



BANK OF ENGLAND

Liquidity Risk, Cash Flow Constraints, and Systemic Feedbacks

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This draft: November 2009

Abstract

This paper models liquidity feedbacks in a quantitative model of systemic risk. Previous related work incorporated the outright closure of funding markets to institutions in a balance sheet-based model for UK banks which itself included macro-credit risk, income risk and network interactions. The focus here is on the systemic implications of banks' defensive actions when suffering funding liquidity problems and trying to meet a cash flow constraint. The model incorporates a number of channels important in the recent financial crisis. As the bank loses access to longer-term funding markets, its liabilities may become increasingly short-term, further undermining confidence. Stressed banks' defensive actions include liquidity hoarding and asset fire sales. This behaviour can trigger funding problems at other banks. In presenting results, we analyse scenarios in which these channels of contagion operate, and conduct stochastic simulations to illustrate how liquidity feedbacks markedly increases the amplification of distress.

Key words: Systemic risk, financial stability models, funding liquidity risk, contagion.

JEL classification: G01, G21, G32

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The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or Bank for International Settlements.

We are grateful to the following people who have provided valuable contributions and comments: David Aikman, Piergiorgio Alessandri, Niki Anderson, Richard Barwell, Emily Beau, Geoff Coppins, Jason Dowson, Bruno Eklund, Prasanna Gai, Harry Goodacre, Simon Hall, Andy Haldane, Elizabeth Martin, Emma Mattingley, Will Kerry, Nada Mora, Emma Murphy, James Purchase and Matthew Willison. We would also like to thank seminar participants at the Bank of England for helpful comments and suggestions.

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1 Introduction

The global financial crisis of 2007-09 served to reiterate the central role of liquidity risk in banking. Such a role has been understood since Bagehot (1873). This paper develops a framework that promotes an understanding of triggers and system dynamics during periods of financial instability and simulates the impact of these effects in a quantitative model of systemic risk.

The starting point of our analysis of funding market distress is that although the failure of a financial institution may reflect solvency concerns (driven by stocks) it invariably manifests itself through a crystallisation of funding liquidity risk (determined by flows). In a world with perfect information and perfect capital markets, banks would only fail if their underlying fundamentals rendered them insolvent. In such a world, examining the stock asset and liability position of a bank would be sufficient to assess its health, and solvent banks would always be able to finance random liquidity demands by borrowing from other financial institutions. In reality, informational frictions exist and capital markets are not perfect. Hence, a bank may find it difficult to obtain funding if there are concerns about its solvency, regardless of whether or not those concerns are substantiated. In such funding crises, the stock solvency constraint no longer fully determines the survival of the bank; what matters is whether the bank has sufficient cash inflows, including income from asset sales and new borrowing, to cover all cash outflows. In other words, the bank's cash flow constraint becomes critical.

Previous related work (Aikman *et al*, 2009) introduced funding liquidity risk into the Bank of England's Risk Assessment Model for Systemic Institutions (RAMSI). This is a comprehensive balance-sheet model for the largest UK banks, which models the different items on banks' income statement (via modules covering macro-credit risk, net interest income, non-interest income, and operating expenses), and integrates feedback effects between banks. In that version of RAMSI, systemic risk stemmed from the connectivity of bank balance sheets via interbank exposures (counterparty risk); the interaction between balance sheets and asset prices (fire sale effects) and – on the funding side – confidence effects that affected conditions. Bank failure occurred when a bank was shut out of funding markets. But that paper did not incorporate the bank's flow constraint and the contagion channels only operated after one or more banks had failed.

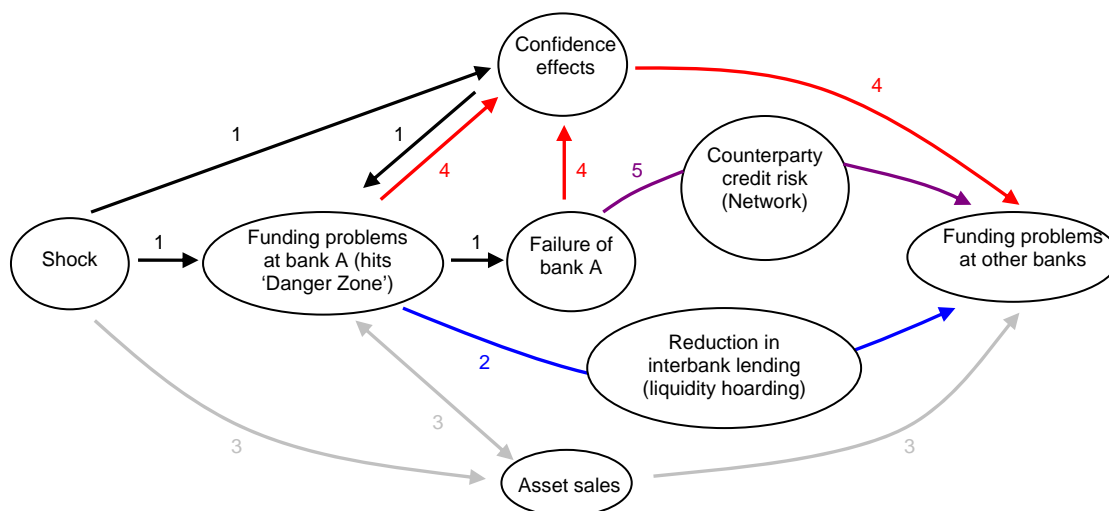
This paper develops RAMSI by setting out a conceptual framework for assessing how systemic risk may escalate as defensive actions taken by distressed banks worsen funding conditions for other banks. We implement the approach quantitatively using a model that accounts for banks' cash inflows and outflows in each period in order to identify funding pressures.

