mismatches. It will consist of a cash flow analysis based on contractual data and system-wide shocks affecting banks' cash flows and asset liquidity (as proxied by stressed haircuts). In contrast to the MFRAF analysis, where liquidity problems are idiosyncratic as they are triggered by solvency concerns about individual institutions, banks will be subject to market-wide liquidity shocks in the liquidity stress test. The outcome will be a survival horizon under stress. To reflect the evolution of liquidity conditions during a crisis, the stress horizon will be six months. Both asset haircuts and funding runoff rates will be time-varying to be consistent with the dynamics of the stress test scenario and the characteristics of asset classes and funding sources, as they exhibit different degrees of vulnerability. The stress test will incorporate management actions by assuming that banks liquidate liquid and illiquid assets proportionally to their asset holdings to cover net cash outflows. The model will not include endogenous second-round effects, but the assumed changes in asset prices do reach asset fire sale levels at some point.

Netherlands Bank, Liquidity Stress-Tester

The Netherlands Bank's Liquidity Stress-Tester model is an empirical algorithm based on supervisory data on banks' liquidity positions (van den End (2010, 2012)). Stress scenarios are generated through stochastic simulations of univariate shocks to market and funding liquidity risk exposures of banks. The model includes both market-wide effects and idiosyncratic reputation effects. Credit risk and bank solvency are modelled implicitly rather than explicitly, through changes in the valuation of assets and liabilities. Monte Carlo simulations produce the liquidity ratios after the first- and second-round effects of a scenario.[22] Second-round feedback effects are driven by the number and size of reacting banks and the similarity of their reactions.

Some versions of this methodology (van den End (2012)) also include a central bank reaction function, through which the effects of unconventional monetary policy measures on banks' liquidity positions can be simulated. The reaction rule and elasticities of the spillover effects of banks' reactions are based on findings in the literature as well as (subjective) assumptions. Another limitation is that contagion does not occur due to network effects among banks. Instead, it results from the effects of balance sheet adjustments on prices and volumes in the markets and funding channels to which banks are exposed. While the model is calibrated on data from Dutch banks, it can be applied to

[22] Details are given in van den End (2010, 2012). The 2010 paper defines the buffer as the prevailing regulatory liquidity buffers, whereas the 2012 version uses the LCR and NSFR.

other countries' banking systems as well. Komárková et al (2011) modified the model for Czech banks, and Nadal De Simone and Stragiotti (2010) for banks in Luxembourg.

Hong Kong Monetary Authority

The HKMA has used a liquidity risk model to assess the Hong Kong banking system on an ad hoc basis. Interaction between credit and liquidity risk is modelled following Wong and Hui (2009). Negative asset price shocks increase banks' liquidity risk by raising the default risk, thus inducing deposit outflows, depressing the marketability of banks' assets and increasing the risk of drawdowns on contingent liabilities. In the framework, the linkage between the banks' market and credit risk is established with a Merton-type model, while the liquidity risk of individual banks is quantified by Monte Carlo simulations. The HKMA has the general intention of extending the model, for example to incorporate the interaction between the macroeconomic conditions and banks' liquidity risk, but it has not yet developed a new version of the model.

Bank of Korea

The Bank of Korea's Systemic risk Assessment model for Macroprudential Policy (SAMP) includes a funding liquidity contagion module that measures the contagion of funding liquidity shocks across the banking system by using a network model together with asset and liability maturity structures. This module captures interactions between banks' default risk and funding liquidity risk. It estimates liquidity withdrawals, liquidity shortages and additional funding costs. To capture the contagion effects of funding liquidity risk, the Bank of Korea modifies a network model incorporating the maturity structure of banks' assets and liabilities. If the net worth of a bank that is not in fundamental or loss-contagious default falls below the default threshold point due to losses in the liquidity contagion stage, a liquidity-contagious default occurs and the losses incurred subsequently are re-estimated. Since the model internalises such effects of liquidity shocks as deposit run-offs and interbank liquidity hoarding, it can be used not only for liquidity stress testing but also for measuring liquidity risk in the banking system. SAMP currently evaluates only liquidity risk as a whole, without breaking it down into separate risks by currency. However, given that most crises in Korea have been related to foreign currency liquidity problems, the Bank of Korea plans to improve this module so that stress tests on foreign currency liquidity can be conducted.

Bank of Mexico

The Bank of Mexico has conducted stress tests where both idiosyncratic and macroeconomic shocks can cause contagion if the shock leads to a failure of an individual bank. The model is based solely on a macroeconomic approach where individual bank failure is triggered by deteriorating economic conditions that may increase the initial number of bank failures, making banks more vulnerable to losses arising from the initial bank failure. The source of the macro shock is related to both market and credit shocks (see Martínez-Jaramillo et al (2010), Lopez-Castañón et al (2012) and Solórzano-Margain et al (forthcoming) for model descriptions).

The Bank of Mexico's methodology and results are based on actual bilateral exposures. Current data include information related to a wide range of financial market participants such as commercial banks, brokerage houses, pension funds, investment funds and some foreign international banks. The approach focuses on banks' solvency (ie, individual bank failures are based on an assessment of whether the bank's capital ratio is above the 8% Basel II threshold). The methodology is continually evolving and, while liquidity risk is currently not included, it is expected to be incorporated soon. The stress-testing results are published in the Bank of Mexico's *Financial System Report*.

International Monetary Fund

The IMF has used a number of methods for conducting liquidity stress tests. One approach following Čihák (2007) focuses on deposit withdrawals and is applied to simple financial systems with

little market funding. For advanced economies with more complicated funding structures, Schmieder et al (2012) have established a richer framework that allows risks from wholesale funding to be analysed, as well as the interaction between market and funding liquidity, and the interaction between liquidity and solvency risk, in addition to simpler bank run-type risks. It also allows the LCR and NSFR to be assessed in line with prospective Basel III regulations.

Separately, a few experimental approaches focus on system-wide liquidity risks. Barnhill and Schumacher (2011) propose a method where systemic liquidity shocks materialise as a result of solvency distress and network effects among banks. The framework assumes that bank funding distress is caused by declining solvency ratios and uncertainty about asset values due to macrofinancial shocks and solvency contagion among banks through network effects. The model also internalises the interaction between funding liquidity and market liquidity: funding distress for multiple banks causes asset fire sales and the model endogenously determines the resulting haircut on liquid assets, which exacerbates the initial funding shock. As an example, the model is applied to US banks but could also be applied to other systems.

Two other frameworks aiming at measuring systemic liquidity risk primarily by using market indicators have been proposed by the IMF (2011a). The first one – the systemic liquidity index – monitors current systemic liquidity conditions, rather than stress testing for potential systemic liquidity risk. The index is constructed by looking at common components of violations in various arbitrage conditions (such as covered interest parity), which materialise when market liquidity dries up. The second approach applies contingent claims analysis to simulate the joint probability of banks experiencing liquidity strains (ie the probability that banks' risk-adjusted Net Stable Funding Ratio falls below a given threshold). Changes in relevant market factors in (market-wide or bank-specific) stress affect the valuation of the components of NSFR, leading to a change in the probability of liquidity shortfalls for each bank and for the system (Jobst (2012)).

4.4 Combined bottom-up and top-down approach

The Central Bank of the Republic of Austria has implemented an approach that includes second-round effects into liquidity stress tests by adding behavioural reactions into a bottom-up stress test design. In this approach, (some) banks were provided with liquidity stress scenarios. Banks then indicated which steps they would take to mitigate the impact of the stress scenarios and at what horizon. In a second step, the behavioural reactions were analysed and potential second-round effects were identified by the supervisor or central bank. Two scenarios were provided; a market and a combined market and idiosyncratic shock. The stressed cash flows, securities flows and the profit and loss effects were estimated by banks in a bottom-up fashion. Based on the separate behavioural reactions template, second-round effects were identified by the Central Bank of the Republic of Austria: the stressed cash flows were stressed again in a top-down fashion. In sum, the liquidity stress tests consisted of three scenarios, of which one was endogenously derived based on the scenario results and banks' behavioural reactions to the combined scenario (behavioural reactions in the market scenario did not yield second-round effects).

Based on the reported behavioural reactions, the Austrian authorities concluded that a complete drying-up of liquidity was a likely second round-effect. The exercise contained a second top-down analysis. All banks reported that under severe liquidity stress they would not roll over unsecured interbank lending. This was unforeseen in the initial scenarios. In the second round, all rollover rates on interbank liabilities were set to zero (in addition to the stressed cash flows under the initial bottom-up scenario).

The advantage of such combined bottom-up and top-down stress tests is that they allow a cash-flow rather than a stock approach and weigh market liquidity shocks against the counterbalancing capacity. In addition, they capture potential second-round effects. Nevertheless, the approach also has a number of drawbacks. Data intensity is high; unless a fully fledged maturity

mismatch-reporting template is in place, a targeted data-gathering exercise has to precede the stress test. This is costly and data quality can be sub-optimal. Finally, the second-round effects have to be estimated from data generated in the exercise, as well as through expert judgment and the relevant literature.

