Market and Funding Liquidity Stress Testing of the Luxembourg Banking Sector[♣]

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Abstract

This paper performs market and funding liquidity stress testing of the Luxembourg banking sector. Liquidity shocks are instrumented using stochastic haircuts and run-off rates. The first round effects and the endogenous response of banks are modeled; second-round effects are also considered and are the result of the impact of banks' reactions on market prices and reputation. A shock to the interbank market and a shock to related-party deposits of Luxembourg banks illustrate that banks' business lines shape the net effect of the shocks on banks' stochastic liquidity buffers. Related parties play a fundamental role in banks' reactions to shocks. While from a systemic viewpoint, second-round effects do not affect banks' buffers relatively more than first round effects, there are major differences across banks depending on their business model and buffer composition. Second-round effects exemplify the relevance of contagion effects that reduce the systemic benefits of diversification. For Luxembourg, with its high number of subsidiaries of large foreign financial institutions, the results indicate the importance of monitoring the liquidity of parent groups to which Luxembourg institutions belong. Consistent with a major lesson from the crisis, understanding financial stability is impossible without a proper understanding of international banking activities. In addition, the results show the relevance of system-wide measures to minimize the systemic effects of liquidity crises, both ex-ante and ex-post, such as sound liquidity management frameworks and contingency plans, robust liquidity buffers, and deposit insurance. The liquidity stress testing framework of this paper also illustrates a macroprudential tool able to provide quantitative judgments in order to incorporate financial stability considerations into monetary policy decision-making.

JEL Classification Numbers: E5, C1, G2

Keywords: stress test, liquidity risk, banks, stochastic, macroprudential

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[♣] Preliminary version, please do not quote.

I. Motivation

The severity and peculiarities of the current crisis have motivated a wide spread rethinking of financial, monetary and supervisory frameworks. From accounting rules to the operation of rating agencies, from the role of central banks and their objectives to the basic paradigm of prudential supervision, academic research, high level meetings, working groups and task forces have started to set the pillars of new institutions and market practices aiming at minimizing the risk of a similar crisis repeating itself in the future.

One major policy message from the crisis is the need to develop the macroprudential element of financial stability policy. It is now generally accepted that micro prudential regulation and supervision of individual institutions and markets, while necessary, is not sufficient, because it does not consider the interactions among financial institutions and between the financial system and the real sector. For macroprudential policy to minimize the risk that financial instability would result in broader costs to the economy, it needs to develop quantitative macroprudential operating targets to measure and monitor the main determinants of systemic risk, both in its time series dimension (e.g., countercyclical capital charges) and in its cross-section dimension (e.g., interbank lending concentration limits) (Borio and Drehmann, 2009). As a result, a number of macroprudential instruments are already in use or under consideration, admittedly in a context in which much remains to be done to properly understand the macroprudential transmission mechanism in general, and specifically, its interaction with monetary policy.

Macro stress tests belong to the set of operating instruments that have been used to trace the response of the financial system to large, but plausible exogenous shocks. While forward-looking in their nature, they have suffered from the failure to capture in a robust way the feedback effects between the financial system and the macroeconomy, and to portray a key aspect of financial distress, namely, that small shocks can have large systemic effects (Drehmann, 2009). In a cross-section dimension, stress tests have incorporated the interactions between institutions, markets and infrastructure to study how these contribute to the vulnerabilities of the financial system. Stress tests have proven to be useful operating instruments for central banks, supervisors and banks. However, it was not until well into 2007 that it became clear that a top priority for financial stability is to strengthen the understanding of the role of interconnectedness among financial institutions, of common exposures to risks, of the endogeneity of agents' responses, of the conditionality of parameters on stress events, and other significant systemic features.

One peculiarity of the current financial crisis has been the seizing up of the interbank market. This dramatically revealed the endogeneity of liquidity in a fiat-currency economy, and the ensuing need to take into account liquidity risk in stress testing exercises of the banking system. Rapid changes to endogenous liquidity can quickly reverberate through the financial system and exhaust banks' liquidity buffers via asset price changes, drying up of liquidity lines, and outright paralysis of the interbank market as a result of large increases in counterparty risk and uncertainty. However, market liquidity and funding liquidity[1] have not often been taken into account by banks, monetary authorities and supervisors in their stress-testing models in ways that make clear the systemic implications of liquidity shocks (IMF, 2008). Liquidity stress testing has become an essential part of IMF Financial Sector Assessment Programs since 2001, which have assumed shocks to deposits, to wholesale funding and used cross-border scenarios in which foreign parent banks stop funding the domestic subsidiaries (Moretti *et al*, 2008). Clearly, enhanced frameworks for systemic liquidity stress testing will become a crucial instrument for international bodies called to perform macroprudential tasks, such as the recently created ESRB.

Most banks' stress-testing exercises have not included the intrinsic relation between counterparty credit risk, funding and market liquidity. In part, this was the result of a widely held view in the literature that competitive interbank markets foster resilience and are robust. Yet, the crisis has made obvious that more thought needs to be given to the design of interbank market infrastructure, including collateral frameworks.

In addition, even in most available stress testing exercises and contingency funding plans, banks do not consider the feedback effect of their actions on the price of assets or on their reputation as they react to recover their desirable liquidity buffers—during the crisis, some banks did experience difficulties in selling assets or pledging assets in secured lending (ECB, 2008).

Given the existence of (non-risk related) deposit insurance and the history of central bank intervention to provide sufficient liquidity during crises, moral hazard considerations suggest that

[1] According to the Basel Committee on Banking Supervision (BCBS), 2008, market liquidity risk is "the risk that a firm cannot easily offset or eliminate a position at the market price because of inadequate market depth or market disruption." According to the BCBS, funding liquidity risk is the risk that a bank will be impaired in its "ability to fund increases in assets and meet obligations as they come due" and "at a reasonable cost." Similar definitions are in Brunnermeier and Pedersen (2009). Market liquidity risk has become more significant as a result of securitization.

banks hold suboptimal levels of liquidity. Overall, liquidity risk is underpriced and the crisis has made clear that it was excessive.

Finally, more is still needed for robust liquidity stress testing, such as incorporating off-balance sheet risks, covering cross-border transmission channels, modelling the behavioural responses of agents, and including non-bank financial institutions.

In Luxembourg, the Law of 24 October, 2008, made the Banque centrale du Luxembourg (BCL) responsible for the surveillance of the general liquidity situation on the markets as well as financial market operators. As a result, the BCL has been building a series of tools to assess the general liquidity of the market and market participants. Rychtarik (2009) develops an approach to measure the liquidity risk sensitivity of banks in Luxembourg from the viewpoint of the impact of shocks on banks' liquidity ratios. The test is applied to a sample of 32 banks to identify the most severe scenario (or combination of scenarios), and the most vulnerable banks in the system.[2] Rychtarik and Stragiotti (2009) describe the liquidity position of Luxembourg banks using two different scores, (1) across "peer" banks, and (2) over time. Their framework identifies banks with weaker liquidity positions across 21 risk factors, and allows to draw conclusions on trends within the Luxembourg banking sector as a supervisory tool. This study represents a natural follow up of that work at the BCL. This research takes a stochastic approach to systemic liquidity stress testing, while being fully compatible with, and operational for, analyzing bank-level liquidity risk as well. It focuses on both market and funding liquidity risk, uses industry and ECB-determined haircuts and run-off rates, includes banks' reactions to the shocks, and incorporates the possibility of a drying up of funding from cross-border parent banks. Second–round, feedback effects as a result of joint banks' reactions on asset prices and banks' reputation are also simulated.

The next section has a selective literature review. Section III describes the model framework. Section IV, discusses the data, haircuts and run-off rates used. Section V explains the model simulations for Luxembourg banks of a systemic shock to the interbank market and a related-party withdrawal shock. Section VI concludes. Appendix A illustrates a traditional run-on-deposits shock.

[2] The explored scenarios are a run on a bank, the use of committed loans by counterparties, the netting of the bank's position with the parent financial group, and changes in conditions of refinancing operations with the Eurosystem.

II. Literature review

While there are excellent surveys of systemic stress testing of banks (e.g., Quagliarello, ed., 2009), there is no survey of systemic liquidity risk stress testing of banks. The literature area to cover for that purpose is vast. This task is well beyond the objective of this paper. Instead, the remainder of the section contains a brief survey of recent theoretical and empirical work on selected topics relevant for liquidity stress testing.

Macro liquidity risk encompasses several strands of literature. First, *leverage and liquidity interaction* have played an important role in the current crisis. Gromb and Vayanos (2008) model financial market liquidity as provided by financially constrained arbitrageurs who depend on external capital. Liquidity dry-ups follow periods of low returns for arbitrageurs' risky investment opportunities. The authors' welfare analysis shows that arbitrageurs may fail to take socially optimal positions in their investments and provision of market liquidity because they fail to internalize the price effects of their investment decisions. Adrian and Shin (2008) suggest that in a financial system where balance sheets are continuously marked-to-market, asset price changes show up immediately as changes in net worth, and elicit responses from financial intermediaries who adjust the size of their balance sheets. This means that leverage and the strength of economic activity reinforce each other. Thus, aggregate liquidity can be seen as the rate of change of the aggregate balance sheet of financial intermediaries.

Second, *liquidity hoarding* has been another feature of banks' behavior during the current crisis. Kobayashi *et al* (2008) observe that liquid lenders decreased their exposure or stayed out of the market as they feared that they might suffer from interim shocks, and that none would lend to them if a potential additional liquidity shortage arises. Instead, for Eisenshchmidt and Tapking (2009), banks hoard because of uncertainty about their own future needs and collateral shortages despite ample central bank liquidity supply. Acharya *et* al (2008) provide empirical evidence of banks' predatory behavior during several banking crises.

A third issue is markets' incompleteness, and the implication that *aggregate liquidity shocks* cannot be hedged. For Allen and Gale (2005), system-wide liquidity needs cannot be satisfied at the fundamental value of assets in equilibrium, so prices have to fall to compensate liquidity holders for the cost of holding excess liquidity. Instead of looking at preferences, Diamond and Rajan (2005) show that in a general equilibrium framework early liquidation of long-term investments may not provide sufficient liquidity to ensure that all banks meet early claims, and thus, some banks fail. Fernando *et al* (2008) provide an empirical assessment of market collapse due to an aggregate liquidity shock that result from the commonality of investors' liquidity needs.

Brunnermeir and Pedersen (2009) seminal paper *links market and funding liquidity* of traders, a fourth issue. During crises, decreases in market liquidity and funding liquidity are mutually reinforcing and produce liquidity spirals, which can be either margin spirals or loss spirals. Margin spirals occur when a decrease in funding compels a dealer to provide less market liquidity. If margins increase as market liquidity decreases, the initial decline in funding tightens the dealers' funding constraint further, which in turn forces them to diminish their trading and so on, leading to a margin spiral. The loss spiral happens when a dealer who holds a security and faces a funding problem, tries to sell the security. In so doing, she reduces market liquidity and incurs losses that reinforce the initial problem. Drehmann and Nikolaou (2009) find strong empirical evidence that market liquidity is low when funding liquidity demands are high, and that this relationship only occurs in stressed conditions.

A fifth topic is *informational frictions* which plague financial markets and are crucial to understand liquidity risk. Heider *et al* (2009) argue that credit risk is an important factor in explaining the recent breakdown of the interbank market. In their model, increased counterparty credit risk leads to higher interest rates in the money market, and asymmetric information may lead to adverse selection and eventually to a complete market breakdown.