Imposing such a cash flow constraint on each bank makes it possible to assess a number of transmission channels present during a period of funding distress for one or more banks. Theoretical models of bank runs (e.g. Diamond and Dybvig, 1983; Rochet and Vives, 2004; Goldstein and Pauzner, 2005) can be considered in terms of this flow constraint. As the distressed bank loses access to longer-term funding markets, the average maturity of its liabilities decreases. This further weakens its funding liquidity position. In an attempt to stave off a liquidity crisis, the distressed bank takes defensive actions, which may in turn have a systemic impact. In particular, hoarding liquidity (interbank loans) shortens the wholesale liability structure of other banks; while selling assets at fire sales prices may affect the mark-to-market valuation of banks' held-to-maturity assets, which in turn affects funding conditions.

Figure 1 provides a stylised view of the operation of the flow constraint and how banks' actions during a funding crisis may affect the rest of the financial system. A funding crisis is triggered by an external shock that undermines confidence in the bank (channel 1 in Figure 1). A bank that is experiencing severe funding problems may take actions with systemic implications (channels 2 and 3). If it is unable to access secured and/or unsecured funding markets it may hoard liquidity, which could intensify the funding problems of other stressed banks (channel 2). It could also sell assets, which could depress market prices for these assets and potentially precipitate funding problems at other banks (channel 3). We also explore how funding problems could spread via confidence effects (channel 4; see Chen, 1999) and, in the event of a bank failure, via counterparty credit risk (channel 5; see, for example, Allen and Gale, 2000).

[Further discussion of related literature to be added.]

Figure 1: Funding Crises in a System-Wide Context

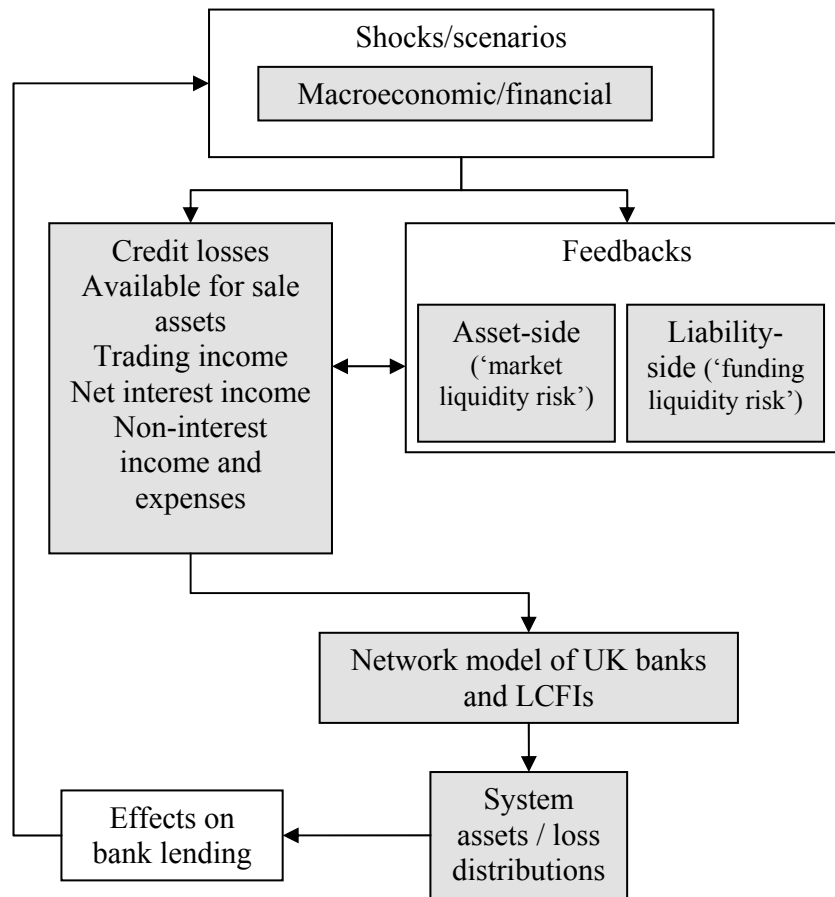


The paper is structured as follows. Section 2 contains a brief overview of RAMSI, focusing on the first round effects of shocks (excluding systemic feedbacks). Section 3 provides the conceptual and theoretical framework for our analysis, focusing on the potential triggers and systemic implications of funding liquidity crises through the lens of the bank’s cash flow constraint. Sections 4 and 5 focus on our quantitative modelling – section 4 provides details on how we model the closure of funding markets to individual institutions; section 5 presents details and partial simulation results of how the systemic feedbacks work in practice. Section 6 presents full model simulation results which identify the contribution of funding liquidity risk and systemic liquidity feedbacks to the projected outcomes for the banking system, and section 7 concludes.

2 An Overview of RAMSI

Figure 2 illustrates the modular structure of RAMSI and the mapping from shocks to systemic risk. The transmission dynamics hinge crucially on two factors – the nature and scale of shocks and the structural characteristics of the financial system. In such an environment, balance sheet interdependencies and asset and liability-side feedbacks make for complex, non-linear behaviour. RAMSI produces asset distributions for individual banks and for the aggregate banking system by linking together the shaded modules presented in Figure 2. The unshaded module – feedbacks to the macroeconomy – is left for future work.