4.5 Assessment of liquidity stress-testing methods

Integrated models for macro stress testing are complex and can make the causal linkages and final results less transparent. The models may violate a basic rule in macro stress testing, ie that models must be kept sufficiently straightforward, transparent and flexible in use. Moreover, results should be easy to communicate to policymakers and the public (Kwast et al (2010)). On the other hand, integrated models potentially provide a more complete picture of the possible impact of tail events, by taking into account multiple transmission channels and feedback effects.

An important caveat with regard to the use of stress tests is the considerable uncertainty surrounding the estimates associated with stress scenario outcomes. Stress scenarios usually specify situations that never materialise and so the accuracy of stress-test estimates can never be directly assessed. Data on liquidity crises are scarce and in stress situations correlations may differ from past experience. Data gaps in general are an issue for liquidity stress testing. In particular, contingent liquidity risk is hard to quantify, for instance with regard to required collateral pledges in case of a rating downgrade. Hence, macro stress-testing models have to cope with large parameter and model uncertainties. Taleb et al (2012) propose a heuristic that detects biases from ignoring non-linearities and provides additional information on the robustness of stress tests.

Existing methodologies for liquidity stress-testing risk generally assume no government assistance or central bank reactions in order to assess the ability and scope of banks to survive without support. However, the calibration of systemic stress scenarios is typically based on historical crises that often featured government and/or central bank intervention. As a result, the scenario may not be extreme enough to be consistent with the objective of the exercise.

The expanded central bank facilities (including widened collateral criteria) and the treatment thereof in the LCR do not obviate the need for a critical assessment of central bank reliance on stress tests (Section 6.3). While the concern has shifted from surviving without market access to the availability of eligible collateral for central bank funding (as in IMF FSAPs), it makes sense to apply liquidity stress tests with and without assumed access to central bank facilities, as was done in some recent FSAPs.

Liquidity stress tests are a useful macroprudential instrument in that they include scenarios with common shocks across institutions and system-wide features such as network effects. Although macro stress tests are not early warning devices, they can unveil sources of systemic risk and vulnerability through regular system-wide monitoring. Macro stress tests can complement other tools and processes and foster communication about financial stability risks.

5. Best practices in banks' liquidity stress testing – bottom-up approaches[23]

5.1 Overview

This section outlines recent developments in banks' liquidity stress testing in the aftermath of the 2007–09 crisis and identifies gaps and shortcomings in methods and scenarios that could benefit from further research. It builds on earlier work to provide a more detailed survey of banks' best practices in liquidity stress testing and contingent funding planning.

The starting point for the Workgroup's update is the ECB (2008) paper *EU banks' liquidity stress testing and contingency funding plans*, which is augmented with more recent information from a wide group of authorities. The ECB paper summarises the findings of a survey among large EU banks carried out in October 2007. To identify areas where banks have made progress, the group made efforts to collect recent regulatory information to be used as a second source of information. The 2007–09 crisis has prompted regulators and supervisors to more intensively monitor banks' internal liquidity stress tests and this input thus informs us about banks' efforts to improve internal liquidity stress tests and contingency funding plans. Moreover, by involving regulators and supervisors outside the EU as well, the results have become more general than those of the ECB paper.

In addition to authorities' findings, the Workgroup also surveyed available vendor model solutions. While large banks appear to build their own bespoke liquidity risk stress tests, small and medium-sized banks seem to use more or less off-the-shelf models. The vendors surveyed are involved in both types of approaches. Collection of information about vendor models for liquidity stress testing allows for further generalisation of the findings.

5.2 Large banks' liquidity stress tests

In order to get a proper understanding of which findings are still valid from the 2008 ECB publication and to identify areas where further research might be valuable, it is useful to distinguish between the major components of liquidity stress tests: (i) stress scenarios, (ii) methods and models used to quantify scenario impact on a bank's liquidity situation (including underlying assumptions), (iii) time horizons, (iv) the perimeter covered (particularly important for globally active banks), and (v) stress-test results and their purpose. Below, these aspects are discussed first, followed by an overview of vendor models approaches and, finally, the Workgroup's overall findings.

5.2.1 Stress scenarios

Banks appear to have started thinking about incorporating interactions among risk factors in their internal stress tests (in particular the interaction between credit risk and liquidity risk). Prior to the crisis, EU banks conducted stress tests using both adverse market conditions (market- and system-wide scenarios) and idiosyncratic (bank-specific) scenarios, as well as combinations of the two. However, few banks applied all scenario types in parallel. Some banks focused on isolated risk factors in their scenarios, implicitly assuming that risk factors are independent, which is obviously too optimistic.

[23] Drafted by Pausch (Deutsche Bundesbank) with contributions from Pohl (Swiss Financial Market Supervisory Authority FINMA) and Pogach (Federal Deposit Insurance Corporation).

However, the Workgroup's more recent observations suggest that market or system-wide scenarios and, in particular, combined scenarios are gaining importance in banks' internal liquidity stress tests. After the Lehman Brothers default, banks started to develop or expand their use of such scenarios. However, from a methodological perspective, this has turned out to be difficult; an easy-to-implement procedure to achieve such interactions is still lacking. More research seems to be needed in this regard.

The majority of banks considered idiosyncratic rating downgrades, sometimes complemented by deposit withdrawals, losses on loans, wholesale funding liquidity run-offs and operational risk events. Usually expert judgment provided the basis for calibrating the quantitative impact of stress events. Statistical analysis of historical data was less common.

A comparison of the idiosyncratic scenarios used by banks showed a high level of diversity. In terms of stable funding sources in an idiosyncratic stress event, banks relied largely on central bank and interbank market funding. The latter, however, has proven to be an unreliable funding source in the crisis of 2007–09 as, for instance, shown by the recent academic literature discussed in Chapter 3.

Before the 2007–09 crisis, market-wide scenarios considered specific situations with a strong focus on interbank and bond markets. About half of the EU banks surveyed in 2007 considered a downturn in a particular geographical area (eg emerging markets, European liquidity crisis), the cause of the stress event (eg subprime market liquidity crisis, change in monetary policy), the closure of key funding markets, or negative economic indicators. Other banks usually applied a set of assumptions which could be combined more flexibly. Some of the most common assumptions were deterioration in asset marketability, the unavailability of securitisation market, the closing of unsecured interbank markets, drawdowns of granted credit lines, withdrawal of wholesale funds, and disruptions in foreign exchange markets. In sum, a strong focus of the assumptions on unsecured interbank markets and the bond market was evident. However, in the aftermath of the crisis, there appears to be a stronger focus on retail deposits as a stable source of funding.

While prior to 2007 there was a strong focus on stress scenarios covering national markets, recently an international perspective has gained importance. Other shortcomings that need to be addressed in the future are the inclusion of the systemic dimension of liquidity crises (eg simultaneous disruption of all or most of the key funding markets, herd behaviour, interaction of market liquidity and funding liquidity), funding needs related to off-balance sheet vehicles and exposures, second-round effects due to behavioural interactions among market participants, the profit-and-loss impact of widening spreads in connection with longer-lasting stress situations, potential changes of funding terms, and disruptions in foreign currency funding.

Stress scenarios are mostly still revised periodically – usually once a year. However, banks also mentioned other events that trigger extraordinary revisions of banks' liquidity stress-test scenarios. Examples are changes in regulation and monetary policy as well as business developments and market changes. Therefore, the recent crises can be expected to have initiated a significant revision process. The Workgroup observed some major developments: First, the magnitude of shock events in all types of scenarios has increased. That is, the size of shocks considered before the onset of the crisis in 2007 proved generally too small. Second, new liquidity risk drivers are considered (eg unavailability of wholesale funding in a crisis).

Both authorities and interviewed vendors confirmed that many banks consider the LCR and the NSFR as specific scenarios in their internal liquidity stress tests. The calculation of both the LCR and NSFR builds on a number of stress assumptions with respect to banks' short-term and long-term liquidity, respectively.

5.2.2 Methods, models and time horizon

Traditionally, the most common method used by banks to measure liquidity risk is the cash flow maturity mismatch approach. The popularity of this approach follows from its advantages:

transparency, flexibility, and simplicity. However, the disadvantages of the approach (potentially unobserved cash flow mismatches inside liquidity buckets, exclusion of feedback and second-round effects) may require methodological improvement.

The liquidity stock approach and the balance sheet maturity mismatch approach are, although not uncommon, used less often. Some banks even use a combination of cash flow gap analysis and the liquidity stock approach. A general shortcoming of all approaches is that liquidity risk is considered independently from credit risk and market risk, that reputational risk associated with some funding sources is ignored and that the profit-and-loss effects of longer-lasting stress situations are not considered.

The Workgroup's current observations, inside as well as outside the EU, do not show banks starting a large-scale process of revising their internal liquidity stress-testing methods and models. Most banks still apply some kind of gap analysis or stock approach. Revisions are limited to extending the considered time horizons and to attempts to take into account the profit-and-loss effects of liquidity events. Modifications primarily concern assumptions underlying the existing methods and models. One development is clear: as far as banks engage in any revisions, they aim at ensuring compatibility with Basel III liquidity standards and, in particular, the LCR. This is a necessary precondition for implementing the LCR (and the NSFR) and meeting regulatory requirements.