Another strand of literature is *central bank's willingness to provide liquidity* as it has important implications for banks' incentives. As liquid assets usually have lower returns than illiquid assets, holding liquid assets may have an opportunity cost in terms of foregone higher returns. In the presence of an interbank market and asymmetric information, banks may rationally choose to hold lower levels of liquid assets and rely on other banks' liquid asset holdings (Repullo, 2005). Cristensen *et al* (2009), using a yield curve model, find that central bank operations in the current crisis seemed to lower interbank market spreads.

A seventh area is *cross-jurisdictional* issues. Given that liquidity supervision (and provision in the Euro area) is the responsibility of host countries, cross-jurisdictional issues matter for liquidity risk stressing. Countries have developed their own regime to ensure the liquidity of local entities. However, many international groups manage liquidity globally, and thus setting a common standard might help in reducing costs for international banks. This potential diversification benefit depends crucially on the actual dependence between the different shocks and the (legal) structure of the banking group. Schanz and Speller's (2009) model highlights that in the case when markets know little about the subsidiaries' insolvency risk, a regulator who wants to minimize the occurrence of liquidity shortages within her jurisdiction might want to require the subsidiary to hold a pool of liquid assets locally. Cetorelli and Goldberg (2008) find that the large global banks rely on internal capital markets with their foreign affiliates to help smooth domestic liquidity shocks. They show that the existence of such internal capital markets contributes to an international propagation of domestic liquidity shocks to affiliated banks abroad.

Eight, models that provide *micro foundations* to the analysis of financial intermediaries, including endogenous reactions of banks and non-bank economic agents are in its infancy, and from an empirical viewpoint, they are still far from reflecting empirical regularities. Goodhart *et al* (2006) model is one such attempt; it assumes heterogeneous banks and investors, and develops endogenous feedback mechanisms and default. Liquidity is modelled via banks' loan supply.

Finally, with or without micro foundations, *contagion models* are relevant to understand the transmission of shocks in the interbank market. Contagion may happen via deposit withdrawals following depositors' fear that banks will not be able to meet their obligations due to losses in the interbank market (Allen and Gale, 2000). Or, contagion can simply occur following defaults of interbank counterparties (von Peter, 2008), and be magnified by a financial accelerator (Adrian and Shin, 2007), or it may even result from settlement and payment systems failure. Upper (2007) surveys papers which apply counterfactual simulations to assess the danger of contagion given banks mutual credit exposures, but this has not yet been done for liquidity risk, except in van den End (2008). Boss et al (2006) model for market and credit risk stress testing is put into an interbank network and is used by the Oesterreichische Nationalbank. Off-balance sheet contingencies are not included, and feedback effects arising from market and funding liquidity risks are also missing. Recently, Wong and Hui (2009) develop a liquidity stress testing framework where liquidity and default risk result from negative asset price shocks. This causes deposit outflows, a fall in market liquidity, and banks suffer from draw downs from their contingent credit lines. They model the effect of shocks on the default risk of banks (using a Merton's PD) and in banks' deposit outflows. Contagion risk is incorporated via the interbank market. The model is applied to a sample of 27 Hong Kong banks.

III. The modelling framework

The framework used in this paper to analyze systemic liquidity risk draws on the model developed at the De Nederlandsche Bank by J.W. van den End (2008), adapted to take into account Luxembourg idiosyncrasies. Therefore, only a succinct description of the model will follow. Importantly, the model is flexible enough to fulfil the need of both liquidity surveillance of individual market operators and of markets, as required by the Luxembourg Law of October 2008. It therefore can be used following a top-down or a bottom-up approach.

The model encompasses market and funding liquidity risk in a macro stress-testing framework that uses balance sheet data. It takes into account the first and second-round (feedback) effects of shocks, including the price effects on markets following behavioural reactions of heterogeneous banks and idiosyncratic reputation effects. The model also allows the exploration of leverage and liquidity issues, and the implementation of interbank shocks due to banks' hoarding. Importantly for Luxembourg and other international financial centres, the application of the model takes into consideration two cross-jurisdictional issues: it allows the interaction between parent and subsidiaries/branches via deposits, and it also incorporates currency risk via haircuts. A drawback of the model is that contagion lacks micro foundations: the effect of market shocks on banks' default risk and deposit outflows is not modelled. Market stress caused by other economic developments is exogenous to the model.

The model is set up to measure the impact of market and funding liquidity shocks on banks' liquidity buffers.[3] Data availability makes possible to use the model only at a quarterly frequency.[4] Shocks are implemented via stochastic haircuts and run-off rates on assets and liabilities, respectively. As a result, stochastic liquidity buffers incorporate, at least partly, the possibility of rapid changes in asset values, the short-supply of stress situations data and their limited value, and proxy for uncertainty in the model parameters and banks' reaction functions. To increase the model capacity to reflect the financial data behavior, Monte Carlo simulations of haircuts and run-off rates are performed using a log-normal distribution as it is consistent with the

[3] Liquid assets and liabilities are close, but not identical, to the ones considered by the banking sector supervisor, the Commission de Surveillance du Secteur Financier, to determine the 30 percent prudential liquidity ratio.
[4] New reporting requirements will likely make possible to run the model at a monthly frequency and with a greater degree of granularity in the near future.

nonlinearities of liquidity stress occurrences. Therefore, in the simulations, the distribution for the draws is adjusted to reflect tail events, implemented by assuming three standard deviations.

The model contains three stages, each of which is stochastic. The shock represents the first stage. Given that granular balance and off-balance sheet information is used, shocks can be implemented in a flexible way. Banks' reactions to mitigate the impact of the shock on their liquidity buffers constitute the second stage. Those reactions, especially if quite generalized and similar, or if they result from large institutions' actions, may have systemic consequences in the form of falls in asset price, increased margins calls, and more expensive funding. This, together with additional losses as a result of the interaction between liquidity risk and credit risk or to reputational effects, constitutes the third stage of the model.

i. First and second stages

Bank *b* liquidity buffer in the baseline situation *0*, B_0^b , is:

$$B_0^b = \sum_{i=1}^{n} I_i^b , \tag{1}$$

the total stock of available liquid assets I_i^b for $i = 1, \dots, n$. The liquidity buffer is made of cash, deposits at the BCL, ECB eligible collateral, liquid debt securities, listed stocks, interbank assets available on demand, and money market funds available on demand.[5] The buffer B_0^b is intended to allow the bank to absorb the liquidity shock and to buy time to take measures, if necessary, to remain solvent.

The liquidity shock in the model can happen via the asset side or the liability side of the on-balance and off-balance sheet of the bank. The shock to bank b, E_1^b , is:

$$E_1^b = \sum_{i}^{n} I_i^b \times w\_sim_{1,i} , \tag{2}$$

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[5] See Tables 1 and 2 for the list of assets included in the buffer and the associated haircuts, as well as liquid liabilities and their associated and run-off rates, respectively.

where I_i^b are liquid asset and liability items of the bank *b*, and $w\_sim_{1,i}$ are the stochastic weights associated with item *i* as a result of the first shock (recall that weights are assumed to come from stressed events at three standard deviations, or $w_i \approx 3\,\sigma$).[6] The liquidity buffer after the shock becomes B_1^b:

$$B_1^b = B_0^b - E_1^b. \qquad (3)$$

There is in fact, a distribution of buffers associated with the distribution of stochastic weights. Following the shock, bank *b* has its buffer affected negatively and will take actions to restore it either because it must comply with regulatory measures, or because of liquidity management considerations. In the model, it is assumed that banks react when the ratio $\frac{E_1^b}{B_o^b} > \theta$, with θ estimated at 30 percent. The threshold value θ was estimated regressing the ranking of the one-period lagged changes in the baseline buffer as a result of the (e.g, interbank) shock on the ranking of changes in the balance sheet items for a rho Spearman correlation coefficient at the 99 percent confidence level.[7] This proxies for the lack of information on the level of banks' risk tolerance.

When the bank reacts to restore its buffer, it is assumed that it can repo securities with the central bank, can sell liquid securities, and importantly in Luxembourg, draw liquidity from parent banks.[8] Banks are assumed to be unable to finance themselves in the market affected by the shock.[9] It is also assumed that money market funds held by banks cannot be used by banks to react to the shock because of their relatively lower liquidity.[10]

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[6] Monte Carlo simulations of haircuts and run-off rates are performed by taking 50,000 draws from a log-normal distribution. The use of this distribution is consistent with the nonlinearities of significant liquidity stress occurrences and risk management practice. In the simulations, the distribution is adjusted to reflect tail events, or three standard deviations. The log normal distribution used is: Exp [(N(0,1)*(weights(i)/3)], subject to the constraint that haircuts and run-offs rates ≤ 1.

[7] The relatively low frequency of the data available clearly limits this part of the analysis. It can be argued that three months is sufficiently long a period to accommodate not only banks' responses to the shock that reduced their buffers, but also the result of asset price changes and bank asset-liability management operations unrelated to the shock. However, estimation by IV of the coefficient of changes in the baseline buffer and balance sheet items does not change the conclusions dramatically.

[8] Obviously, an area where the model can be improved is by modeling the reaction function of banks explicitly. The choice of assets and liabilities that banks use to replenish their buffers may be the outcome of contingency funding plans or of liquidity management operations.

[9] This is different from van den End (2008).

[10] Money market funds held as investment represent a small part of the balance sheet of Luxembourg banks.

Once a bank takes actions to restore its baseline buffer, the share of each balance sheet item *j* used (for $j = 1, \ldots$, m) is proportional to the relative importance of the item on the balance sheet ($I_j^b / \sum_j^m I_j^b$), reflecting the bank's business model. The size of the transactions that a bank conducts with instrument *j* is expressed by RI_j^b,

$$RI_j^b = (B_0^b - B_1^b) \times (I_j^b / \sum_j^m I_j^b). \tag{4}$$

Following the bank's reaction, the new buffer is $B_{2,}$ and as RI_j^b is positive, $B_1 \leq B_2$. In addition, $B_2 < B_0$, since the buffer can not be fully restored due to the shock in the first stage (as reflected in $w\_sim_{1,j}$). Therefore, RI_j^b refers to the size of the transactions required to generate the liquidity needed after the shock. The liquidity buffer after the mitigating actions (B_2) of a bank is:

$$B_2^b = B_1^b + \sum_j^m RI_j^b \times (1 - w\_sim_{1,j}), \tag{5}$$

with $B_2 > B_{1,}$ The flexibility of the model allows to shut down and open up quite easily different sources of funding and market liquidity. For example, as explained above, following an interbank market shock, this source of funding disappears altogether. In that case, $w\_sim_{1,j} = 1$, implying that banks have no possibility to enter the interbank market as the haircut is 100 percent. Alternatively, in the case of repo markets, this situation would mean that certain collateral of banks may become worthless.

ii. Third stage

The third stage illustrates the effects on banks' buffers of banks' reactions on market prices and banks' reputation. In the literature, these are normally referred to as feedback effects and endogenous parameter variance (Sorge, 2004). In the model, it is implemented as further haircuts and run-off rates, i.e., $w\_sim_{1,j} \leq w\_sim_{2,j} \leq 1$. Feedback effects are larger if more banks react so that ($\sum_b q$) is relatively larger, and if their reactions are more similar ($\sum_b RI_j^b$). For example, transactions in the large interbank market will have relatively less effects, i.e., $w\_sim_{2,i}$ is relatively smaller than in the case of transactions in relatively more illiquid markets. Therefore,

$$w\_sim_{2,j} = w\_sim_{1,j} \times \left[\sum_b q \wedge (1 + \sum_j^m RI_j^b / \sum_b \sum_j^m RI_j^b) \times s \right] / \sum_b q \ . \tag{6}$$

Higher values of RI_j^b reflect a higher liquidity demand; so, relatively larger transactions will have more impact on prices than small transactions. Similarly, relatively larger banks will have stronger feedback effects than small banks. As in Nier *et al* (2008), the price of banking assets is a decreasing function of the amount of liquidated assets and the semi-elasticity of the price effects (a measure of market illiquidity). Therefore, equation (6) reflects market illiquidity through the weights ($w\_sim_{2,j}$).