Figure 2: RAMSI framework

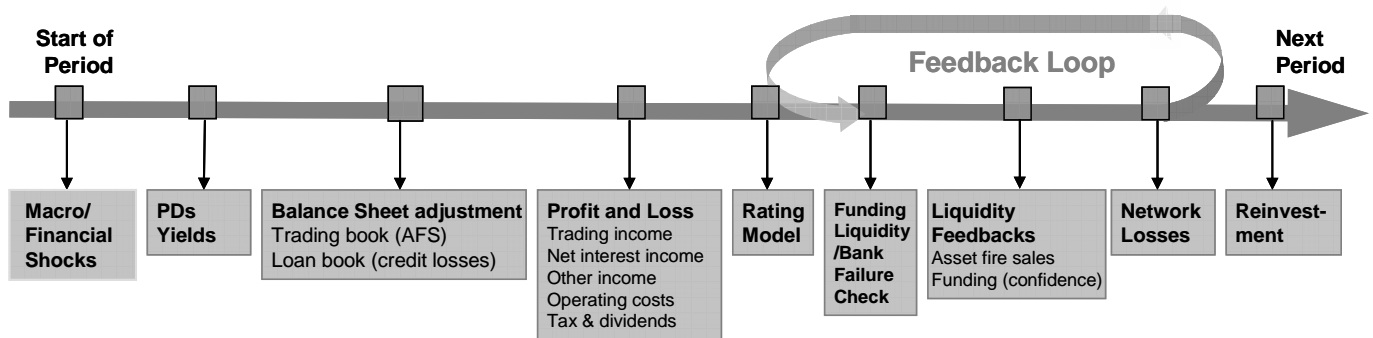


RAMSI’s modular structure is based on comprehensive individual bank balance sheets, supporting an analytically rich model that allows us to examine the likely sources of profits and losses on a disaggregated and aggregated basis. At the core of the version of RAMSI used in this paper are detailed balance sheets of the group of largest UK banks (ten at end-2007).¹ The balance sheets are highly disaggregated, with approximately 400 asset classes and 250 liability classes. Each of the asset and liability classes is further disaggregated into a total of eleven buckets (five maturity buckets and six repricing buckets). Data are mainly extracted from published accounts but are supplemented from regulatory returns. As some balance sheet entries are unavailable, we use rules of thumb based on other information or extrapolations on the basis of our knowledge of similarities between banks to fill in the data gaps. Much of the granularity

¹ Membership of the major UK banks group is based on the provision of customer services in the United Kingdom, regardless of country of ownership. This paper uses end-2007 balance sheets, at which time the members were: Alliance & Leicester, Banco Santander, Barclays, Bradford & Bingley, Halifax Bank of Scotland, HSBC, Lloyds TSB, Nationwide, Northern Rock and Royal Bank of Scotland.

arises from decomposition of the trading book and available for sale (AFS) assets. Since trading income and portfolio gains and losses on AFS assets are not the focus of this paper, we do not model these exposures here.

Figure 3: Model dynamics*



* The trading book and available for sale (AFS) assets are not included in this version of RAMSI.

The sequence of events is illustrated in Figure 3. The model can be run over any time horizon, though the simulations presented below use a three-year horizon, sufficient time for some adverse shocks to be reflected in credit losses, and consistent with the horizon central banks often use when stress testing their financial systems (Hagen et al (2005), Bank of England (2007) and Sveriges Riksbank (2007)).

The first round effects (up to the start of the feedback loop in figure 3) are discussed more fully in Aikman et al (2009). We use a large-scale Bayesian VAR (BVAR) to capture the evolution of macroeconomic and financial variables. The BVAR is the only source of shocks in RAMSI, thereby preserving a one-for-one mapping from macroeconomic variables to default risk, which is useful for story telling purposes. The BVAR is estimated on quarterly data over the sample period 1972 Q2-2007 Q4. The model includes 24 domestic and foreign (US and EU) variables and has two lags.² Our prior treats every variable in the system as a white noise process centred on a constant. This is a special case of the Minnesota prior popularised by Litterman (1986):

² The selection criteria for variables include their contribution to explaining macro-developments and also their contribution to explaining developments on balance sheets. The UK variables are real GDP, CPI inflation, Real FTSE All-Share, the yield curve, unemployment, real house prices, real commercial property prices, income gearing, corporate lending, 10 year corporate spread. For each of the United States and Euro area we include CPI, real GDP, the 3-month T-Bill rate and the 10-year Government bond rate. We also include real oil prices and world equity prices.

essentially, we adapt the standard Minnesota prior to the case where all unit roots have been eliminated by data transformations.³

The credit risk module treats aggregate default probabilities (PDs) and loss given default (LGD) as a function of the macroeconomic and financial variables from the BVAR. Credit losses are derived as the product of the relevant aggregate PD times LGD times each bank's total exposure to the sector,⁴ though we adjust the aggregate write-off rate for each bank to account for heterogeneity in the riskiness of banks' portfolios.⁵ We model credit losses arising from exposures to UK households (mortgages, credit card, and other unsecured borrowing), UK corporates, plus households and corporates in the United States, euro area and rest of the world.

For most of the loan book, interest income is modelled endogenously. Banks price their loans on the basis of the prevailing yield curve and the perceived riskiness of their debtors: an increase in actual or expected credit risk translates into a higher cost of borrowing. We use the risk-neutral asset-pricing model of Drehmann *et al* (2008) to capture both sources of income risk in a consistent fashion. For other parts of the balance sheet, including all of the liability side, we calibrate spreads based on market rates and other data. For example, we assume that interbank assets and liabilities receive/pay the risk-free rate plus the Libor spread, while banks pay negative spreads relative to the risk-free rate on some household and corporate deposits (if the negative spread implies a negative interest rate, the interest rate paid is assumed to be zero).