Banks have started to consider longer stress periods, typically six to 12 months. Before the crisis, time horizons for stress test scenarios of EU banks were short. The majority of banks reported that they focused on short-term (one to four weeks) and medium-term (two to six months) time horizons in their market-wide scenarios. Only a minority of banks considered scenarios over a longer period of six months to one year. The recent crises, however, show that stress situations may be lasting longer and can be characterised by a series of shock events. As a consequence, banks have also started to consider longer stress periods, typically six to 12 months. Several banks even consider horizons of two or more years in their internal liquidity stress tests.

Maturity gap and stock approaches are not well suited to long-horizon stress tests. Banks typically use wider time buckets as the time horizon increases. That is, while in the short run the stress impact is determined for each day or week, time buckets spanning several months are used for the longer-run calculations. Most banks however do not explicitly model cash inflows and outflows inside the buckets. As a consequence, a liquidity shortage *inside* a certain (long) time bucket might materialise undetected by standard liquidity stress test approaches. Current research, therefore, needs to address this aspect urgently.

5.2.3 Perimeter covered

The perimeter and scope of banks' liquidity risk stress tests seem to be driven by data availability. The BCBS (2008) *Principles for sound liquidity risk management and supervision* state that liquidity risks should be evaluated both under "business as usual" conditions as well as under various stress test scenarios and that tests should be carried out at both a disaggregated level (eg legal entity, geographical region) as well as at the aggregate group-wide level. Regarding these aspects, the ECB (2008) report finds significant differences between banks. The main driver for the perimeter and scope of banks' liquidity risk stress tests seems to be data availability. This brings the issue of IT integration for the entire banking group to the fore. The IT structure may be particularly challenging when a bank changes business profile (eg product mix, key counterparties) and when there are structural changes in the market environment. Under stress, these issues might become especially acute.

For large cross-border institutions or in the case of intra-group liquidity flows, the quality of liquidity stress tests significantly improves when they are carried out at the level of single entities (subsidiaries, branches) as well as on the group level. Moreover, cross-border banks may face additional risk compared to banks with a strong national or regional business focus. In particular barriers to cross-border transfers of liquidity inside a banking group might be worth considering in

liquidity stress tests. Barriers to liquidity transfers inside a banking group may also occur should ring-fencing – as suggested by the Vickers commission and the Liikanen report – be implemented. Crisis-induced changes in stress-testing practices have not yet led to a significant improvement and therefore more input from the academic literature may prove valuable. This view is supported by authorities' observations from both inside and outside the EU.

5.2.4 Purpose and use of stress-test results

Liquidity stress tests are tools to support risk management. Liquidity stress tests should help inform banks' tolerance towards liquidity risk. The implementation of risk tolerance in liquidity risk management differs among banks, however, and supervisors still observe shortcomings with the integration of liquidity risk stress tests into banks' total risk management.

A majority of banks use a limit system where liquidity risk stress tests are just one of the components taken into account. It is common for banks to also include expert judgments and statistical measures of past liquidity positions. Another common quantification of risk tolerance, the survival period of a bank, is in contrast to limit systems a direct outcome of a liquidity risk stress test. The survival period defines the moment a bank runs out of liquidity under a certain scenario. It is easy to see that, in either case, the scenario design and the liquidity stress test method and model drive the results of the exercise.

Alternatively, risk tolerance can also be quantified as a buffer over a bank's minimum liquidity requirement. Prior to the crisis, only a minority of banks proceeded in this way. Against the background of the lessons learned in recent financial crises, significant improvement is required in this regard. For instance, Grant (2011) points out that banks' liquidity buffers proved too small during the 2007–09 crisis and that one reason for this was the insufficient use of liquidity risk stress-test results in determining the size and composition of liquidity buffers. Moreover, the case studies in Chapter 2 point to the same conclusion.

Banks have started to think about the definition and composition of liquidity buffers available to absorb liquidity stress. Before the onset of the crisis in 2007, many banks thought about buffers in terms of liquidity inflows and borrowing capacity to cover outflows. Current thinking goes towards asset liquidity (rather than liability liquidity) taking into account that in the crisis several asset classes turned out to be less liquid than expected. The ongoing discussion about the fine-tuning of Basel III liquidity standards shows that more research is needed on what, in the end, defines liquid assets.

Funds transfer pricing (FTP) is an important part of banks' enterprise risk management as it translates market-based financial risk information into steering incentives inside large and complex banking groups. FTP "is the process through which banks allocate earnings to the various lines of business in which they are engaged."[24] A recent international survey among 38 large banks identified more or less severe defects in the FTP approaches of these institutions and argues that these shortcomings made banks take on too much structural liquidity risk as a result of extensive maturity transformation.[25] There is agreement in the recent literature that liquidity stress tests need to be an instrument that informs FTP because sound FTP requires liquidity costs to be taken into account during times of stress (institution-specific, market-wide and combinations).[26] Therefore, sound liquidity stress tests appear to be a prerequisite for sound FTP rather than the reverse.

[24] Wyle and Tsaig (2011), p 1.

[25] See Grant (2011), p 3.

[26] See Dermine (forthcoming), Grant (2011) and Wyle and Tsaig (2011).

An open question in this context, which the Workgroup could not settle, is whether and to what extent the internationally standardised liquidity standards LCR and NSFR affect FTP. It is not known whether banks have incorporated LCR and NSFR into their FTP processes. Parts of the recent literature argue that FTP needs to take into account LCR and NSFR requirements anyway.[27] The Workgroup, however, believes that this will only be the case when the Basel liquidity standards prove binding for individual banks' decisions. At the moment the group could not find evidence that this is the case. One reason for this may be that the industry favours FTP approaches that are broader (in terms of, eg, observation period, relevant stress scenarios) than the regulatory metrics LCR and NSFR.[28]

5.3 Vendors' approaches for liquidity risk management and stress testing

Six liquidity risk measurement vendors were invited to present their solutions to the Workgroup. Vendor models should be designed to meet banks' current and future demands regarding liquidity stress-testing tools. As a result, detailed information about vendor models reveals what the state of play is in liquidity risk stress testing and in which direction model developments are moving. In collecting information, the Workgroup started by (i) compiling a list of vendors who offer solutions for liquidity risk management and liquidity stress testing; and (ii) screening publicly available information about vendors and their products. In a second step, some vendors whose approaches looked promising were contacted and preliminary interviews were conducted. Finally, six vendors were invited to present their solutions to the Workgroup in more detail. To guide presentations, a list of questions (available on request) was compiled and sent to presenting vendors. The main insights from this information-gathering exercise are summarised below.

5.3.1 General observations

Vendor models appear to be particularly useful to meet the stress-testing needs of small and medium-sized banks. Such banks often lack the resources needed to develop and implement fully fledged bespoke systems.

Vendor model practices are evolving. The introduction of liquidity standards in Basel III (LCR and NSFR) has obliged vendors to offer compliant solutions. However, lessons learned in the 2007–09 crisis show that future vendor models for liquidity risk management and stress testing need to be better integrated into a bank's total risk management process. To date, no industry-standard or dominant vendor has emerged.

Some vendors offer liquidity risk tools as a part of their enterprise risk management solution (ERMS) while others provide a liquidity tool on a more or less standalone basis. The former often try to replicate the LCR whereas the latter can often compute the LCR, not as the key output but rather as one of the scenarios considered. In general, however, all solutions seem to build on some variant of gap analysis in combination with a stock approach.

Standalone liquidity risk modelling solutions are often provided together with advisory services. With respect to the data quality and the complexity needed to achieve a comprehensive liquidity risk calculation, liquidity risk models contained in ERMS seem to have an advantage. Liquidity stress tests are then integrated in the total risk management process and their results feed directly into the bank's decision-making process. With standalone liquidity risk solutions, banks may find it more difficult to ensure compatibility with other risk management models.

[27] See Dermine (forthcoming).

[28] See Professional Risk Managers' International Association (2012).

5.3.2 Stress-testing approaches and calculated figures

Vendor models span a wide range of liquidity stress-testing approaches. Practices vary from models that calculate the LCR only to models which use stochastic balance sheet modelling to calculate the effects of liquidity stress scenarios based on macroeconomic shocks. Other models can even calculate intraday liquidity risk. Overall, vendor models therefore appear to be very similar to large banks' own models discussed earlier. The key figures that are calculated are:

- time to illiquidity (time required to liquidate specific assets);
- cash flow-based liquidity gap analysis (sometimes with currency and/or business entity breakdown) with and without evolution of the counterbalancing capacity; and
- liquidity-at-risk (similar to value-at-risk, liquidity-at-risk defines the liquidity shortfall at a predefined confidence level).

Most currently available models focus on liquidity gaps for different time horizons for predefined inflow and outflow assumptions. This approach is similar to that of the LCR. Concerning the parameters relevant to the scenario, the vendors in general do not provide standard scenarios (as is the case with respect to the LCR parameters). Instead, customers have to set their own institution-specific scenarios. This is in contrast to credit risk, for example, where external firms will often supply benchmark values for internal models.[29] There was just one exception where a vendor seems to be systematically collecting liquidity data from different banks in order to provide information on a client's liquidity situation relative to its peers.