In addition, banks' reactions also affect more or less asset prices depending on prevailing market conditions: asset prices will fall less, ceteris paribus, when the exogenous level of market stress, *s*, is lower than when it is higher. Stressful market conditions magnify the negative price effects of the number of banks that react ($\sum_b q$), and the similarity of their reactions ($\sum_b RI_j^b / \sum_b \sum_j^m RI_j^b$) as both factors tend to dry up market liquidity.

An additional effect of banks' reactions to restore their liquidity buffers is on their reputation via signalling effects (Holstrom, 2008, BIS, 2009a) and the well known stigma of central bank borrowing (e.g., Furfine, 2001). These forces increase haircuts on assets and run-off rates on liabilities; and this is represented in the model as $w\_sim^*_{2,j}$ (with $w\_sim_{2,j} \leq w\_sim^*_{2,j} \leq 1$). Again, the reputation effect will be dependent on the market conditions (*s*) driving the feedback effects via signalling under asymmetric information. Reputation risk is expressed as follows:

$$w\_sim^*_{2,j} = w\_sim_{2,j} \times \sqrt{s} \ . \tag{7}$$

Finally, the feedback effects of the third stage without reputation consequences are reflected by E_2^b :

$$E_2^b = \sum_j^m ((I_j^b + RI_j^b) \times (w\_sim_{2,j} - w\_sim_{1,j})), \tag{8}$$

with $w\_sim^*_{2,j}$ rather than $w\_sim_{2,j}$ if banks suffer from reputation effects. The liquidity buffer after the second-round effects (B_3) becomes,

$$B_3^b = B_2^b - E_2^b. \tag{9}$$

The model does not take into account any reaction from the monetary authority which could mitigate the impact of the shock.

IV. Data, haircuts and run-off rates

The composition and measurement of the liquidity buffer play a central role in this stress testing exercise. This is consistent with van den End (2008) and the literature on stress testing liquidity risk (BIS 2009a, ECB 2008). The definition of the buffer follows the balance-sheet approach to stress testing. The quarterly database covers 52 banks for the period 2006Q1-2009Q3; as of 2009Q3, the sample represents nearly 90 percent of total bank assets. Lacking information on 1-quarter banks' liquidity projections and gaps, flows are projected assuming that balance sheet items follow random walk generating processes.[11] This means that the scenario effects could be felt through both deteriorating liquid stocks and flows. Each balance sheet item is evaluated according to a homogeneous set of haircuts, applicable to each financial instrument of the same type (e.g., listed shares, debt instruments, funds) and featuring the same economic characteristics (i.e., currency, country of origin, type of counterparty). Importantly, measurement of assets

[11] This is equivalent to taking the last observation of the 5397 lines of banks' buffers. The forecast function of the random walk process $y_t = y_{t-1} + \varepsilon_t$ is flat; it is $E_t y_{t+1} = y_t$.

included in the buffer acknowledges that the same kind of asset may enjoy different liquidity characteristics depending on the currency of denomination.[12]

The liquidity buffer is a portfolio of high quality, highly liquid unencumbered securities as defined in the BIS, 2009b guidelines; those guidelines are also followed for the definition of the haircuts and run-off rates.[13] As a result, several components of banks' portfolios are withdrawn, such as unlisted shares, shareholding participations, and debt instruments issued by entities located in countries excluded from Tables 1 and 2. Overall, however, the buffer used in this paper is more conservative than what is being proposed in the BIS, 2009b.[14] The most significant off-balance sheet items included are committed credit lines. Derivatives held by banks in Luxembourg are not included in this study. As a result, the definition and measurement of the buffer aligns the model not only with Luxembourg idiosyncrasies, but also with current work in several fora in the field of macroprudential supervision and banks' liquidity risk management.

The definition and measurement of the buffer are constrained by the available data quality and time span. The BCL reporting database used for this study encompasses several dimensions.[15] Included balance sheet items are debt instruments, listed shares, money market funds, and cash. Types of counterparties for debt instruments are banks, non financial institutions (e.g., corporate, holding companies, other private sector entities), central government (governmental institutions, central and regional governmental institutions such as the German Republic or the Land of Bavaria), supra-national organizations (international organizations, e.g., the European Investment Bank and the International Monetary Fund). There is no counterparty discrimination for listed shares. Geopolitical counterparty classifications are: for debt instruments, Eurozone countries (non European Economic Area), G10 non Eurozone countries, European Economic Area (no Eurozone), other countries. And for listed shares, they are Eurozone, United States, Japan, AAA

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[12] The model is flexible enough to be used for an exchange rate shock. This is not done in this study, however.

[13] Available unencumbered assets are marketable as collateral in secondary markets and/or eligible for central banks' standing facilities.

[14] As an illustration, in the BIS document, securities with effective remaining maturities of less than one year have a zero percent haircut (in the BIS terminology, a "required stable funding factor"), while in this paper, their haircuts oscillate between 2.5 percent and 90 percent, depending on the country of issuance, the currency of denomination, and the type of counterparty.

[15] For a more extensive explanation of the type of counterparties and balance sheet items included in the definition of the liquidity buffer, see:
http://www.bcl.lu/fr/statistiques/methodo_notes/methodology_statistics.pdf , and
http://www.bcl.lu/fr/reporting/Etablissements_de_credit/index.html.

foreign currency rating countries.[16] The categorized currencies of issuance of financial instruments are the Euro, the United States Dollar, the Japanese Yen, and AAA foreign currency rating (e.g., Swiss Franc, Norwegian Krone, Singapore Dollar). If available, residual maturities are preferred to contractual maturities.[17] Haircuts apply to each possible combination of type, counterparty, geopolitical origin, currency of issuance and maturity are on Table 1.

Table 1- Liquidity buffer: haircuts applied to selected balance sheet items

				RESIDUAL MATURITY - HAIRCUTS			
TYPE OF BS ITEM	TYPE OF ISSUER	CURRENCY OF ISSUANCE	COUNTRY OF ISSUANCE	<1 year	1<year<2	year>2	unspecified
listed stocks		EUR	EUROAREA	n/a	n/a	n/a	50%
		USD	US	n/a	n/a	n/a	50%
		JPY	JAPAN	n/a	n/a	n/a	50%
		AAA FOREIGN CCY RATING	AAA FOREIGN CCY RATING	n/a	n/a	n/a	50%
		EUR	EUROAREA	n/a	n/a	n/a	50%
		USD	US	n/a	n/a	n/a	50%
		JPY	JAPAN	n/a	n/a	n/a	50%
		AAA FOREIGN CCY RATING	AAA FOREIGN CCY RATING	n/a	n/a	n/a	50%
Debt financial instruments	credit institution	EUR	EUROAREA	20%	30%	40%	50%
			G10 (NON EEA)	30%	40%	50%	60%
			EEA (NO EUROAREA)	40%	50%	60%	70%
		USD	EUROAREA	30%	40%	50%	60%
			G10 (NON EEA)	40%	50%	60%	70%
			EEA (NO EUROAREA)	50%	60%	70%	80%
		JPY	EUROAREA	30%	40%	50%	60%
			G10 (NON EEA)	40%	50%	60%	70%
			EEA (NO EUROAREA)	50%	60%	70%	80%
		AAA FOREIGN CCY RATING	EUROAREA	50%	60%	70%	80%
			G10 (NON EEA)	60%	70%	80%	90%
Debt financial instruments	non financial institutions	EUR	EUROAREA	40%	50%	60%	70%
			G10 (NON EEA)	50%	60%	70%	80%
			EEA (NO EUROAREA)	60%	70%	80%	90%
		USD	EUROAREA	50%	60%	70%	80%
			G10 (NON EEA)	60%	70%	80%	90%
			EEA (NO EUROAREA)	70%	80%	90%	100%
		JPY	EUROAREA	50%	60%	70%	80%
			G10 (NON EEA)	60%	70%	80%	90%
			EEA (NO EUROAREA)	70%	80%	90%	100%
		AAA FOREIGN CCY RATING	EUROAREA	70%	80%	90%	100%
			G10 (NON EEA)	80%	90%	100%	100%
Debt financial instruments	Government	EUR	EUROAREA	2,5%	5,0%	7,5%	10,0%
			G10 (NON EEA)	5,0%	7,5%	10,0%	12,5%
			EEA (NO EUROAREA)	7,5%	10,0%	12,5%	15,0%
			X1	70,0%	80,0%	90,0%	100,0%
		USD	EUROAREA	5,0%	7,5%	10,0%	12,5%
			G10 (NON EEA)	7,5%	10,0%	12,5%	15,0%
			EEA (NO EUROAREA)	10,0%	12,5%	15,0%	17,5%
			X1	80,0%	90,0%	100,0%	100,0%
		JPY	EUROAREA	5,0%	7,5%	10,0%	12,5%
			G10 (NON EEA)	7,5%	10,0%	12,5%	15,0%
			EEA (NO EUROAREA)	10,0%	12,5%	15,0%	17,5%
			X1	80,0%	90,0%	100,0%	100,0%
		AAA FOREIGN CCY RATING	EUROAREA	7,5%	10,0%	12,5%	15,0%
			G10 (NON EEA)	10,0%	12,5%	15,0%	17,5%
			EEA (NO EUROAREA)	12,5%	15,0%	17,5%	20,0%
			X1	90,0%	100,0%	100,0%	100,0%
Money market funds	Credit institution	EUR	EUROAREA	n/a	n/a	n/a	50%
		USD	US	n/a	n/a	n/a	60%
		JPY	JAPAN	n/a	n/a	n/a	60%
		AAA FOREIGN CCY RATING	AAA FOREIGN CCY RATING	n/a	n/a	n/a	70%
Cash	All sectors	All currencies	All countries	0%	0%	0%	0%

Haircuts are based on banks' practice in Luxembourg (Rychtarik, 2009, Stragiotti, 2009), industry standards (Standard & Poor's, 2007), ECB requirements (ECB, 2006) and also judgement. For instance, the matrix of haircuts stresses the relevance of information on geopolitical as well as macroeconomic data; the country of origin and the currency of each financial instrument play a

[16] The foreign currency ratings were derived from the website of Standard & Poor's (2009); an updated version is in http://www.standardandpoors.com/ratings/articles/en/us/?assetID=1245202906346.

[17] The BCL reporting allows banks to report the *residual maturities* according to a set of predefined time buckets, namely below 1 year, between 1 and 2 years, longer than 2 years, and unspecified maturity. These maturity buckets may not completely fit this study needs in terms of liquidity risk assessment of a given item of the balance sheet. Nevertheless, to a certain extent, these buckets seem sufficient for determining the haircuts applicable to the buffers.

significant role in the evaluation of haircuts. However, given that the available reporting does not discriminate across types of securities (e.g., callable bonds versus bonds held to maturity), some simplifications are necessary.