Spreads on certain liability classes also depend on the credit rating of the bank in question. These spreads are modelled endogenously in two stages. First, we use an ordered probit model (adapted from Pagratis and Stringa (2009)) to examine the sensitivity of Moody's senior (long-term) unsecured ratings to a number of key bank performance indicators and macroeconomic variables. The assigned ratings are mapped to credit spreads using Merrill Lynch's indices of UK sterling bond spreads associated with different credit ratings. This approach implies that if the fundamentals of a bank deteriorate, its credit rating may be downgraded, increasing its future funding costs

³ In a Bayesian context, all parameters are treated as random variables and the data are used to estimate their probability distribution rather than to obtain point estimates. We abstract from model uncertainty and use means of the estimated posterior parameter distributions.

⁴ That is, we model 'expected credit losses', and trace out variation in expected credit losses driven by macro fundamentals.

⁵ These adjustments are made on the basis of historical differences between write-off rates of individual banks and aggregate write-off rates. This implies that a relatively 'safer' bank continues to incur lower credit losses than the typical bank.

We also include simple models for non-trading income and operating expenses. Profits are then computed as the sum of all sources of income, net of expenses and credit losses. We deduct taxes and dividends from profits, assuming that the tax rate and ratio of dividends to profits are in line with recent history.

The focus of this paper is a detailed assessment of adverse developments in funding conditions. We start by calibrating the onset of funding crises and outright closure of short-term and long-term unsecured funding markets to particular institutions based on a series of indicators. To inform our analysis, we draw on theoretical models, information from banks' own liquidity policies and evidence from past episodes of funding stress including recent experience, such as the failure of Northern Rock.

If a bank is shut out of long-term funding markets, the average maturity of its liabilities will decrease, further undermining confidence, and better informed retail depositors withdraw funds. Once a bank is shut out from long-term funding markets it takes defensive actions to protect its liquidity position. As described in more detail in Section 3, the bank hoards liquidity (interbank assets) by shortening the maturity at which it is prepared to lend in wholesale markets. This implies that the wholesale liabilities of other banks shorten, weakening these banks' liquidity positions.

If fundamentals deteriorate even further, the bank is eventually shut from short-term funding markets and it enters a second phase of liquidity crisis, the trigger for which is described in section 4. The bank's insolvency is not inevitable at this point, but – in the absence of short- and long-term wholesale funding – it is forced to take further defensive actions in order to ensure it has funds to meet all obligations becoming due. These are described in detail in section 5. Some of these defensive actions may have further systemic implications. In particular, the bank may completely withdraw all interbank lending. Or it may sell its available for sale (AFS) assets at fire sale prices, creating asset-side feedbacks that cause remaining banks to suffer temporary (intra-period) mark-to-market losses.

In the extreme, the bank may be unable to meet its flow constraint. At this point, it fails, triggering a further feedback loop. Failure may alternatively occur if the bank's capital falls below the regulatory minimum. Upon failure, because of bankruptcy costs, a fraction of the failed bank's assets are lost, reducing the amount available to its creditors on the interbank

network. Funding markets suffer ‘confidence contagion’ that renders banks with similar characteristics to the failed bank more vulnerable to being shut out of funding markets. If a further bank fails after we account for the second-round effects, then the loop repeats until the default cascade ends.

In the absence of bank failures (or after the feedback loop has completed), we update the balance sheets of surviving banks using a rule of thumb for reinvestment behaviour. Banks are assumed to target pre-specified Tier 1 capital ratios, and invest in assets and increase liabilities in proportion to their shares on their initial balance sheet. In this paper, this latter assumption will be relaxed in extreme circumstances, when banks may divert some or all of reinvestment funds to meet liquidity needs.

3 Funding Liquidity Risk in a System-Wide Context: Conceptual and Theoretical Issues

3.1 The Cash flow Constraint

A bank is liquid if, in every period, cash outflows are smaller than cash inflows, along with the stock of cash held and any cash raised by selling assets (or repoing those assets).⁶ The cash flow constraint can be written in more detail as:

$$\begin{aligned} & Liabilities_{(due)} + Assets_{(new/rolled\ over)} + Off\text{-}balance\ sheet_{(liquidity\ demand)} \\ & < \\ & Net\ Income + Liabilities_{(new/rolled\ over)} + Assets_{(due)} + Off\text{-}balance\ sheet_{(liquidity\ supply)} + Value\ of\ Assets\ Sold \end{aligned}$$

or, breaking down these components further:

$$\begin{aligned} & WL_D + RL_D + WA_{N,R} + RA_{N,R} + OFB_{LD} \\ & < \\ & Net\ Income + WL_{N,R} + RL_{N,R} + WA_D + RA_D + OFB_{LS} + LA^S + \sum p_i * ILA_i^S \end{aligned} \tag{1}$$

where:

- $WL(A)$ are wholesale liabilities (assets),
- $RL(A)$ are retail liabilities (assets),
- OFB are off-balance sheet items affecting liquidity demand (LD) or supply (LS),
- LA^S are the proceeds from the sale of liquid assets such as cash or government bonds,
- ILA_i^S is the volume of illiquid asset i sold,

⁶ Consistent with the rest of RAMSI, this cash flow constraint assumes that there is no policy intervention to widen central bank liquidity provision in a way which would allow banks to obtain more cash from the central bank than they could obtain through asset sales or repo transactions in the market.

- p_i is the price of illiquid asset i , which is may be below its fair value and possibly even zero in the short run.
- Subscripts D, N and R refer to obligations which are contractually due, newly issued or bought, and rolled over respectively.