With respect to the perimeter covered, vendor models show a mixed picture. Some models allow measures to be broken down, for example for individual currencies, subsidiaries, legal entities, business areas or portfolios. The ability to do this depends mainly on the granularity of the database. Providers of ERMS have an advantage here, as much of the data needed are already in the system. The possible frequency of calculations is also very different and varies from one-offs, in the case of assessments, to real-time calculations, for example of the LCR.

Some vendor products will solve for optimal strategies to meet minimum liquidity requirements. In the field of advisory-based products, there are also solutions that provide optimisation engines that can suggest specific funding strategies and other balance sheet changes to meet certain objectives – such as becoming LCR-compliant. Some providers try to take into account second-round effects and have plans for calculation of profit-and-loss effects, but these functionalities are still at an early stage. In this regard, ERMS also seem to have an advantage over standalone liquidity risk solutions.

5.4 Summary and issues for further research

Liquidity risk measurement has increased in importance. In the aftermath of the 2007–09 crisis, liquidity risk stress tests appear to have gained importance in banks' internal stress testing. Observations suggest that banks increasingly consider liquidity risk stress testing as an important part of their enterprise risk management and decision-making process. The increasing supply of vendor solutions with these capabilities supports this view.

[29] One potential explanation may be related to operational risk. On the one hand, liquidity risk appears to be highly institution-specific. Benchmark values for internal models or benchmark scenarios might prove completely inadequate to cover the liquidity risk of a specific institution. On the other hand, given the complexity of recent vendor models, which is particularly relevant to ERMS, individual banks may find it very difficult to calibrate models correctly and choose adequate stress scenarios. As a result, banks might have an incentive to stick with inappropriate benchmark starting values and scenarios.

Improved methodologies to measure liquidity risk are needed. From a methodological perspective, banks as well as vendor models appear to have made relatively little progress so far. They still apply "old" approaches (cash flow maturity mismatch, liquidity stock, balance sheet maturity mismatch approach). Revisions appear limited to underlying assumptions accompanied by a lengthening of the time horizons considered. Major adjustments can be observed with respect to stress scenarios: banks – even when they implement vendor solutions – increasingly focus on combined scenarios that consider idiosyncratic and market-wide stress events in parallel; banks have increased the sizes of specific shocks, and have started to consider new risk factors such as wholesale funding drying up in times of stress.

Methodologies need to jointly model liquidity and credit stress including second-round or "feedback" effects. Banks' internal liquidity risk stress tests as well as vendor solutions appear to require improvement in several aspects. In particular, methods and models need to better account for interactions between major risk factors (especially the interaction between credit risk and liquidity risk) and to allow for an assessment of profit-and-loss effects and second-round effects of specific stress events. Another modelling issue appears to be the detection of intra-bucket liquidity gaps: when extending the time horizon of their liquidity risk stress tests, banks usually also increase the time span of the buckets they consider in the longer term. This, however, raises the risk that liquidity shortfalls within these long time buckets might be missed.

Major open issues include how to address the evolution and effects of liquidity stress over time as well as the question of which assets will remain liquid in a stress scenario. Past stress scenarios appeared static as they, in particular, failed to consider disruptions of all or most key funding markets, herd behaviour, and the interaction of funding and market liquidity. Moreover, stress situations were normally considered short-term events. But the 2007–09 crisis showed that stress can be long-lasting, involve a sequence of shocks and change funding terms over time. In addition, funding needs related to off-balance sheet exposures need to be considered more carefully. A final open issue is banks' liquidity buffers. As banks have started to think about liquidity buffers in more detail, a solid definition seems necessary when it comes to determining the adequate composition and the optimal size of a bank's liquidity buffer. Unfortunately, to the best knowledge of the Workgroup, the existing (theoretical and empirical) literature offers little guidance on how to address these open issues. Considering its importance, research on these issues may prove useful.

6. Other considerations in liquidity stress testing[30]

This chapter discusses a number of stress-testing issues related to the interaction of banks with the non-bank financial sector and with central bank operations. It also provides additional detail on the interaction of liquidity and solvency risk, the importance of the macro environment, and network, feedback and second-round effects. Some of these issues have already been touched upon in earlier chapters but are discussed more extensively in this chapter.

6.1 Interaction with non-bank financial intermediaries

The most important non-bank financial institutions that supply bank funding are shadow banks (ie money market funds, hedge funds and SPVs), **insurance companies, pension funds and asset managers.** The interactions between these groups of financial intermediaries touch on many aspects of liquidity stress tests: both contractual and behavioural inflows and outflows as well as the counterbalancing capacity are all different for non-banks as compared to banks.

Non-bank financials not only provide funding to banks but are also financed by banks. As a consequence, the behaviour of non-bank financials affects banks' contractual inflows and outflows**.** Asset markets also link banks and non-banks through collateral requirements, which may create feedback loops between market and funding liquidity, liquidity risk exposure and risk-bearing capacity. Liquidity is an endogenous characteristic of assets that depends on the state of the economy and the financial system.

6.1.1 Systemic liquidity – theory

The experience of the 2007–09 financial crisis demonstrates that modern banking cannot be viewed in isolation from capital markets.[31] Liquidity in the banking system has to be interpreted and analysed as a systemic phenomenon. In normal times, markets, instruments and counterparties can offer close substitutes for obtaining liquidity, and liquidity risk is reduced through diversification across all these liquidity sources. During times of systemic liquidity stress, what were once close substitute sources for liquidity may no longer be. Some instruments become safe havens, while others experience strongly reduced market liquidity. In addition, the sudden shift in liquidity may alter expectations and the behaviour of institutions. When systemic liquidity is high, banks may self-insure their liquidity risk (ie they are more willing to lend and supply-side tenors are longer) and rely on future availability of liquidity. This behaviour increases liquidity and fosters positive feedback-loops and network externalities. Such behaviour can however reverse quickly, magnifying the impact of a liquidity reversal in any instrument or market segment. The risk of such reversals is defined as systemic liquidity risk.

During a lending boom, the importance of retail deposits shrinks in favour of an increase in non-deposit liabilities, bank leverage, and bank liquidity risk. Examples of "non-traditional" bank liabilities are, for instance, repos and financial commercial paper. The use of overnight repos became so

[30] Drafted by Schmitz (Central Bank of the Republic of Austria), Bevilacqua (Bank of Italy), Liu (UK Prudential Regulation Authority), Schmieder (Bank for International Settlements) with a contribution by van den End (Netherlands Bank).

[31] See eg Brunnermeier (2009), Gorton and Metrick (2012) and Brunnermeier and Pedersen (2009) for the interrelation between market and funding liquidity, Adrian and Shin (2010) and Geanakoplos (2010) for the interdependence of liquidity and leverage.

prevalent before the financial crisis that Wall Street investment banks were rolling over a quarter of their balance sheet overnight (Brunnermeier (2009)). The change in the liability structure during boom times in favour of wholesale funding also leads to a shortening of funding maturities.

When times are good, banks will lend more to each other. In terms of intermediation, the greater use of interbank lending is associated with longer intermediation chains. Shin (2010) gives an illustrative example where the funding of a retail mortgage involves four other parties and is eventually financed by households owning shares in money market funds.[32] These long intermediation chains fundamentally change the nature of banking by interlinking banks and capital markets in such a way that the financial system itself becomes a potent amplifier of booms and busts, so that liquidity becomes a systemic phenomenon (see, eg, Gorton and Metrick (2012)).

When stress arises, systemic dynamics can feed a downward spiral where individual actions to protect the banks' self-interest precipitate disaster. Perceived risks increase and borrowers become nervous and curtail their exposures. Leverage decreases, asset prices fall and some credit losses occur. A greater proportion of funding has to come from outside claimholders and interbank funding disappears rapidly. Liquidity dries up. If banks cannot find additional "outside" funding, they must reduce asset holdings by curtailing lending or selling assets.

The systemic nature of liquidity suggests that liquidity stress tests must focus on stress scenarios that involve a combination of runs by wholesale creditors, asset fire sales, and the risk of a general credit crunch. Common exposures through repurchase agreements, reliance on money market funds and linkages to clearing houses and exchanges should form a central part of the scenarios. Moreover, shocks can also originate from outside the banking sector (eg regulatory reform of US MMFs). The dynamics of the bank/non-bank interaction under stress should inform the conceptual approach to liquidity stress-test design.

6.1.2 Measuring systemic liquidity

Many of the proposals for measurement of systemic liquidity still lack realism. An example is the liquidity maturity index proposed by Brunnermeier et al (2012). The index assigns liquidity values to all liabilities (negative liquidity values), assets (positive liquidity values), and off-balance sheet commitments of each bank in the system under severe stress.[33] It accounts for the interaction between funding and market liquidity and the interaction between leverage and liquidity (ie the liquidity of assets is endogenous). In a companion paper (Brunnermeier et al (2011)), the authors suggest gathering comprehensive data on financial companies' capital and liquidity sensitivities with respect to a large set of individual risk factors and scenarios that combine these risk factors. Although helpful, this proposal places considerable trust in firms' internal models and glosses over the importance of behavioural changes in a crisis.[34] Duffie (2012) suggests a similar but more streamlined approach that reduces the

[32] Shin's analysis is also mirrored in other recent theoretical contributions, such as in Brunnermeier and Pedersen (2009), Geanakoplos (2010), Geanakoplos and Fostel (2008) and Gennaioli et al (2011).