A haircut does not depend always on the *type* of security. For instance, no distinction is made between the haircuts of asset-backed securities and corporate bonds issued in the same currency by the same type of entity, in the same country. This issue becomes somehow less relevant if put in the context of the approach taken, which is partly inspired by the ECB implementation of monetary policy operations. Indeed, for the latter, the *type* of financial instrument becomes less relevant regarding the eligibility criteria.

The BCL reporting distinguishes four types of *maturities*. In this context, several hypotheses have to be made. It is not feasible to always distinguish across different securities based on their maturities. For example, within the category of debt instruments with a maturity below 1 year, it is not possible to determine what amount represents commercial paper and what amount represents other financial instruments. However, this classification is useful as a proxy for the degree of liquidity of the instruments.

The same framework supports the determination of run-off rates. These rates are set to reflect several facets of potential liquidity shocks of systemic and idiosyncratic nature. The run-off rates are based on (1) historical observation of past shocks in the Luxembourg banking sector; (2) the same practice and literature references used for haircuts and; (3) information received from surveys sent to banks. Table 2 displays the run-off rates of balance sheet items relevant for the shocks simulated in this study.[18]

The framework used for haircuts and run-off rates is, however, only an operational reasonable starting point. A major weakness of stress testing models has been the use of historic data for haircuts and run-off rates given that realized elasticities under stress conditions are, most likely, going to be quite different. Therefore, this study applies a stochastic approach.

[18] Money market funds' deposits are excluded from the table because they are held mostly, albeit not exclusively, by custodian banks. The practice of these banks in Luxembourg seems to exclude these funds from their maturity transformation activity. The BCL database does not allow a distinction between custodian and non-custodian banks (Rychtarik and Stragiotti, 2009, take a different approach, not followed in this paper, and assume as scenario a potential withdrawal of deposits from funds). Note that run-off rates do not refer to intraday liquidity risk, the main risk custodian banks face.

Table 2 - Run-off rates applied to selected stressed balance sheet items

				RESIDUAL MATURITY - RUN-OFF RATES			
TYPE OF BS ITEM	TYPE OF ISSUER	CURRENCY OF ISSUANCE	COUNTRY OF ISSUANCE	<1 year	1<year<2	year>2	unspecified
Liabilities							
Deposits - retail - Luxembourg		all currencies	all geopolitical areas		Not / applied		20%
Deposits - retail - non Luxembourg		all currencies	all geopolitical areas		Not / applied		20%
Deposits - corporate - all		all currencies	all geopolitical areas		Not / applied		50%
Deposits - banks - non Related Parties		all currencies	all geopolitical areas		Not / applied		65%
Fiduciary deposits - banks 1Y		all currencies	all geopolitical areas		Not / applied		90%
				RESIDUAL MATURITY - HAIRCUTS			
TYPE OF BS ITEM	TYPE OF ISSUER	CURRENCY OF ISSUANCE	COUNTRY OF ISSUANCE	<1 year	1<year<2	year>2	unspecified
Assets							
Interbank deposits	Credit institution	all currencies	EUROAREA	10%	30%	50%	70%
			G10 (NON EEA)	20%	40%	60%	80%
			EEA (NO EUROAREA)	20%	40%	60%	80%

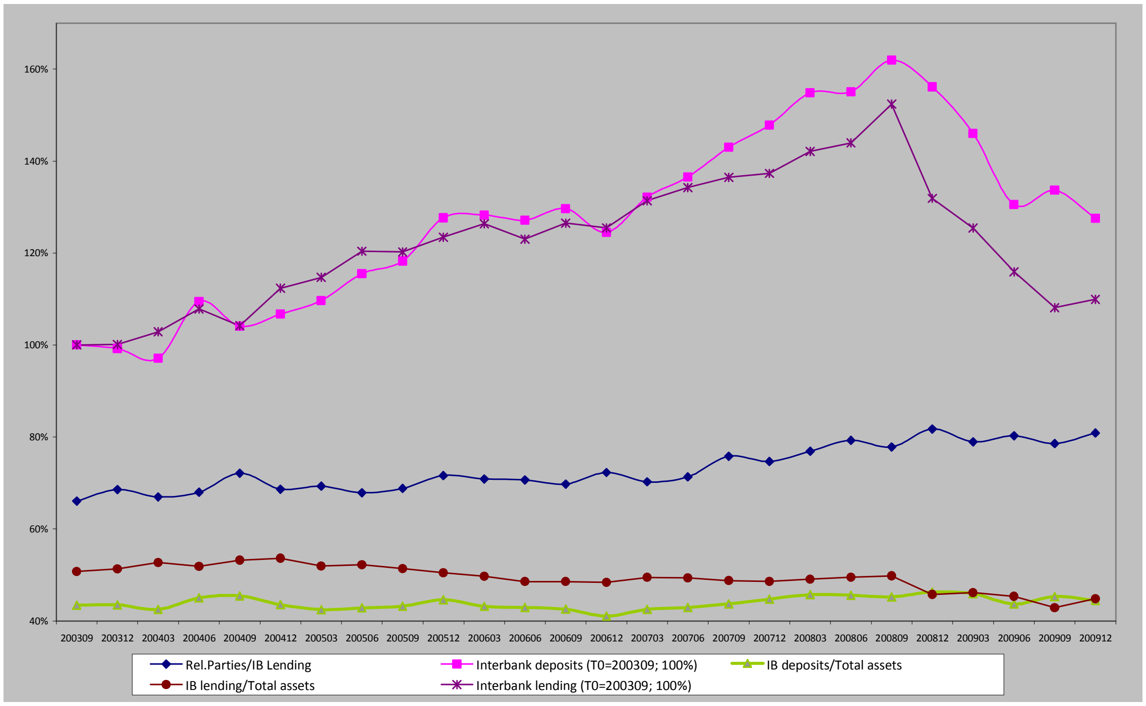
V. Simulation results

i. Choice of the shocks and calibration of market stress

The macro stress test exercise covers several aspects of market and funding liquidity risk. The following shocks test the resilience of the Luxembourg banking sector. First, a *systemic shock to interbank loans* is assumed to affect the whole banking sector. The entire stock of interbank loans undergoes a severe, albeit plausible stress. Effects on a selected set of countries are also discussed. Second, *related-party deposits* suffer a withdrawal shock. The choice of these shocks is based on the importance of the interbank market in Luxembourg, and the fact that most banks are subsidiaries or branches of large foreign banks.

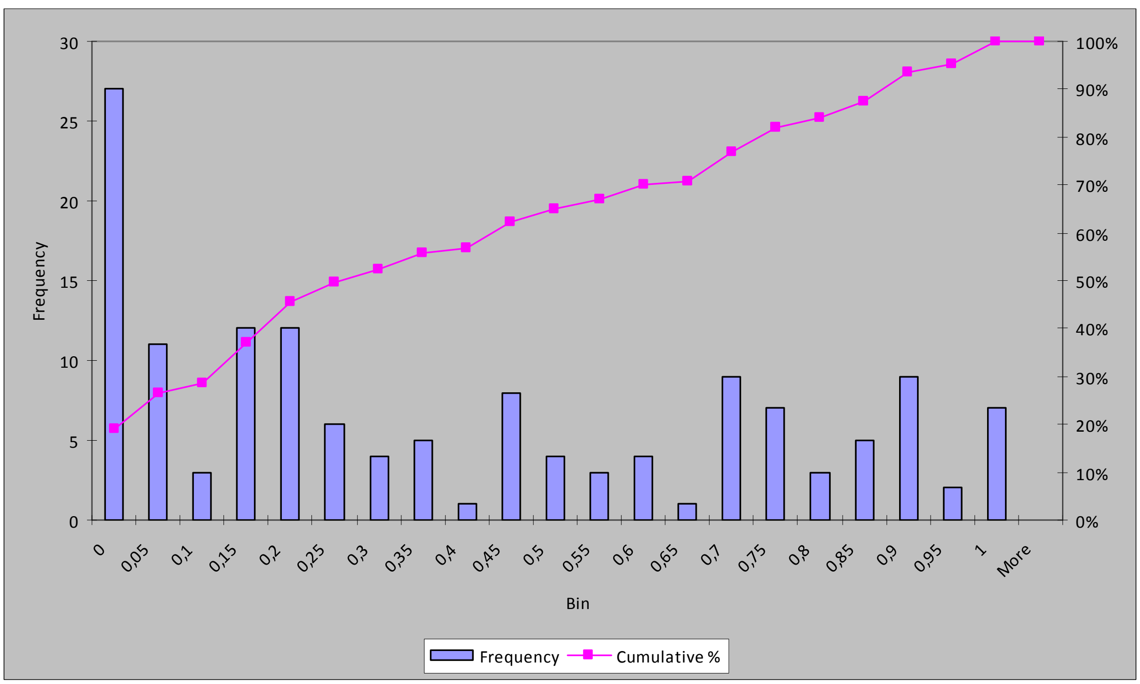
The interbank market (lending or deposits) represents about 50 percent of banks' total assets (Figure 1). The share has been quite stable over the sample period, although during the crisis there was a fall in the ratio of interbank lending to total assets. In addition, interbank lending to related parties, while traditionally high, increased recently, most likely the result of accrued liquidity needs of parent banks.

Figure 1 – Importance of the interbank market in Luxembourg



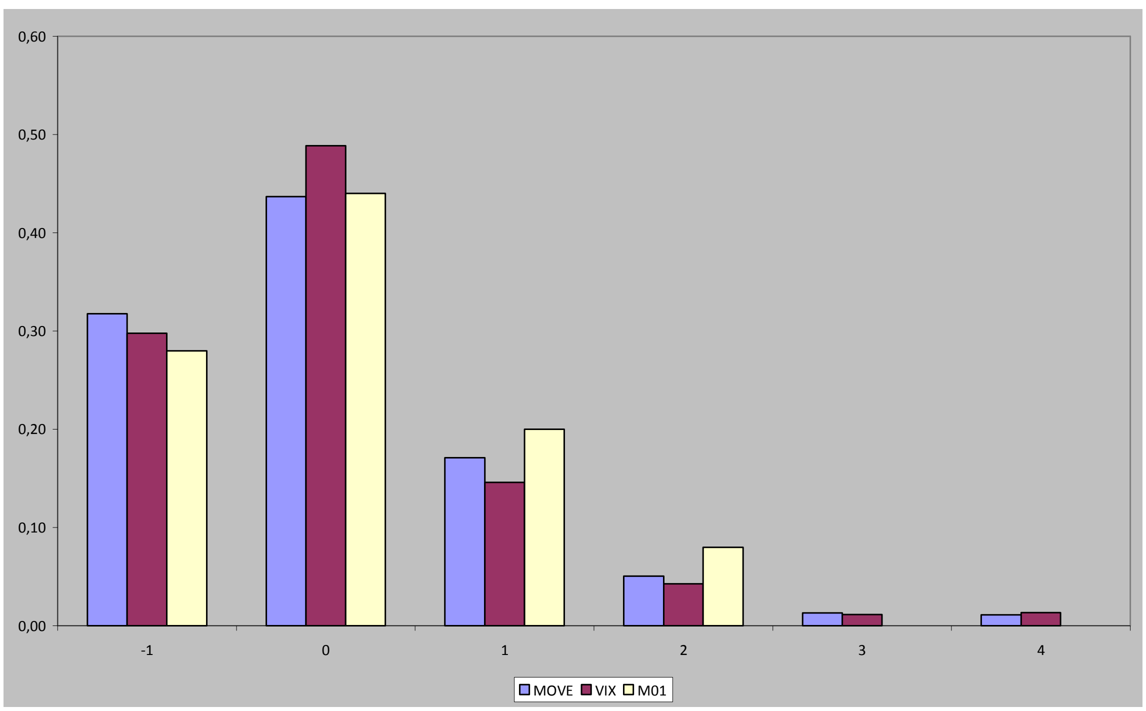
Out of a total of 143 banks, only 27 banks do not lend to related parties, and 35 banks make more than 50 percent of their interbank lending to related parties (Figure 2). In fact, more than 80 percent of the liquidity buffer of the 52 banks used in the simulations is related-party loans.