We note several issues. First, the flow constraint is written in terms of *contractual* maturities as these are the ultimate drivers of funding liquidity risk in crises. But the constraint can also incorporate behavioural maturities which are different from the contractual ones by equating certain due payments (WL_D or RL_D) one-for-one with rolled over payments (WL_R or RL_R). For example, many retail deposits are available on demand. In normal conditions, a bank can expect the majority of these ‘loans’ to be rolled over continuously and hence the behavioural maturity is much higher. But, in times of stress, depositors may choose to withdraw, so the behavioural maturity may collapse to the contractual one.

Second, equation (1) still provides a high level view of the flow constraint. For example, in practice, the financial liabilities category splits into several markets (such as interbank borrowing, unsecured bonds, securitisations, commercial paper). These separate markets may have quite different characteristics that make them more or less susceptible to illiquidity. For example, an investor’s propensity to lend will change significantly dependent on the contractual maturity of the funding market. Furthermore, particular markets may attract a particular type of investor, and that investor may be more or less likely to change sentiment rapidly and therefore withdraw funding quickly. And the proceeds from some markets are used for particular reasons (for example, the commercial paper market) that may lead to investors withdrawing funds.

There are too many factors relevant to funding market dynamics to incorporate them all. However, there are two that we judge to be sufficiently important to split them out separately. First, we differentiate between secured and unsecured markets. And second, we split unsecured funding into longer-term and shorter-term markets. We discuss these in more detail later in the paper.

3.2 *The Trigger for Funding Problems*

Under normal business conditions, banks are able to meet their cash flow constraints in every period, as they will always be able to obtain new wholesale funding. But, as highlighted by channel 1 in Figure 1, adverse shocks may interact with confidence effects to precipitate funding

problems and possibly the failure of one or more institutions. Much of the theoretical literature on funding liquidity risk is focussed around modelling this possibility.

In general terms, funding problems can be captured in the flow constraint by setting $WL_{N,R} = 0$ and, in extreme cases, $RL_{N,R} = 0$. But specific models can also be cast in terms of the flow constraint. For example, Diamond and Dybvig (1983) assume there is only one illiquid investment project ILA_i which pays a high, certain payoff in period 2 but a low payoff p_i if liquidated early in period 1 (the high period 2 return guarantees that the bank is always solvent). The asset also does not pay any interest in period 1 ($CFA = 0$). The bank is entirely funded by demand deposits (RL_D). It is known that a fraction of depositors only care about consumption in period 1, while other agents (which cannot be distinguished by the bank) are patient and prepared to wait until period 2, though they can withdraw in period 1 if they wish. To satisfy interest payments CFL and withdrawals of early depositors, the bank invests a fraction of its deposits into liquid assets LA^S . Given that all other terms in the flow constraint are assumed to be zero, equation (1) in period 1 for the Diamond and Dybvig bank looks like:

$$CFL + RL_D^{early} + RL_D^{late} < RL_R^{late} + LA^S + p_i * ILA_i$$

Under normal circumstances, late depositors roll over their demand deposits ($RL_D^{late} = RL_R^{late}$) and the bank can meet its flow constraint without having to sell the illiquid asset. But if late depositors are not willing to roll over and start a run on the bank ($RL_R^{late} = 0$), the bank is forced to start selling its illiquid assets at p_i , which is assumed to be below the fair value of the asset. Given that the bank is fundamentally sound, bank runs should not happen. But, as payoffs are low when all late depositors run, an equilibrium exists in which it is optimal for all agents to run. This generates the possibility of multiple equilibria, whereby fundamentals do not fully determine outcomes and confidence has an important role.

Even though very stylised, this model captures several key features of liquidity crises. First, contractual maturities matter in a liquidity crisis as the ‘behavioural’ maturities of late depositors collapse in stressed conditions from two periods to the contractual maturity of one period.

Second, funding and market liquidity are closely related. If the bank's assets were liquid, so that p_i would equal the fair value, the bank could always sell assets to satisfy unexpected liquidity demands and would never be illiquid but solvent. As discussed in the introduction, to assess the riskiness of banks in this case, it would be sufficient to focus on the stock solvency constraint rather than look at a combination of stocks and flows.

Third, confidence and beliefs about the soundness of an institution and the behaviour of others play an important role for the crystallisation of funding liquidity risk. Both issues will become apparent from our case studies. However, the result that bank-runs are purely driven by sunspot equilibria is not particularly realistic: bank runs only tend to occur when there are strong (mostly justified) doubts about the fundamental solvency of a bank. Chari and Jagannathan (1988) therefore introduce random returns and informed depositors in the model, which can induce bank runs driven by poor fundamentals. More recently, global game techniques have been applied to this problem (Rochet and Vives, 2004; Goldestein and Pauzner, 2005). Importantly, bank runs in these models only occur when bank fundamentals are weak, even though it can still be the case that a bank is illiquid but solvent.

3.3 *The Spread of Funding Crises*

Figure 1 identified several channels through which a funding crisis at one bank could spread to the rest of the financial system. Historically, when funding crises have affected a range of institutions, these institutions have tended to have similar characteristics. For example, this was evident in the U.K. during both the secondary banking crisis of 1973-75 and the small banks crisis of the early 1990s. This may partly reflect exposures to common asset classes. But it also highlights the potential role of confidence contagion (channel 4 in Figure 1). This could be interpreted through fundamentals, whereby a liquidity crisis in one institution reveals some information on the likelihood of insolvency of other banks with similar investments. As shown by Chen (1999), once depositors have observed other bank runs, it can be optimal for them to run on their bank under certain conditions, even though it may be fundamentally sound.⁷ Alternatively, confidence contagion could simply reflect panic, whereby investors decide to run on similar banks because of sentiment. Arguably, the turmoil at the US securities houses following the failure of Lehman Brothers reflected this effect.

⁷ Contagious bank runs can also affect the investment incentives of banks, making system-wide banking crisis even more likely (see Drehmann, 2002, and Acharya and Yorulmazer).