[33] All liabilities are assumed to be drawn at the earliest possible time (based on contractual maturities) except sight deposits (assumed to be stable even under severe liquidity stress). Commitments are fully drawn although the resulting loans might be repo-ed and would then receive a positive liquidity value. All assets receive a haircut based on empirical evidence on repo haircuts and/or market price fluctuations under stress. Only central bank reserves and government bonds are considered fully liquid even under systemic stress.

[34] All financial firms would be covered by the scheme (especially non-bank financials). The reported data would be the output of firms' internal risk models. Core scenarios would remain unchanged over time resulting in a panel data set. The authors briefly touch on banks' behavioural reactions, feedback and network effects. They suggest that supervisors should also gather data on firms' behavioural reactions in all possible scenarios (contingency funding plans), check the consistency across these and publish the results. Firms would then adjust their reactions and this recursive process is assumed to lead to a stable equilibrium of consistent contingency funding plans.

number of reporting firms and the underlying scenarios to 10. He includes a network dimension by requiring firms to report their 10 largest counterparty exposures.

At present, most systemic liquidity risk measures rely on a stock approach, internal models and inconsistent scenario implementation. The stock approach to liquidity measurement and stress testing is increasingly replaced by a cash flow approach in banks (Fiedler (2007)) and in banking supervision (eg Banking Supervision Committee (2009, 2010), CEBS (2010b), Schmieder et al (2012)). In addition, it may be problematic to rely on firms' internal risk models when constructing a systemic risk measure. The stress scenarios that form the basis of these measures must be based on judgment and are unlikely to be comprehensive. Moreover, due to differences in risk management models, as well as in the interpretation and implementation of scenarios, the data generated by these suggestive approaches are unlikely to be fully comparable across reporting institutions.

Chen et al (2012) construct a volume and price series for "global" liquidity distinguishing between core and non-core liquidity. The former consists mainly of total resident deposits at banks while the latter refers to total non-resident deposits at banks plus loans and securities (excluding shares) of non-banks, non-bank financials and banks. The price series for core liquidity is constructed by volume-weighted spreads of resident deposits (up to one year) and the six-month interbank offered rate. The price of the non-core component is estimated using a dynamic factor model. This global liquidity measure is unlikely to be useful for liquidity stress testing. The maturity structure of the individual items is not taken fully into account; all items are equally weighted in the volume series irrespective of their liquidity value and/or roll-over risk; and the measure of spreads convolutes a number of drivers of such spreads with very different implications (eg liquidity and credit risk).

One possible approach for constructing a systemic liquidity risk indicator is to associate the build-up of systemic risk with collective underpricing of liquidity in good times when funding and market liquidity are abundant. Using this approach, IMF (2011b) constructs three indicators of systemic liquidity risk. The systemic liquidity risk index monitors whether arbitrage relationships in various financial market segments hold. Violations are interpreted as indications of lack of liquidity. The systemic risk-adjusted liquidity model uses contingent claims analysis to measure liquidity risk. Individual institutions' liquidity risks are measured and the joint probability of a systemic liquidity event is estimated. The IMF also recommends an integrated macro stress test modelling approach that incorporates solvency and liquidity risk (see Chapter 4 and Section 6.2.1 for a discussion).

It is important to account for the non-bank (or shadow bank) sector in a systemic liquidity measure. The stock of outstanding liabilities of the shadow banking system, as analysed by Pozsar et al (2010), decreased markedly during the crisis. Estimates of the size of the US shadow banking liabilities were roughly $22 trillion in June 2007 (compared to $14 trillion for traditional banking liabilities).[35] By the end of 2008, the total had decreased by about $2 trillion and fell to $15 trillion by early 2012, despite substantial government intervention. Their alternative net measure subtracts double counting and reached a peak of about $17 trillion in June 2007; this measure dropped to about $5 trillion by early 2012.

[35] Pozsar et al (2010) define shadow banks as a network of non-bank financial institutions that engage in credit, maturity, and liquidity transformation but do not have access to central bank funding or public credit guarantees. The network encompasses certain activities of (i) regulated financial corporates, (ii) mortgage and monoline insurers, (iii) unregulated entities, and (iv) money market intermediaries. Examples of (i) are government-sponsored entities, securitisation by broker-dealers, securities lending by insurers, pensions funds, CDS sold by insurers, asset management affiliates of banks, and finance companies. Examples of (iii) are conduits, structured investment vehicles, credit hedge funds and SPVs. Examples of (iv) are money market funds and ultra-short bond funds.

Stress tests should include the effects of rehypothecation. Singh and his various co-authors (Singh and Aitken (2009, 2010); Singh (2011); Singh and Stellar (2012)) study the impact of rehypothecation. Rehypothecation is the process in which collateral recipients use incoming pledged collateral as collateral for their own funding operations. Singh (2011) concludes that the velocity of pledged collateral fell from 3 pre-Lehman to 2.4 post-Lehman.[36] During stress periods, available collateral is used less often, adding to the collateral squeeze, which renders some asset classes too risky to be accepted as collateral (eg ABS). The chain of collateral rehypothecation becomes shorter, substantially reducing systemic liquidity. In practical terms, rehypothecated collateral requires that multiple transactions be recognised in the analysis of outflows, inflows and counterbalancing capacity.

Investor perceptions can be fickle, so that the shadow money supply can be highly unstable. The shadow banking system produces very safe and very liquid assets provided investors believe that they will remain safe and liquid. Investor perceptions of the stability of the shadow banking system money stock are based on beliefs of implied support from regulated banks (eg as sponsors of structured investment vehicles), from credit/liquidity enhancements (eg by monoline insurers) or from seemingly safe collateral (eg repo market, ABCP). Liquidity and capital buffers of the shadow banking components are relatively low compared to the traditional producers of safe and liquid assets, ie banks.

6.2 Integrating capital, liquidity and contagion stress testing

Liquidity risks typically do not materialise in isolation but rather in combination with other risks, such as solvency and contagion risks. Solvency issues are relevant for liquidity stress testing because quickly liquidating assets will come at a cost, which can hurt solvency buffers. During benign times, relatively weak liquidity profiles are still supported by markets at moderate cost. During stress periods, however, even market participants with comparably sound solvency profiles can experience liquidity strains. Recent experience shows that reputational contagion in particular can spread quickly. Liquidity risk analysis and stress tests must thus account for both solvency and contagion risks.

6.2.1 Liquidity and solvency

Solvency and funding costs are linked through the price of funding and collateral requirements. Liquidity stress will increase the cost of funding, especially wholesale funding. Furthermore, stress will increase collateral needs for secured funding sources (eg through margin calls), which has an explicit impact on volume and an implicit effect on the costs of funding.[37]

Evidence suggests that there is a non-linear relationship between solvency (as implied by total capitalisation under the internal ratings-based approach) and funding costs for German and other European banks (Schmieder et al (2012)).[38] Other, related work on the evolution of funding costs under stress has been undertaken as part of the IMF's Global Financial Stability Report (IMF (2011b)), drawing upon the finding that bank solvency is closely linked to the fiscal stance of a bank's home country.

Counterparty credit risk plays a predominant role for secured funding as collateral requirements depend on the rating of a counterpart.[39] A deterioration in solvency (ie a rating

[36] Prior to Lehman, total collateral received by dealers was $10 trillion while the amount pledged by primary sources was $3.3 trillion. After Lehman this changed to $5.8 trillion over $2.5 trillion.

[37] An additional, related effect is that unsecured funding might become unavailable and has to be replaced by secured funding.

[38] See also Davies and Tracey (2012) and Noss and Sowerbutts (2012).

[39] And, naturally, the quality of collateral.

downgrade) or a change in investor expectations may lead to an increase of collateral requirements and a reduction in bank funding. While the impact is highly bank-specific, it is also non-linear, at least once a bank drops below investment grade. Deutsche Bank, for example, reports that a drop in its rating by a single notch results in a loss of funding of about 2%, and that the drop is about three to four times larger for a rating deterioration by two to three notches (Hesse et al (2012). If market conditions deteriorate further, funding markets will close.

Even if market volatility does not impact regulatory capital directly, it might have an impact on funding risk. In the context of the sovereign debt crisis, large mark-to-market losses on sovereign debt holdings, while not necessarily affecting regulatory capital when assets are held to maturity, may still erode confidence and generate liquidity stress. Rising funding costs may also increase a bank's Tier 1 capital under current regulation. The Debit Valuation Adjustment (DVA) associated with the decline in the fair value (FV) of banks' structured notes in the stress is reversed out of banks' Tier 1 capital, while the DVA associated with the FV change in derivative liabilities is included in trading revenue and flows into banks' Tier 1 capital. While changes in the DVA can be associated with a number of factors (eg a change in volatility or vega), a widening of a bank's own credit spread can actually increase a bank's DVA, earnings and Tier 1 capital. Counterparties are unlikely to take comfort in the portion of a bank's regulatory capital associated with the cumulative DVA adjustment.