Figure 2 – Lending to related parties



These structural factors of the banking system justify not only the choice of the shocks, but also the calibration of the parameter *s*, a proxy for market stress, an important component of the second-round effects of shocks. The implied stock volatility index (VIX) and the Merrill option volatility index (MOVE) can be used as proxies of risk aversion. However, the share of stocks and non-related party debt is relatively small in banks' buffers. Related-party loans and deposits are more stable instead (Figure 3). If the standardized distributions of the indices VIX and MOVE were used, normal market conditions (represented by $-1 \leq s \leq 1$) would comprise about 70 percent of total market conditions, and in the tail of the distributions, s = 3, would represent about 4 percent of adverse market situations. Using related-party loans standardized distribution of volatility, normal market conditions would still represent 70 percent of the total, but at s = 3, no adverse market situation would be found. As a result, the simulations use a baseline value of s = 1.1 and show the sensitivity of the interbank shock to the value of *s* by making it 1.5.

Figure 3 – VIX, MOVE and related-party loans volatility frequency distributions
(Normalized values of S&P500 stock price volatility, Merrill Option Volatility Estimate, and related parties volatility)



Market conditions determine the severity of the second-round effects, as shown in equation (6). Figures 4 and 5 display the relationship between the weights used for the second-round effects,

$w\_sim_{2,j}$, and the weights used for the first round effects $w\_sim_{1,j}$. As explained in section III, the similarity of banks' reactions has a stronger effect on market conditions than the number of reacting banks, a typical crowding out effect. Similarly, the signaling effects of banks' use of central bank's refinancing facilities (as illustrated by the recent crisis), is a factor explaining the increase in haircuts and run-off rates during the second round of the simulations. In addition, the sensitivity analysis displayed in Figures 4 and 5, which includes data from the crisis, suggests that using a value of s > 1.5 has little justification in the Luxembourg banking sector situation. As a result, reputation effects would have only a small impact on haircuts and run-off rates and are not included (see equation (7)). In a more general framework, however, reputation effects on parent banks could be considered. This route is not followed in this paper.

Figure 4 – Second-round haircuts multiplication factor $w\_sim_{2,j} / w\_sim_{1,j}$ *and the number of reacting banks [* $\sum_b RI_j^b / \sum_b \sum_j^m RI_j^b$ *) = 0.83]*

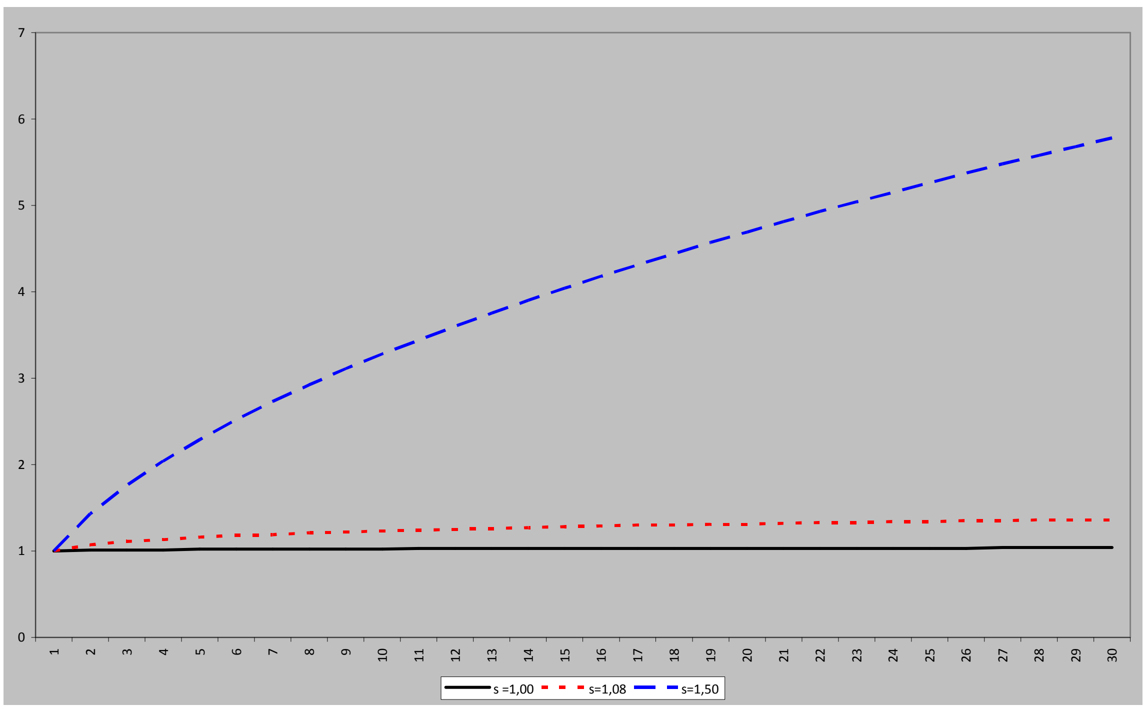
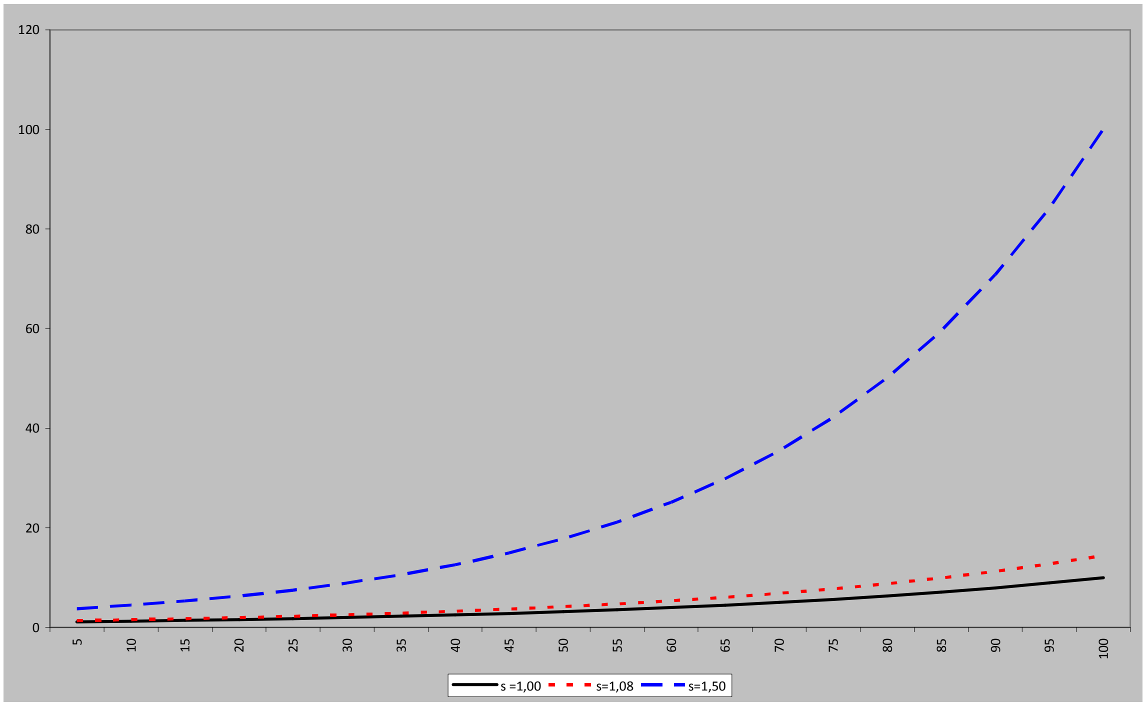


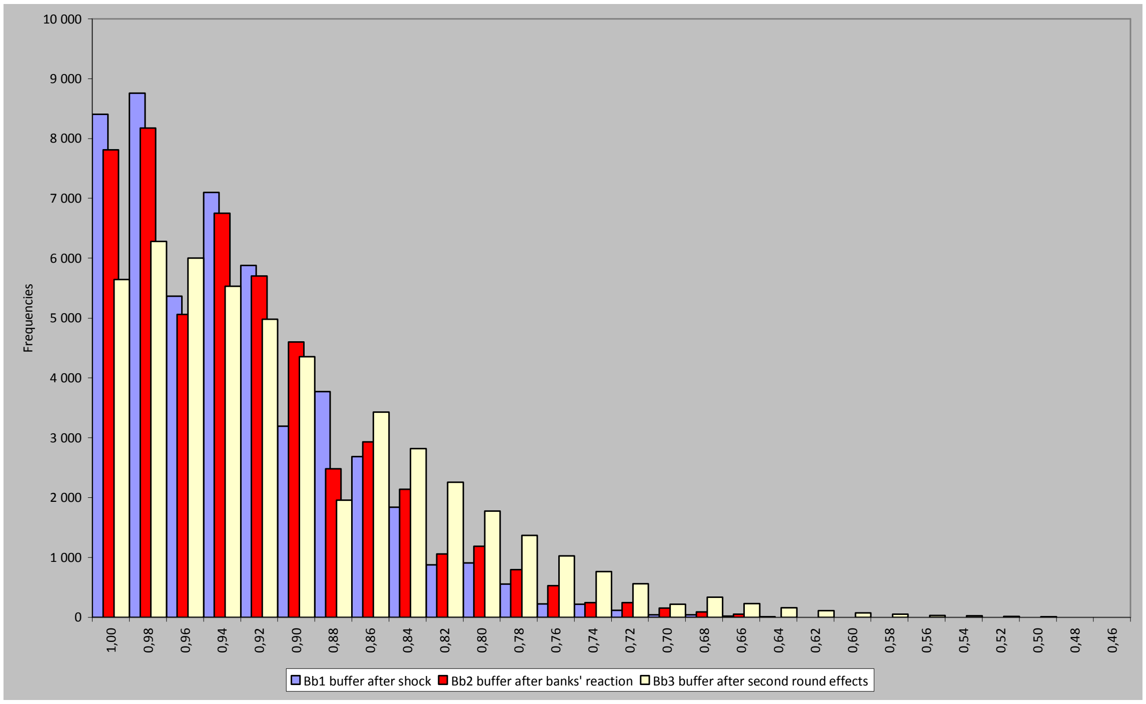
Figure 5 – Second-round haircuts multiplication factor $w\_sim_{2,j} / w\_sim_{1,j}$ *and relative reaction by instrument (q = 10)*



ii. First shock: systemic shock to interbank loans

In the first shock, each bank loses part of the value of its interbank loans. The static part of the loss is set by the weight/haircut matrix on Table 1. The shock hits all the banks carrying these types of exposure. In this type of shock, the interest is not in the outcomes for individual banks, but rather on the banking sector as a whole (Figure 6).