Other possible systemic consequences of funding crises are made clear by considering the short-term (i.e. one-period) cash flow constraint of a bank experiencing funding problems. In particular, suppose that a bank faces a liquidity crisis and cannot or anticipates not being able to access new funding from wholesale markets ($WL_{N,R}=0$). Assume that without undertaking any action, the bank fears that its flow constraint:

$$\begin{aligned}
 & WL_D + RL_D + WA_{N,R} + RA_{N,R} + OFB_{LD} \\
 & < \\
 & Net\ Income + \cancel{WL_{N,R}} + RL_{N,R} + WA_D + RA_D + OFB_{LS} + LA^S + \Sigma p_i * ILA_i^S
 \end{aligned}$$

may not be satisfied. Then, short of defaulting, the bank has six options affecting the left or right hand side of the cash flow constraint. It can:

- (i) use profits (net income) to pay off maturing liabilities;
- (ii) draw on its committed lines from other financial institutions (OFB_{LS});
- (iii) choose not to roll over or grant new funding to other financial institutions ($WA_{N,R} = 0$) (liquidity hoarding) – a milder form of liquidity hoarding which may be adopted by banks if they anticipate the potential for funding problems in the future would be to roll over funding to other financial institutions but only at the shorter maturities which are reflected in the short-term cash flow constraint.
- (iv) choose not to roll over loans to non-financials ($RA_{N,R} = 0$) or reduce committed lines to customers (a reduction in OFB_{LD});
- (v) sell or repo liquid assets (LA^S);
- (vi) sell illiquid assets ($\Sigma p_i * ILA_i^S$).

It is not clear how, in practice, a bank would weigh up the relative costs of these choices. But the ordering above reflects our judgement on the sequencing of banks' defensive actions. This is based both on an intuitive judgement of the costs imposed to the bank in distress by each action and an assessment of the defensive actions actually taken by banks during the recent financial crisis. Below we deal with each option.

In terms of costs to the bank, reinvesting profits in liquid assets (option (i)) is likely to have a limited impact, even though the bank may not be able to undertake some profitable business opportunities. But banks are only likely to be able to raise limited funds in this way, especially if they are experiencing funding difficulties because they have become less profitable. The direct costs of using committed lines (option (ii)) may also be limited. But experience in the financial crisis has often shown that a stressed bank cannot rely on being able to draw on such

lines. And any such draw down may, in any case, send an adverse signal to the markets, weakening confidence and raising funding costs.

In practice, liquidity hoarding (option (iii)) has probably been the most frequently observed defensive action during the recent financial crisis. Liquidity hoarding allows funds to be raised quickly and may be perceived as only having a limited impact on the franchise value of the bank. Furthermore, although such hoarding may involve some reputational costs, these may be seen as less severe than those resulting from other options. In particular, fire sales (option (vi)) may be associated with a real financial loss and a corresponding hit to equity, and which is easily observable in the market, potentially creating severe stigma problems. This perhaps explains why it is difficult to find strong evidence of fire sales during the recent financial crisis. Some banks did sell off chunks of their business, but these appear to have been motivated more by a desire to raise capital than liquidity. Contracting lending to the real economy (option (iv)) is likely to have a less immediate impact on liquidity and so is not a focus here, but the macroeconomic implications are undeniably important and this channel is the subject of ongoing development work

Sales of liquid assets are possible even in the most severe of crises, but such sales are unlikely to be a first line of defence. Their use depletes reserves, making banks more susceptible to failure in subsequent periods. Furthermore, regulatory requirements on liquid asset holdings may limit the scope for sales. That said, selling or repoing liquid assets is likely to be preferable to selling illiquid assets, due to the real costs imposed by the latter course of action.

From a systemic perspective, we are interested in the possible consequences of these actions on the rest of the financial system, especially in the short-run. Options (i), (iv) and (v) are unlikely to affect other financial institutions immediately, even though the restriction of liquidity to non-financial firms may, over time, create macroeconomic feedbacks through a credit crunch (Bernanke and Lown, 1991). By contrast, options (ii), (iii) and (vi), which correspond to channels 2 and 3 in Figure 1, could have significant system-wide effects.

In particular, if a bank draws on committed credit lines or chooses not to issue or roll over funding to other banks, the flow constraints of counterparties will be tightened through a reduction of $FL_{N,R}$. In many cases, counterparties will be able to obtain funding from alternative sources and this will not matter. But funding problems at institutions which are already stressed

could be intensified. Moreover, small banks may find it difficult to access alternative sources of funding even if they are not stressed: indeed, the potential loss of a major funding source for small regional U.S. banks was one of the reasons for the bail-out of Continental Illinois in 1984 [reference to be added]. Yet, despite its potential importance, this ‘funding contagion’ channel has only received limited attention in the literature, though recent theoretical work by Gai and Kapadia (2009) has shown how this type of action can cause an interbank market collapse in which all banks stop lending to each other.⁸

By contrast, asset fire sales have been widely discussed. The potential feedback loop between distress selling and falling asset prices was first highlighted by Fisher (1933). After the failure of LTCM and the resulting liquidity crisis for Lehman Brothers, this idea has been formalised by a wide range of authors (see Shim and von Peter, 2006, for a survey). Mark-to-market losses associated with falling asset prices could raise solvency concerns at highly exposed institutions and clearly have the potential to propagate the initial funding crisis more widely through the system.⁹ Moreover, Brunnermeier and Pedersen (2009) show that severe mark-to-market losses may trigger additional margin calls on *off-balance sheet transactions*. These may come through negative mark-to-market revaluations of the actual positions. Additionally, the value of the collateral backing the margin call may fall. Finally, a fall in bank rating may trigger clauses in the contract requiring additional margin (in the form of cash or collateral). Their model can also be recast in terms of the flow constraint: higher margin calls are equivalent to higher liquidity demands from off-balance sheet items (OFB_{LD}) whilst at the same time, lower asset prices, p_i , reduce available liquidity.