Current models try to simulate how a macro financial shock primarily affecting solvency, reinforced by an idiosyncratic crisis at the bank level, will translate into a drain of funding. Aikman et al (2009) (discussed in detail in Section 4.3.2) can be regarded as the most comprehensive approach to endogenising liquidity risk stress tests in a modelling framework. Barnhill and Schumacher (2011) develop an empirical model linking solvency and liquidity risks, similar to work by van den End (2010) and Wong and Hui (2009). Some recent studies (Chan-Lau (2010), Barnhill and Schumacher (2011)) have used network models to capture the link between solvency and liquidity (as discussed more fully in Chapter 4).

While all these frameworks are a substantial step forward in terms of modelling, many challenges remain. Margin calls for derivatives are one of the key challenges.[40] Similarly, US banks hold deposits in escrow, especially institutions providing mortgage servicing. Once a bank's rating is downgraded sufficiently, a bank can cease to be eligible to hold escrow deposits.

A simple way of introducing interaction between funding liquidity risk and solvency uses haircuts on counterbalancing assets. If banks have to sell assets below book value, the losses affect banks' profit and loss accounts and their capital adequacy ratios. For liquidity stress tests, this implies that volatile assets with high haircuts should not be considered in the counterbalancing capacity, not even with high haircuts. The same is true of assets that, if sold in large amounts, experience substantially negative price reactions. Even with high haircuts, such assets increase solvency risk under liquidity stress.

A longer-horizon liquidity stress-test approach must recognise that solvency and liquidity risks are linked through higher funding costs. This channel is triggered by the funding profile rather than solvency issues alone. As bank funding tenors are typically shorter than their investment tenors and a proportion of the rates are fixed, funding cost increases cannot be recouped immediately by increasing asset margins. Sharp increases in funding costs can translate into negative asset margins that hurt profits. Examples of these dynamics are EU banks with low margin/high volume business models.

[40] As a bank's credit quality deteriorates, it is usually required to post additional collateral to cover derivative liabilities. These triggers are described in a bank's ISDA agreements and could be induced by changes in a bank's rating from recognised external credit assessment institutions, CDS spreads or other credit-related factors (see BCBS (2013), paragraph 118).

Finally, the franchise value of a bank has to be taken into account in liquidity stress tests. If a bank deleverages through its loan book, and loan production is not maintained at a sufficient level due to liquidity constraints, the bank will lose its franchise value. Net interest margin and fee income deteriorate, its share price deteriorates, funding costs increase, tenors and volumes decrease and insolvency pressures build.

6.2.2 Liquidity and contagion stress testing

Standard approaches for simulating liquidity risk and contagion are very helpful in understanding the network topology, but they suffer drawbacks. Typically these models focus on the contractual cash flow links between banks, ie the direct relationship. These links can take the form of interbank unsecured money market transactions, repos, commercial paper, bank bonds and other bank liabilities, but also the form of cross-equity holdings (Boss et al (2004, 2006), Upper (2011), van Lelyveld and Liedorp (2006)). Potential knock-on effects of failing institutions are analysed based on empirical (van Lelyveld and Liedorp (2006)) or hypothetical (Nier et al (2007)) network models. As the models generally focus on a single market, they do not capture contagion via funding markets, reputational effects, and markets for liquid assets held in the counterbalancing capacity. Moreover, the approach was developed for solvency stress tests: once an institution is insolvent, it fails to honour its commitments and counterparties are exposed to losses. Banks can face liquidity stress well before insolvency, and liquidity tests are meant to capture earlier stages of potential strains. Finally, changes in behaviour conditional on actual default(s) are ignored. Incorporating these is not trivial.

Some headway has been made in modelling reputational contagion (Aikman et al (2009) in Chapter 4). One method distils commonalities in bank characteristics (eg business model, capital adequacy ratios) into an index. If one bank faces solvency problems in the stress test, others with similar index values are assumed to be affected as well. They then face higher funding costs, are shut out of some funding markets or face a bank run. Other indirect approaches are to simulate a joint withdrawal of funding from banks with a similar business model, which was one key dimension of stress during the financial crisis that affected investment banks. Relatedly, contagion can be integrated in cash flow-based stress tests via direct interbank exposure (expected contractual cash inflows do not materialise), through assets exposure (bank liabilities in the counterbalancing capacity are subject to an issuer default), or via market-wide stress scenarios (all or a subset of banks are shut out of funding markets and/or face a bank run) (Schmieder et al (2012)). Finally, van den End (2010) suggests methods for estimating or simulating bank behavioural reactions.

6.3 The role of the central bank as a lender of last resort

Central bank support in its lender of last resort function is defined as a discretionary and extra-ordinary deviation from the standard framework of monetary policy implementation. Policy measures may include broadening eligible collateral, lengthening of funding tenors, switching from maximum allotment volumes to full allotment, and any liquidity provided to individual institutions on specific terms that are not available to other market participants. In contrast, an increase of the maximum allotment volume for open market operations in the face of an expected increase of the structural liquidity deficit at the target rate is not considered a lender of last resort operation. The increase of the maximum allotment volume is motivated by monetary policy considerations; otherwise the central bank would not be able to steer its policy rate.

Unfortunately, banks frequently rely on central bank support in times of liquidity stress in their contingency funding plans (CFPs) and in their approaches to liquidity risk management (ECB (2008)). The ECB report identifies this as a weakness, due to potential adverse reputational effects and potential operational hurdles. Specifically “banks should ensure that they can manage their liquidity risk on their own and not rely on central bank refinancing beyond common lending facilities and open

market operations. Extraordinary central bank operations (such as the ECB fixed rate tenders with unlimited volume on 9 August 2007) should not be relied upon in CFPs" (p 45).

Regulation should encourage banks to meet their obligations when they are due (at reasonable cost), but also maintain liquidity buffers that can absorb idiosyncratic and combined (idiosyncratic and market) shocks without relying on extraordinary liquidity support by central banks (CEBS (2009, 2010a), BCBS (2010)). Banks can however make use of standard open market operations and of standing facilities. In liquidity regulation, backward-looking, risk-insensitive stock approaches are being replaced by a forward-looking, risk-sensitive functional approach. In this approach, liquidity stress tests play a central role in ensuring that banks manage their liquidity independent of the state (Schmitz and Ittner (2007), Schmitz (2011).

An important outstanding issue is the extent to which central bank eligible assets should be recognised as liquid assets in qualitative (liquidity stress tests, liquidity buffers) and quantitative liquidity regulation. Banks have argued for full recognition for some time. Recently, some regulators also called for an explicit reliance on the lender of last resort function of central banks in their LCR proposals (eg EU Presidency compromise on the CRD IV/CRR of 22 October 2012). The following section discusses the strength and weaknesses of this approach.

6.3.1 Financial stability perspective

Banks' excessive liquidity risk can have substantial negative ramifications for other market participants, financial markets, society and central banks (eg Schmitz and Ittner (2007), Rochet (2008)). As these costs are not internalised, banks' choice of optimal liquidity risk exposure and liquidity risk capacity deviate from the social optima. The underpricing of liquidity (and other) risks is a common feature of credit booms and particularly so in the build-up to the current crisis (Goodhart (2008), Trichet (2009), Sharma (2011), Tarullo (2012)). To realign liquidity profiles with the social optimum, liquidity regulation has to be binding at the margin. That requires banks to self-insure against liquidity shocks; ie the lender of last resort function cannot always be counted on in liquidity stress tests or contingency funding plans (ECB (2008)).[41]

If central bank eligibility is the criterion for eligibility in the counterbalancing capacity, the stress test essentially assumes that the bank has a *committed* liquidity line with the central bank. Currently these lines are often not fairly priced. Consequently, the private marginal costs of illiquidity for a bank are not equal to the social marginal costs, and banks are unlikely to choose a liquidity risk profile consistent with the social optimum. Liquidity regulation thus does not achieve its purpose. For liquidity regulation to bind at the margin, only assets that are expected to be liquid in private markets should be eligible for the counterbalancing capacity in liquidity stress tests. Alternatively, the liquidity line provided by the central bank needs to be priced so that it equals the opportunity costs of holding liquid assets.

Quantitative liquidity requirements can be used to address the problems of moral hazard associated with the lender of last resort function (Ratnovsky (2009), Cao and Illing (2008)). Farhi and Tirole (2012) and IMF (2011a) extend the moral hazard problem from the micro level to the macro level. When the entire banking system raises its exposure to liquidity risk (at a given counterbalancing capacity), the central bank may have little choice but to bail the system out.[42] Optimal monetary policy is time inconsistent, as central banks have to change their primary objective from price stability to financial

[41] Alternatively central banks can attempt to actuarially fairly price potential liquidity support.

[42] In Farhi and Tirole's model, strategic complementarities between banks' choices of liquidity risk emerge. Thus, it is optimal for each bank to increase liquidity risk, if other banks are expected to do so as well.

stability. The provision of emergency liquidity and the associated lower interest rate level lead to a further misallocation of capital and precipitates the next financial crisis. In addition, any central bank lender of last resort function reduces the credibility of a "no bailout" commitment and increases moral hazard in the future. Macroprudential liquidity regulation should set liquidity buffers that will enable banks to weather a liquidity crisis without a central bank bailout. Macroprudential policies should thus aim at more accurately pricing contingent liquidity support by central banks. The ensuing internalisation of externalities would reduce the probability that future central bank bailouts will be necessary.