Figure 6 - Systemic shock to interbank loans: shock, system response and second-round effects



The chart displays the impact of the systemic shock on banks' buffers (*Bb1*), standardized by the baseline liquidity buffer *Bb0*.[19] The impact of the banking sector's response function as well as the second-round effects are also represented on the chart (respectively, *Bb2 and Bb3*). On the abscissa, we observe the remaining share of the baseline buffer of the whole banking sector, following the shock and second-round effects. The ordinate displays the corresponding frequencies. The largest potential loss incurred by the Luxembourg banking sector after the occurrence of the interbank shock would be around 36 percent[20] of the baseline buffer *Bb0*.[21] *Bb2* describes the buffers' distribution after the banking sector takes mitigating actions following the initial shock.[22] The buffer *Bb2* is, therefore, the result of adding to the set of buffers *Bb1*, the

[19] The baseline or initial buffer equals one, i.e., *Bb0 = 1*. *Bb1* buffers are calculated by subtracting the first-round effects of the shock from the baseline buffer.
[20] Due to granularity, the presence of positive frequencies associated with 0.64 is not noticeable in Figure 1.
[21] Most Luxembourg banks are subsidiaries or branches of foreign banking groups and play an important role in the financing of the group. As stated above, their major source of financing is the interbank market.
[22] Only banks suffering at least a 30 percent loss of their baseline buffers are supposed to react; they represent 71 percent of the sample. The 30 percent threshold was estimated regressing the ranking of the contemporaneous changes in the baseline buffer as a result of the (interbank) shock on the ranking of changes in the balance sheet items for a rho Spearman correlation coefficient at the 99 percent confidence level. This is used as a proxy for the lack of knowledge of banks' risk tolerance levels.

transactions performed by banks as shock mitigating actions.[23] After its reaction, the banking sector is better off and is expected to be left in a worse case scenario with roughly 66 percent (*Bb2*) of its baseline buffer. This implies a potential loss of about 2 percentage points.[24] Moreover, the associated frequencies indicate that the recovery is in general more likely. *Bb3* is the buffer after second-round effects and highlights the maximum potential loss of the banking sector after idiosyncratic and reputation effects are taken into account.[25] This leads to a general worsening of the liquidity position of individual banks (and of the banking sector as a whole). Indeed, banks forced to liquidate part of (or the entire stock) their buffers to fulfill their financial obligations will generate an increase in the volatility of assets included in their liquidity buffers and their associated haircuts. As illustrated in Figure 6, second-round effects have a large impact on the banking sector: after repeated sampling, on average, the banking sector will suffer a further loss of 16 percentage points (relative to the buffer after reaction, *Bb2*).

Importantly for systemic risk analysis, the 5 percent of the tail of the distribution shows that the banking system losses more than a quarter of its baseline buffer; this figures raises to as much as 36 percent at the 1 percent of the tail of the distribution (Table 3). There is only one bank that finishes with a negative liquidity buffer. A measure of systemic liquidity risk, i.e., the weighted average of negative liquidity buffers is very low, 0.002 percent, given that the troubled bank is small.

The simulation results for the systemic shock to interbank loans when market conditions are already turbulent, represented here by an (exogenous) higher *s* equal to 1.5, are significantly worse. At the 5 percent of the tail of the distribution, the systemic buffer loss after the second-round effects is over 60 percent and at 1 percent of the tail of the distribution it increases to almost 70 percent. There are 14 banks that risk having a negative baseline buffer, at least for some tail realizations of the shock. Systemic risk rises to 0.6 percent.

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[23] Banks are supposed to react, for example, by using securities for repo operations with the central bank, by selling securities, or funding themselves in the unsecured interbank market. Absent a micro-foundation of banks' reactions, the extent to which banks use a particular item of their portfolio to restore the baseline liquidity buffer is determined by the relative importance of the item in the balance sheet, which is obviously a reflection of each bank's business line. This is the approach also followed in van den End (2008).

[24] As a reference, in the DNB liquidity stress testing exercise of Dutch banks, the baseline buffer loss following a credit shock is 40 basis points and following a banking crisis is about 1.1 percent.

[25] Reputation effects are not taken into consideration in the simulations because as discussed below, the Luxembourg banks' buffers have a dominant share of related parties' items. It is not immediately clear what a "reputation effect" would mean in this case. As experienced during the recent crisis, parent companies extended credit lines to their subsidiaries in most cases.

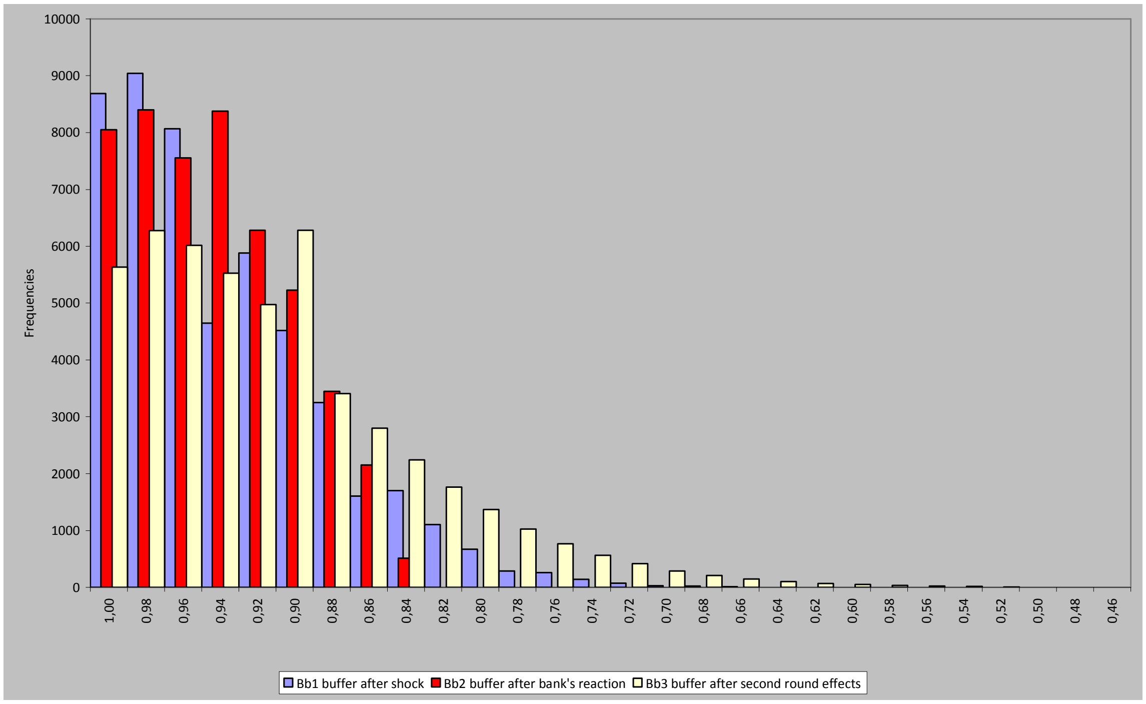
Table3 - Summary results of the systemic shock to interbank loans (million Euros, unless otherwise indicated)

Total number of banks = 52	Number of reacting banks = 37	
	s=1,1	s=1,5
Initial buffer	15 016	--
Buffer after shock	12 250	--
Buffer after mitigating actions	12 284	--
Buffer after second round effects	11 074	5 781
Percent loss wrt initial buffer	-26	-61
Buffer @ 5 percent tail	10 828	4 800
Percent loss wrt initial buffer	-28	-68
Buffer @ 1 percent tail	9 563	3 864
Percent loss wrt initial buffer	-36	-74
Number of banks with negative buffer	1	14
System liquidity risk (weighted, percent)	0,002	0,554

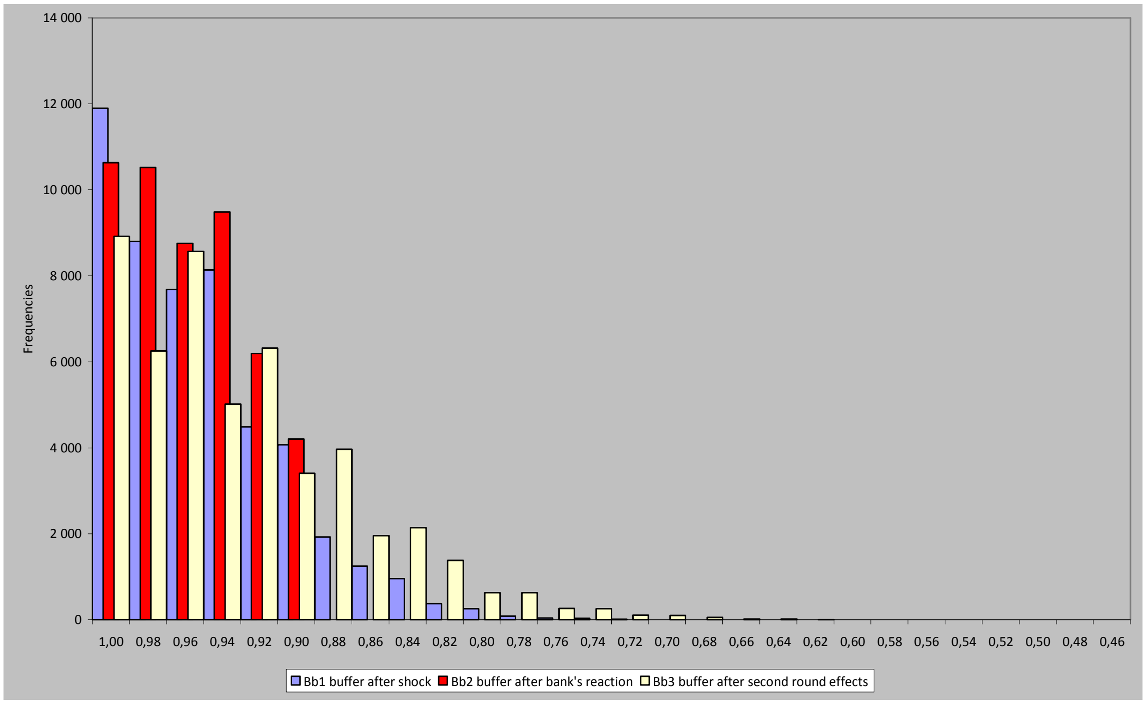
However, results of the shock differ across banks. One major reason for it is the composition of banks' buffers, which is in turn largely a function of banks' business lines. The exercise has systemic relevance in that it makes it clear that banks' business lines and interactions are quite diverse in Luxembourg. As a result, systemic stress-testing must be done in a framework that is flexible enough to accommodate them. Three banks are selected according to their relative importance, their business profile, and their sensitivity to the specific shocks. Selected banks cover most of the spectrum of the current businesses run by the industry. Figure 7 shows the results of the interbank shock on the selected banks' buffers distributions.