If, despite pursuing (i)-(vi), a bank still has insufficient funding, it will be forced to default on its obligations, and its financial counterparties are likely to suffer a loss in the interbank market. This may directly render other banks insolvent, with counter-party credit risk linkages possibly propagating the shock possibly even more widely through the financial system (Allen and Gale, 2000; Freixas, Parigi and Rochet, 2000; Dasgupta, 2004; Alentorn, Nier, Yang and Yorulmazer, 2007; Upper, 2007). However, it is also clear from the flow constraint that a loss of FL_D could lead to a short-term funding problem at a bank even if it still remains solvent.

⁸ Liquidity hoarding driven by concerns about counterparty risk, has, however, received more attention in the literature (e.g. Heider et al (2009); Caballero and Krishnanurthy (2009)).

⁹ Cifuentes, Ferruci and Shin (2005) develop a model along these lines, though their focus is on the pure solvency constraint.

Thus far, we have focussed on the negative system-wide effects from funding crises. But it is important to note that when funds are withdrawn from a stressed bank, they must be placed elsewhere. So some banks are likely to *strengthen* as a result of funding crises through an increase in FL_N and, possibly, OL_N . Indeed, Gatev and Strahan (2006) and Gatev *et al.* (2006) identify this effect in the U.S. banking sector, especially for larger institutions.¹⁰ However, when considering a national banking system, the strength of this countervailing effect is likely to be highly dependent on the type of crisis: in a crisis precipitated by an idiosyncratic shock to one institution, we may expect it to be fairly strong; if much of the banking system is in distress, it is unlikely to have much of an offsetting affect as the banks which strengthen will probably be overseas or there will be a movement into safe liquid assets, such as gilts or gold.

The recent crisis illustrated how funding liquidity risk may also crystallise or intensify through off-balance sheet items. Committed credit and liquidity lines to off-balance sheet vehicles were key sources of risk that initially sparked the recent crisis. But as already discussed, margin calls may exacerbate funding problems, especially since in certain transactions, particularly some conduit liquidity facilities, the amounts that may be required to be placed as collateral can be significant. However, many of the off-balance sheet commitments are highly bespoke, therefore, liquidity characteristics such as rating triggers may not be well documented and captured by risk managers.

4 Modelling the closure of funding markets quantitatively – a ‘danger zones’ approach

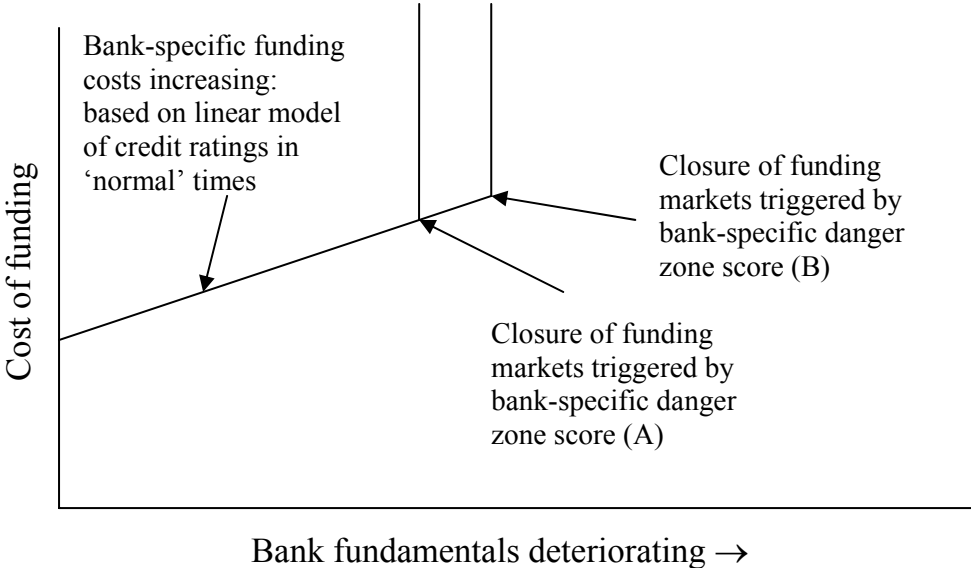
Modelling the outright closure of funding markets quantitatively presents significant challenges, both because of the binary, non-linear nature of liquidity risk, and because liquidity crises in developed countries have been (until recently) rare events for which data are limited. We therefore adopt a simple, transparent (yet subjective) ‘danger zone’ approach under which banks accumulate points as liquidity conditions deteriorate, and face the prospect that certain funding markets may close to them as their score crosses particular thresholds.

We consider it important to model the outright closure of funding markets in a distinct framework. Figure 3 illustrates this point. Though there may be a relatively linear relationship between a deterioration in bank fundamentals and increased funding costs in relatively ‘normal’

¹⁰ It should, however, be noted that Pennacchi (2006) finds that demand deposit inflows cannot be observed prior to the introduction of deposit insurance, indicating that this effect may be driven by regulatory interventions rather than by the underlying structure of banks’ balance sheets.

times (as described in Section 2 of this paper), it is hard to use this approach to identify the closure of funding markets in extreme circumstances given that this is an inherently non-linear process, and could occur at different ratings and funding costs (A or B), depending on the circumstances. Hence we feel that the danger zone approach is more appropriate for identifying the region in which funding markets are likely to shut. Nevertheless, we intend to use the funding cost/ratings model as a cross-check on the danger zone approach.