Liquidity stress-testing practices must not infringe on central banks' discretion. Acting as lender of last resort involves judgment under uncertainty, as central banks should only lend to solvent banks against high-quality collateral and at a penalty rate (ie at least at rates that prevail under stress). Assessing the solvency of a bank facing liquidity stress is no easy task, especially under time pressure (Goodhart (1987)). Given these difficulties, the central bank concept of "constructive ambiguity" might face a severe time inconsistency problem: under time pressure and given the high economic and societal costs of bank defaults, central banks might face strong economic incentives and political pressure to provide lender of last resort support for banks without a rigorous assessment of their solvency and against low-quality collateral In order to avoid such pressure in the first place, lender of last resort support should not be relied upon in liquidity stress tests. Indeed Rochet (2008) argues that liquidity regulation should be introduced to reduce this kind of pressure on central banks.

The traditional role for a central bank is to guarantee the liquidity of the economy as a whole, but not the liquidity of individual institutions (Humphrey (1989)). The market should then allocate liquidity efficiently among banks (Goodfriend and King (1988)). Contrary to popular misperception, Bagehot (1873) advocates that individual banks are self-reliant. Precisely in order to avoid moral hazard when assessing the solvency of a distressed bank, Bagehot (1873) – and also Thornton (1802) – interpret the lender of last resort function differently to today's common perception: the central bank should not bail out individual illiquid banks (unless their solvency is clearly sufficient and they have very good collateral), but protect the sound banks from the negative repercussions of the failure of an illiquid bank. It should do so by providing liquidity to the market. For individual banks' liquidity stress tests, this implies that the lender of last resort function should not be considered as a primary source of liquidity in a stress test scenario.

In the case of banks' liquidity risk exposure in foreign currencies, the home central bank is not capable of acting as lender of last resort (unless non-standard emergency measures are introduced, such as the swap lines between the US Federal Reserve, the Swiss National Bank, the Bank of England and the Eurosystem). Freixas et al (1999) discuss the issue of cross-border exposure. An international lender of last resort is not backed by sovereign taxation power, but by capital, which might lead to a credibility problem. Consequently, the lender of last resort function cannot be considered in liquidity stress tests of foreign currency portfolios, ie when the bank does not have access to the respective central bank.

6.3.2 Monetary policy perspective

The lender of last resort function is distinct from central bank reactions to endogenous shifts of the demand for central bank reserves. If the entire banking system experiences an adverse liquidity shock, the demand schedule for central bank reserves shifts outward. The demand for reserves is then determined by banks' transactions and precautionary demand for liquidity, their expectations regarding the future stability of the money market, of market liquidity of liquid assets, and of the liquidity situation of the banking sector. In order to implement monetary policy, ie ensuring that the policy variable equals the policy target, the central bank has to increase the maximum allotment volume.

The exact demarcation between monetary policy implementation and extraordinary liquidity support is not straightforward. Liquidity shocks have an impact on the structural liquidity deficit and thus on monetary policy implementation even without explicit liquidity support for the

market or individual institutions. Currently, qualitative liquidity regulation allows banks to factor "standard monetary policy operations" into their liquidity stress tests (eg CEBS (2009)). Furthermore, the implementation framework of some central banks (eg the Eurosystem) is highly standardised while others operate in markets at arm's length (eg the US Federal Reserve). As a result the financial stability perspective needs to be complemented by a monetary policy perspective on the treatment of central bank operations in liquidity stress tests.

Tension can emerge between the lender of last resort function and the central bank´s monetary policy function if a bank's idiosyncratic demand interferes with the achievement of targeted policy rates (Freixas et al (1999)). Standard open market operations are conducted as variable rate tenders (eg Eurosystem, Bank of England, US Federal Reserve). The central bank estimates the structural liquidity deficit of the banking sector at the targeted money market rate and the level of autonomous factors (eg changes of demand for banknotes, which are fully accommodated). Then a maximum allotment volume is set, which is communicated to the market. If one bank experiences an adverse idiosyncratic liquidity shock, it would increase its bid volume and bid rate and, at a given maximum volume, this would crowd out bids from other banks and increase the marginal allotment rate. The latter would deviate from the minimum bid rate (the policy rate) and the central bank would thus not be able to implement its policy decision in the market. In order to avoid such a conflict of interest, banks should be incentivised not to rely on the lender of last resort function.

Central bank excess reserves are the most liquid asset in an economy and are clearly eligible in the counterbalancing capacity. The treatment of central bank minimum reserve requirements in the counterbalancing capacity depends on their role in the monetary policy implementation framework of central banks. Some central banks (eg the Eurosystem) impose minimum reserve requirements to determine and to smooth the demand for central bank reserves in open market operations (Schmitz (2006, 2011)). Under this framework, minimum reserves are a binding constraint for banks over the maintenance period imposed solely for monetary policy purposes. In other systems, minimum reserve requirements are explicitly motivated as liquidity reserves for the banking system. They are only effective if the minimum reserve requirement is relaxed to allow the bank to cover net outflows when a bank faces an idiosyncratic liquidity shock. Minimum reserve requirements are then available as counterbalancing capacity. In the former, they are not; they are encumbered for monetary policy purposes. As such, the treatment of minimum reserve requirements in liquidity stress tests should be determined by local authorities and central banks.

The treatment of minimum reserves must be consistent with the central bank framework for monetary policy operations when modelling the outflow section of a liquidity stress test. Consistency is automatically imposed when central bank operations are conducted in assets that are also treated as highly liquid in the counterbalancing capacity. However, if the set of eligible collateral at the central bank is wider than the set of assets included in the counterbalancing capacity of the liquidity stress test, the difference between the run-off factor and the haircut affects the liquidity position of the bank. Operations with the central bank that exceed the minimum reserve requirement should be treated like all other collateralised operations with other market participants based on the underlying collateral

Central bankers are also concerned about incentives for banks to arbitrage liquidity regulation via central bank operations (eg Cœuré (2012)). Differences in treatment between repos with central banks compared to other market participants distort bank behaviour in central bank operations. This could lead to more banks participating in central bank operations, changes to banks' bidding behaviour in open market operations, shifts of demand from short-term (less than 30 days) to longer-term operations (more than 30 days), incentives to post lower-quality collateral with central banks, and changes of the determinants of the demand for central bank reserves. The combination of preferential treatment for central bank operations and for factoring the lender of last resort function into liquidity stress tests may encourage arbitrage between qualitative liquidity regulation and central bank operations.

Liquidity regulation and stress tests might also have indirect effects on the environment in which monetary policy is implemented (Cœuré (2012)). Liquidity regulation aims at reducing banks' reliance on fragile funding sources, such as the short-term unsecured money market (see Chapter 3 on wholesale markets). Some central banks (eg the Eurosystem, US Federal Reserve, Bank of England) choose the overnight rate as the target rate; consequently, banks' diminished reliance on overnight funding can make the market even more susceptible to liquidity shocks, distort the price discovery mechanism, and diminish the role of overnight rates in loan pricing. This affects the transmission channel of monetary policy. Thus, Cœuré (2012) calls for a substantial recalibration of liquidity regulation to avoid a negative impact on overnight markets.

Central banks´ experience with existing liquidity regulations has not been problematic. The Swiss National Bank targets three-month Libor and does not report any negative impact from its liquidity regulation and stress-testing practices on monetary policy implementation. In Sweden, the LCR was introduced in 2013 and the large Swedish banks are already compliant. The Swedish central bank targets the unsecured overnight rate, but does not report any negative impact on its monetary policy operations. The Dutch central bank introduced liquidity regulation similar to the LCR in 2003 and has not reported any adverse impact on monetary policy implementation.[43]

6.3.3 Incorporating central banks in stress tests

In authorities' stress tests, central bank actions are incorporated. The lender of last resort function of central banks is incorporated either via the set of eligible assets in the counterbalancing capacity (including haircuts) or via run-off rates of central bank operations in the outflow section of a standard liquidity stress test.

The EBA *2011 Liquidity Risk Assessment* included illiquid central bank eligible assets in banks' the counterbalancing capacity. In all scenarios, sensitivity analyses were conducted with respect to liquidity that could be generated from these assets via extraordinary central banks support (ie full allotment). In the mild scenarios, lender of last resort capacity was fully recognised. In the more severe scenarios, lender of last resort liquidity was excluded in a step-wise manner by increasing haircuts on the respective assets to 100%. The run-off rate of central bank operations was assumed to be 100%, consistent with the contractual maturity approach taken in the exercise.

The characteristics of the underlying collateral used in central bank operations are an important feature of the stress test. Central bank operations are collateralised. If the collateral posted by a bank is included in the counterbalancing capacity with identical haircuts as in the central bank operation, then recognising central bank liquidity does not have any impact on the liquidity situation of the bank. The gross cash outflow is counterbalanced by a collateral inflow. However, the approach does have an impact when the banks post illiquid assets as collateral with the central bank (assets that are not included in the counterbalancing capacity). The gross outflow is not counterbalanced by an eligible securities inflow; the liquidity situation of the bank worsens relative to a 0% run-off factor for central bank operations.