Figure 7 – Interbank shock: shock, individual banks' responses, and second-round effects

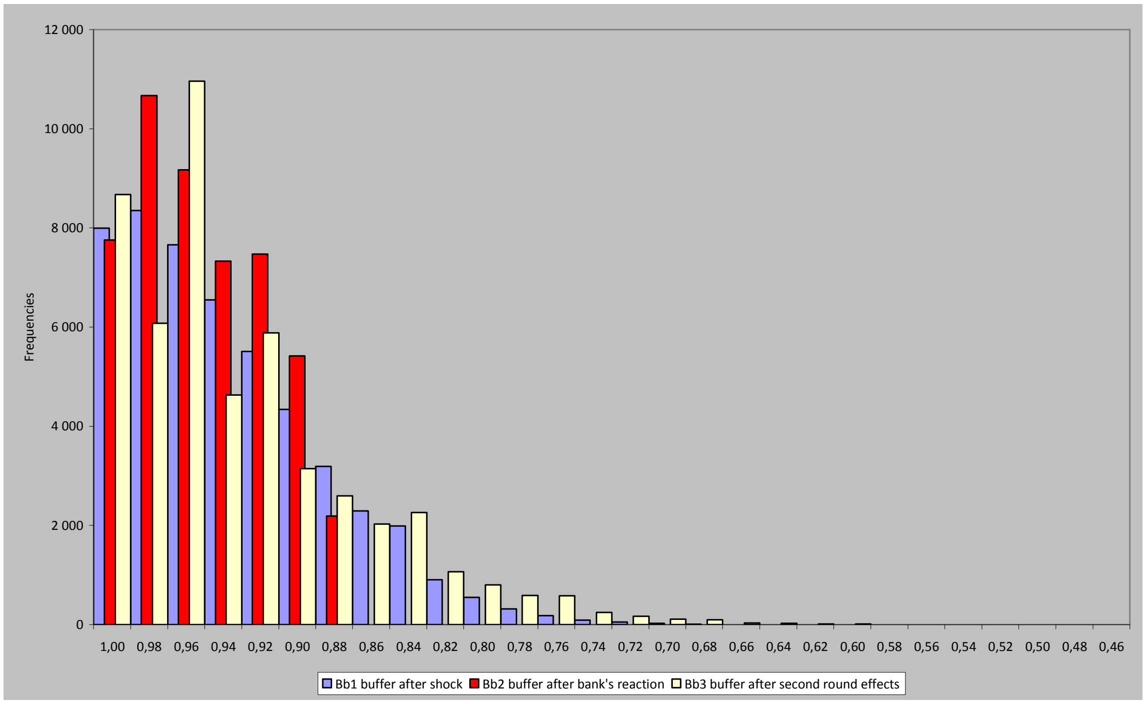
Bank A



Bank B



Bank C



Bank A is mostly a retail bank with important interbank volumes on the assets' side, representing about 38 percent of the initial buffer. Bank B is active in several business lines (i.e., retail, custody, corporate, among the most important ones); its interbank/buffer ratio is 30 percent. Bank C is mainly a global custodian, active in the field of services to investors with an interbank/buffer ratio of 33 percent. Bank A experiences the largest potential impact following the interbank shock. Indeed, its expected buffer in a worst case scenario would be roughly 66 percent of its baseline buffer.[26] Taking remedial actions, bank A would recover roughly 20 percentage points of its baseline buffer loss. Second-round effects affect severely the baseline buffer as bank A experiences a further loss slightly over 30 percentage points, if compared to the buffer after the shock's response (*Bb2*). Bank B and C are less affected by the interbank shock as they are expected to maintain 72 percent and 68 percent of their baseline buffers, respectively, after the shock. After reacting, bank B would recover roughly 18 percentage points of its baseline buffer loss, and bank C would recover 20 percentage points of its baseline buffer loss. The impact of second-round effects on these two banks would imply an expected further reduction of their *Bb2*

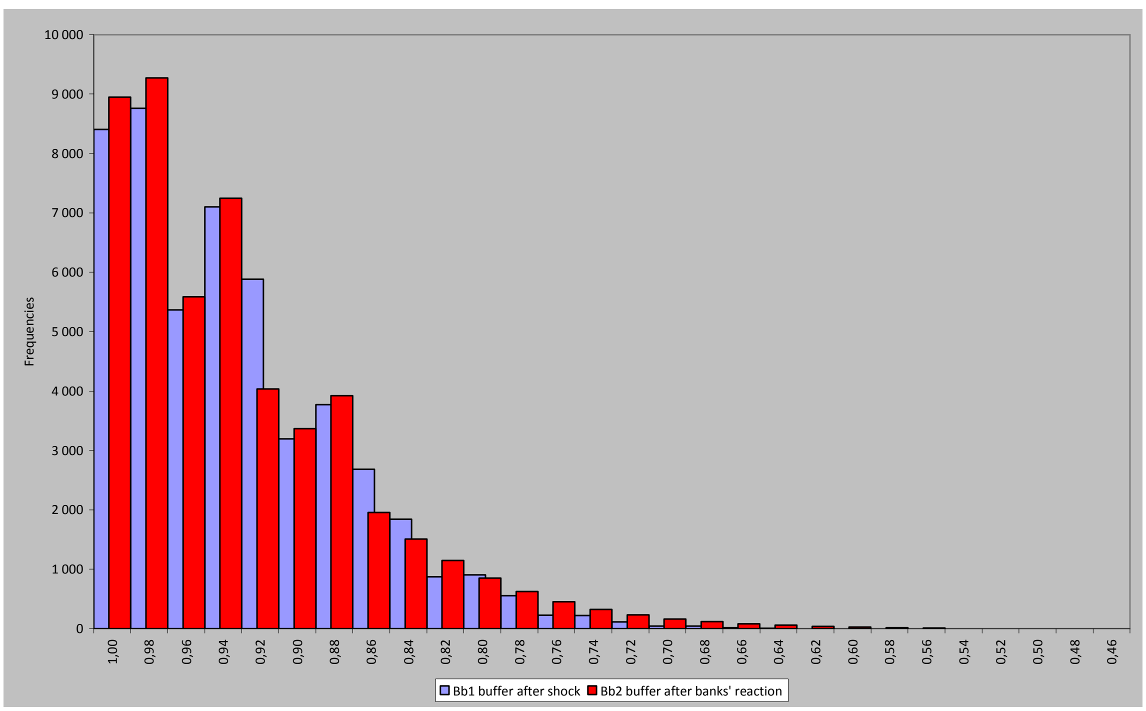
[26] Small losses at the extreme of the distribution are not always visible on the charts due to the scale used.

buffers of 28 percentage points. Any differences across banks can be explained by the different composition of their portfolios, and therefore, their corresponding simulated haircuts.

iii. First shock, systemic shock to interbank loans, excluding related-party deposits

Given the paramount role of related-party deposits in banks' buffers, it is useful to discuss the effects of the interbank shock when banks' reactions to the shock cannot avail themselves of related-party deposits. The profile of *Bb2* changes substantially. The likelihood of the banking sector incurring a severe loss increases; in *Bb2*¸the largest potential loss rises to roughly 46 percent, from 34 percent previously. These results highlight the critical role of related parties in the local banking sector. As regards second-round effects, they do not play a role in the context of shocks affecting or originating from related parties transactions. The reason is the specific haircuts that these items receive in our framework, as they are considered fully eligible in all circumstances (haircuts are equal to 0 for each and every related parties' item).

Figure 8 - Systemic shock to interbank loans: shock, banks' responses, excluding related parties



iv. Second shock: related parties' withdrawal shock

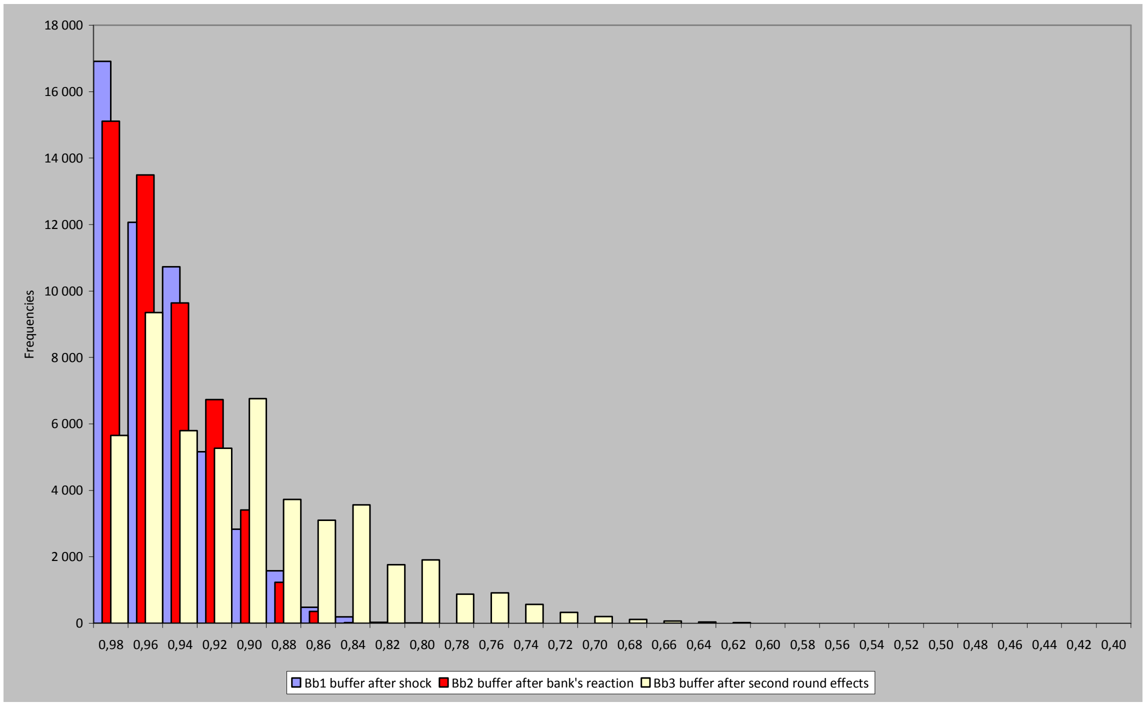
Given that well over one-third of Luxembourg banks' liabilities are intragroup, this shock is very relevant to assess the survival capacity of Luxembourg banks. In this scenario, related entities withdraw their deposits, an important share of banks' funding. Results of the shock on two banks' buffers are displayed on Figure 9. The two selected banks are bank D, with related-parties' deposits representing 22 percent of its baseline buffer, and bank E, with related-parties deposits representing 55 percent of its buffer.

This shock potentially accounts for a loss of 22 percent of bank D's baseline buffer and 40 percent of bank E's.[27] On average, banks' reaction does not allow the banks to recover much of the loss incurred during the shock. Bank D can recover about 8 percentage points of its initial loss, and bank E can recover just 4 percentage points. Second-round effects significantly impact both banks. Bank D loses 24 percentage points of its *Bb2* buffer, and ends up with a buffer just above 60 percent of its baseline value. Bank E loses 15 percentage points of its *Bb2* buffer and ends up with 48 percent of its baseline buffer. These results show the potentially severe impact that the withdrawal of intragroup positions of Luxembourg banks can have given their strong reliance on this source of funding.