In the Banking Supervision Committee's *Pilot concerted round of common liquidity stress tests* (Banking Supervision Committee (2010)) regular central bank operations were explicitly modelled in one of the scenarios. The scenario included a tightening of the very loose liquidity policy of the Eurosystem at the time (ie a return to variable rate auctions and a tighter set of collateral). Again, consistent with the contractual maturity approach of the pilot, the run-off rate for central bank

[43] Sources: A report submitted to the ECC by Sveriges Riksbank; personal conversations of the authors with Dutch and Swiss central bank officials.

operations was 100%. Banks' access to central bank liquidity was limited by a maximum that was derived from their allotment before the beginning of the current financial crisis (ie limited to banks' margining requirements). The lender of last resort function was not taken into account in the counterbalancing capacity.

The following recommendations summarise issues related to the lender of last resort function in liquidity stress tests:

- The treatment of minimum reserve requirements in liquidity stress tests depends on their function (monetary policy purpose or financial stability purpose) and usability. The treatment of the respective central bank operations (cash outflows) should be consistent with the treatment of minimum reserve requirements.
- Arbitrage opportunities between liquidity regulation, stress testing and central bank operations should be avoided. Except for the minimum reserves that are encumbered for monetary policy purposes (and not explicitly usable as liquidity reserve under liquidity stress) central bank operations should not be treated differently from collateralised operations with other counterparties.
- Only assets that are expected to be liquid on private markets should be eligible for the counterbalancing capacity in liquidity stress tests.
- Only central bank operations must be taken into account in liquidity stress tests that would not trigger other (adverse) developments (eg contingent capital conversion or financial instrument clauses).
- Only central bank operations should be considered which do not subordinate other public creditors of the bank (eg the deposit insurance scheme).
- The lender of last resort function cannot be considered in liquidity stress tests of foreign currency portfolios, ie when there is no access to the relevant central bank.

6.4 Macrofinancial issues in liquidity stress testing

The liquidity risk of banks is conditional on the macrofinancial environment. In particular the balance of payments position and the monetary structure have implications for liquidity risks of banks. We discuss each of these two aspects in turn.

The integration of global financial markets has led to an increase in wholesale funding from counterparties located in other jurisdictions, increasing the risk associated with sudden reversals. Lack of domestic savings generally creates a dependence on foreign funding, particularly wholesale funding. As a result the interconnectedness between lending and borrowing banks across borders increased substantially before the crisis. This trend suddenly reversed in the crisis when increased risk aversion urged banks to withdraw to their home markets (De Haas and van Lelyveld (forthcoming)). Cross-border liquidity risk issues (cross-border funding of subsidiaries and liquidity lines of parent banks) have proven to be important sources of liquidity stress.

Cross-border risks are closely related to the balance of payment situation of a country. If the jurisdiction of a bank is a net receiver of funding, it implies cross-border risks for its funding liquidity, in particular for short-term borrowing. This type of funding is prone to sudden stops of capital as investors withdraw from that country in stress. Foreign banks that have provided lending to counterparties in a distressed country face cross-border risks on their asset side.

The European debt crisis has underscored that balance of payments issues remain relevant even in highly integrated markets. The crisis showed that stress on the macrofinancial level can compound bank specific liquidity problems and exacerbate the stress situation. Even more so since

macro risks and banking problems are usually mutually reinforcing factors – which tend to work through confidence effects, among others, that are likely to increase the liquidity stress.

Monetary arrangements can limit central bank financing in stress. In countries that have their own currency, the central bank can act as a lender of last resort for governments. This underpins the liquidity value of banks' government holdings. However, the liquidity value is not unlimited. If banks were to massively pledge government bonds at the central bank (for instance, in the case of a shock to sovereign risk) it is likely that the currency would come under downward pressure. This opens up additional channels of risk to banks' liquidity positions. Banks should be aware of this in their liquidity stress-testing assumptions and contingency funding plans.

In a currency union, governments cannot rely on their own central bank as lender of last resort. This makes government bonds prone to convertibility (currency) risk, at least as perceived by investors. Investor perceptions of convertibility risk are an additional risk factor that could give rise to capital outflows from countries in a currency union. Even more so since in a currency union – ie an integrated financial market – banks tend to rely more on wholesale funding from other parts of the union. Capital flight due to convertibility risk may urge banks to resort to central bank funding. However, in a currency union this access may be limited by the union-wide collateral framework, which will not be tailored to a particular jurisdiction.

6.5 Network, feedback and second-round effects

Network and feedback effects are rarely modelled in liquidity stress tests. Arguably, the interbank market is a network of participating banks (Eisenschmidt and Tapking (2009), Schmitz (2011)). Positive network externalities and dynamics apply: the more banks participate and the higher the market volume, the easier it is to obtain funding, and the lower the risk of market dislocations due to idiosyncratic risk at any individual market participant.

Prior to the financial crisis, most empirical literature showed that an individual institution was typically not able to trigger a domino effect (Upper (2011)). However, diversification of credit risk across many borrowers may have ambiguous effects on systemic risk in the presence of loss amplification mechanisms. Short-term depositors in the network might run (Battiston et al (2012)) and, once liquidity stress sets in motion a reduction of volumes and participation, this could lead to a negative feedback loop. The adverse shock to the interbank market reduces the insurance function and, at the same time, it increases incentives for banks to self-insure against liquidity shocks by holding excess reserves. With fewer banks participating in the market and volumes being lower, idiosyncratic shocks have a stronger impact on the market – both on volumes and rates. Thus, the market becomes more prone to liquidity shocks, which further reduces its (perceived) "insurance value" exactly when this is most needed. Classical network dynamics emerge, with ever-increasing self-insurance and falling participation.[44]

Empirical studies that use network analysis to perform liquidity stress tests are rare, although work is on the way at several institutions. An exception is the RAMSI model developed by the Bank of England (see Aikman et al (2009), Section 4.3.2). The model is a comprehensive balance sheet model for the largest UK banks, which projects the different items on banks' income statement via modules covering macro credit risk, net interest income, non-interest income, and operating expenses. However, in the model, contagion can only occur after bank failure due to confidence contagion, default

[44] See Gai et al (2011) for a theoretical model of the interbank network in which contagion arises from liquidity and haircut spirals.

in the network of interbank exposures (counterparty risk), or from fire sales that are assumed to depress asset prices at the point of default. Behavioural reactions such as liquidity hoarding or pre-default fire sales are not captured. Kapadia et al (2012) show that liquidity feedbacks may markedly amplify stress based on the RAMSI model. In their model, as banks lose access to longer-term funding markets, bank liabilities become increasingly short-term, further undermining confidence; stressed banks' defensive actions, including liquidity hoarding and asset fire sales, may also trigger funding problems at other banks. Cont et al (2013) put forward a quantitative methodology for analysing the potential for contagion and systemic risk in a network of interlinked financial institutions.

Feedback and second-round effects can be captured by modelling banks' behaviour under stress. Obviously, banks' crisis behaviour can contribute to the stress in the financial system. This can be modelled either based on past market data or as part of a bottom-up liquidity stress test (van den End 2010). Implicitly, banks' reactions to liquidity stress are taken into account as, for example, rollover rates on various bank assets are derived from past experience. However, few banks have experienced severe idiosyncratic liquidity shocks and, for those that have, data are scarce with respect to their behavioural reactions.[45] Van den End (2010) presents a stress-testing model endogenising market and funding liquidity risk by including feedback effects that capture both behavioural and reputational effects. Using a Monte Carlo approach, he applies the framework to Dutch banks and shows that second-round effects had a more substantial impact than first-round effects (ie that liquidity risks are highly non-linear), resulting from collective behaviour and suggesting that banks should hold substantial liquidity buffers.

Feedback effects can also be caused by fire sale spirals. The distinction between asset fire sales due to liquidity stress and asset sales as consequence of portfolio rebalancing in the face of changing market expectations (eg macroeconomic conditions) is very challenging (Shleifer and Vishny (2011)). Similarly, it is not straightforward to disentangle price reactions to asset fire sales from price reactions to changing market expectations. The RAMSI model (see Aikman et al (2009)) incorporates fire sales via a simple model of asset liquidation with calibrated parameters. Diamond and Rajan (2010) develop a model of the observed drying-up of some asset markets in the face of the recent economic and financial crisis. Again, the challenge is to disentangle cause and effect between volume, banks' liquidity and sudden changes of market perception of entire asset classes. Anand et al (2012) examine the role of macroeconomic fluctuations, asset market liquidity and network structure in determining contagion and aggregate losses in a stylised financial system, and demonstrate that the mark-to-market effects of fire sales can contribute to financial instability in a systemic crisis.

In concerted rounds of common liquidity stress tests, it is possible to include banks' reactions to liquidity stress as conducted by ECB (2008), Banking Supervision Committee (2009), and the Central Bank of the Republic of Austria in 2010 (see Chapter 4 for more details). In addition to the standard data on cash flows and securities flows, banks are asked to provide a second template that quantifies their behavioural reactions for each of the scenarios. Reactions are then accounted for in a second set of stress-test calculations. This approach offers the clear advantage of scenario-specific behavioural reactions and detailed quantifications concerning the different instruments employed and the timing of the measures taken. A drawback is that data collection can be difficult.

[45] An interesting data source in this respect could be banks' contingency funding plans as these should contain the banks' reactions to various liquidity stress scenarios. But, as supervisors might not be able to share the relevant information, the practical use of such data might be limited.

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