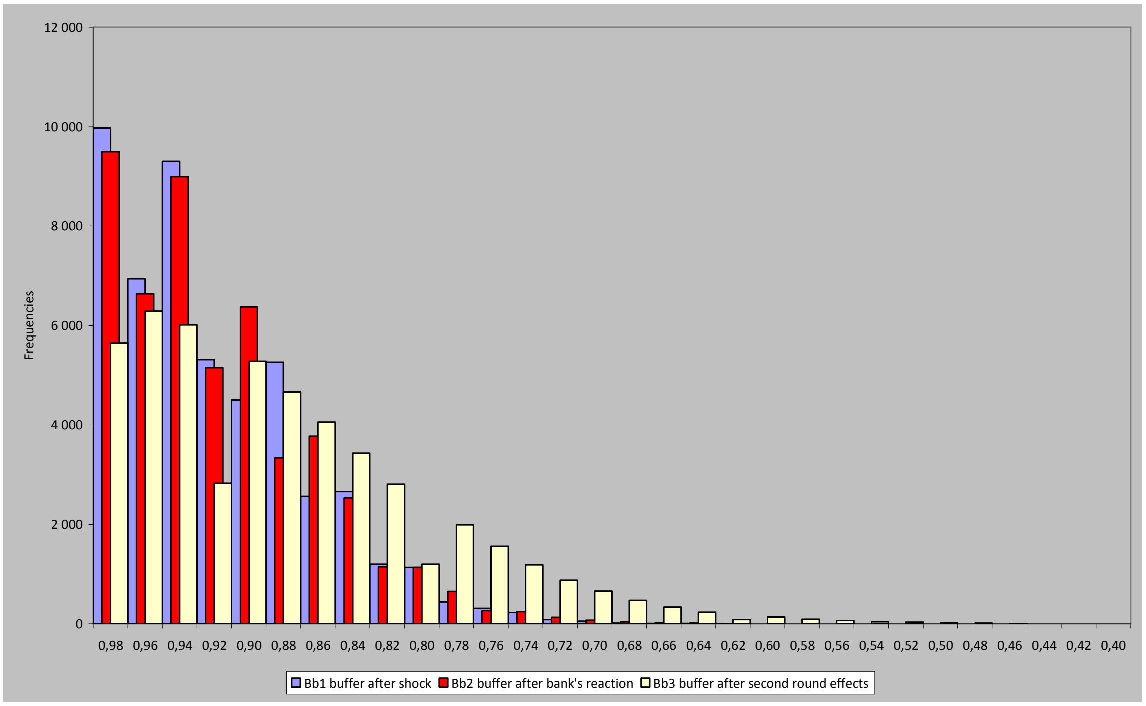
Figure 9 – Related-parties withdrawal shock: shock, banks' responses and second-round effects

Bank D

[27] Bank D's results are shown for illustrative purposes as the shock would not prompt a bank's reaction given that the shock does not reduce its baseline buffer beyond the 30 percent threshold.



Bank E



VI. Conclusions and policy implications

This paper is a study of market and funding liquidity stress testing of the Luxembourg banking sector. Liquidity shocks are instrumented using stochastic haircuts and run-off rates. The modeling framework is flexible enough to deal with systemic and individual banks' shocks. It includes not only the shock and banks' reactions to mitigate the effects of the shocks on their liquidity buffers—first and second stages—but also the endogenous effects on banks' buffers of banks' collective actions and their impact on asset prices—third stage.

A shock to the interbank market and a shock to related-party deposits of Luxembourg banks illustrate that banks' business lines are important in shaping the net effect of the shocks on banks' stochastic liquidity buffers. Related parties play a fundamental role in banks' reactions to shocks. Systemic second-round effects seem to play a less important role than first round effects, although results vary widely across banks, and for certain banks, the opposite is true. Second-round effects should be taken into account because by affecting asset prices they diminish the benefits of diversification and can more than offset banks' mitigating actions. In addition, they illustrate how contagion may operate, independently of the correlation between a given shock, and business line and buffer composition.

Given the large number of subsidiaries of complex banking groups in Luxembourg, the results suggest the importance of monitoring the liquidity of parent groups. This is consistent with a major lesson from the recent financial crisis: understanding financial stability is impossible without a proper understanding of international banking activities.

Results also indicate the importance of system-wide measures to minimize the systemic effects of liquidity shocks, both ex-ante and ex-post, such as sound liquidity management frameworks and contingency plans, robust liquidity buffers, and deposit insurance. The study illustrates an important macroprudential tool to incorporate financial stability considerations into monetary policy decision-making. It provides a framework to produce quantitative judgments on systemic risk and financial stability.

The development of macroprudential elements of financial stability policy is in its infancy. Much remains to be done in terms of refining operational frameworks for liquidity stress testing. Regarding this paper framework, one important area for improvement is endogenizing banks' reactions to shocks. Similarly, the modeling framework should make explicit the transmission mechanism of shocks within the financial sector and between the financial and the real sector. In addition, the matrix of haircuts could be made still more granular to allow a distinction between secured- and unsecured-market pleadgeable assets, or among different proxies of market stress depending on the country of location of parent banks' headquarters.

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Appendix A

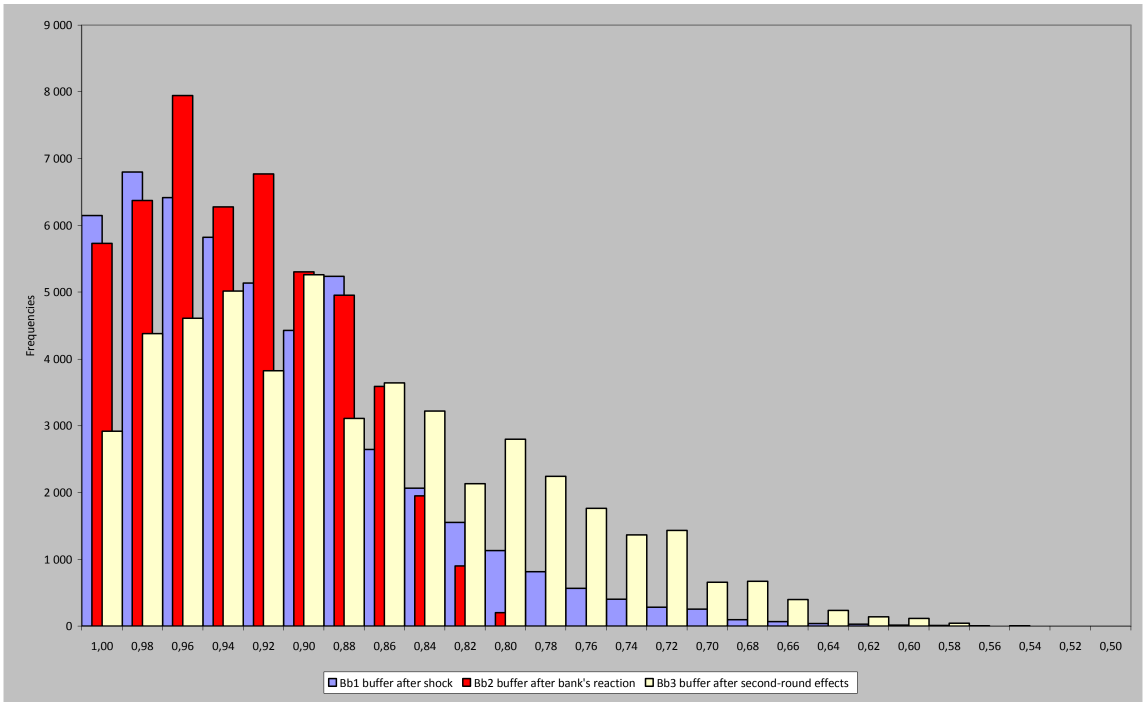
A run-on-deposits shock

The shock on deposits is a very severe event for bank A and a moderately severe event for bank B. The outcome is due to the fact that both banks rely on funding from retail and corporate clients, but to quite a different degree. The shares of deposits shocked represent 88 percent and 37 percent of bank A's and bank B's baseline buffers, respectively.[28] These results are shown in Figure A1.

The shock on bank A's deposits has an important impact on its buffer: the bank is expected to lose potentially up to 47 percent of its liquidity buffer after the shock. The bank's response improves its buffer allowing it to recover 30 percentage points.

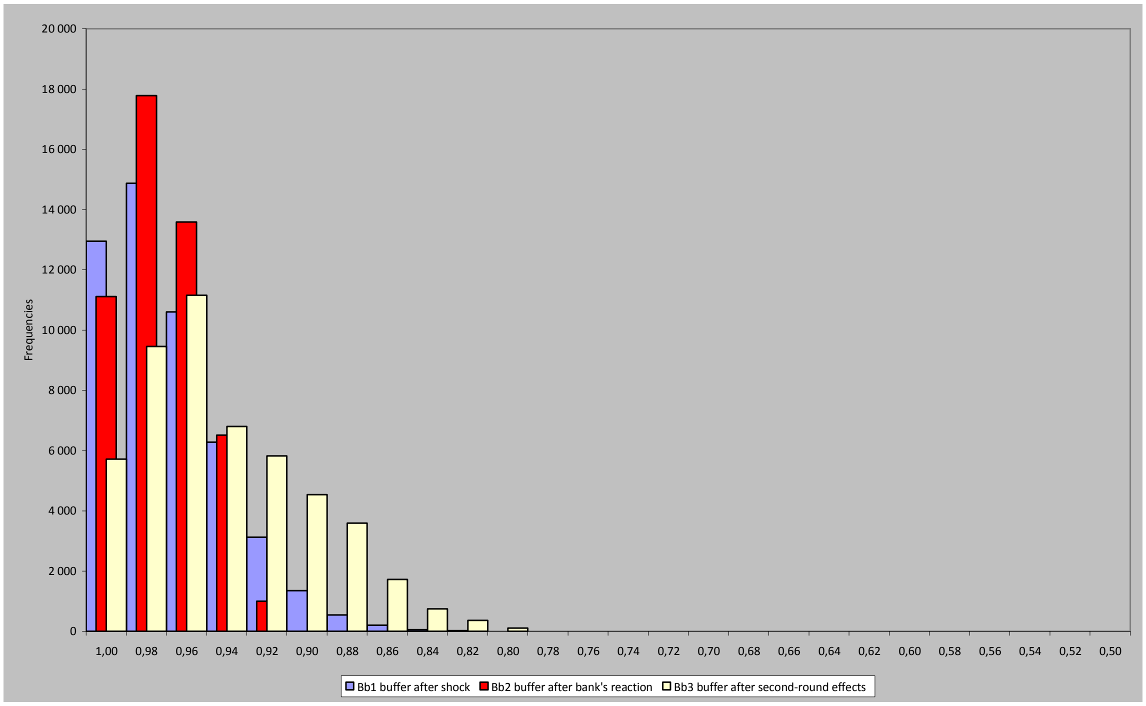
Figure A1 – Run-on-deposits shock: shock, banks' responses and second-round effects

Bank A



[28] More specifically, the main difference between these two banks is the large amount of related-party deposits in bank B.

Bank B



Although bank B does not lose up to 30 percent of their baseline buffer, its reaction is shown here for illustrative purposes. Bank B, whose largest potential loss equals 19 percent of its baseline buffer, has quite a different profile from bank A. Following the bank's mitigating actions, bank B recovers up to 13 percentage points of its baseline buffer so that is left with a loss of 6 percent.

Second-round effects also have different effects on banks' buffers, but less so, given that they operate via a generalized increase in market volatility and wide-spread asset price changes. Banks A and B end up with a buffer that is 57 percent and 79 percent of their baseline buffers, respectively. Second-round effects are important enough to more than offset banks' mitigating actions following the shock. While banks' business lines matter for the severity of the impact of the shock and the offsetting effects of banks' mitigating actions, second-round effects affect banks more generally. For example, a custodian bank (not shown here), for which a deposit shock will not matter much in terms of buffer losses, is left with 80 percent of its baseline buffer as a result of second-round effects. These results clearly illustrate how contagion may operate and thus, the relevance of measures to minimize the risk of a run of deposits for the stability of the banking system.