Figure 3: The operation of funding liquidity risk



In order to assess triggers for funding liquidity stress we draw on a variety of sources. Specific indicators of funding stress relate to three key areas that theoretical models (Chen (1999) and Goldstein and Pauzner (2005)); from information in banks’ liquidity policies and contingency plans, as summarised in ECB (2002), BIS (2006) and IIF (2007); from banks own published liquidity policies; and from behaviour observed during financial crises. These studies highlight the importance of solvency, liquidity and confidence (Figure 4). The framework allows for feedback effects. In particular, the closure of certain funding markets to an institution: (i) may worsen that bank’s liquidity position through ‘snowballing effects’, whereby the bank becomes increasingly reliant on short-term funding; and (ii) may adversely affect ‘similar’ banks through a pure confidence channel. Recent events have emphasised that market-wide liquidity factors can also play an important role in affecting confidence and hence contributing to funding stress. To proxy for these factors, the framework captures a greater risk of funding stress in periods when the market interbank spread is elevated.

Figure 4: Closure of funding markets in RAMSI

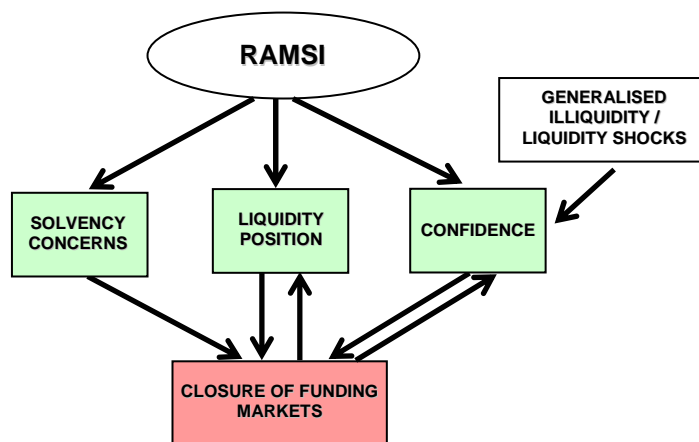
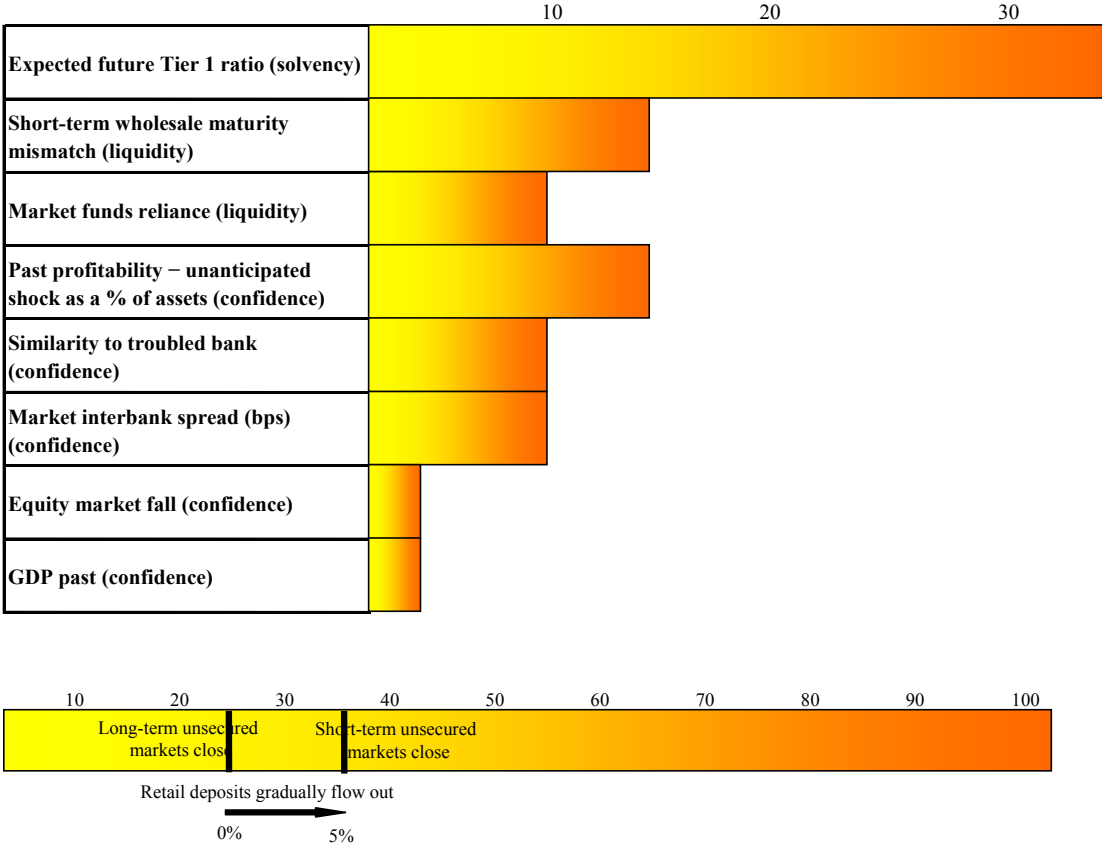


Figure 5 presents the set of eight indicators (the underlying factor that each is trying to proxy is mentioned in brackets), along with the aggregation scheme and the thresholds at which short-term and long-term unsecured funding markets are assumed to close to the bank. In constructing the weighting, we place roughly equal weight on three main factors that can trigger funding crises: (i) concerns about future solvency; (ii) a weak liquidity position/funding structure (for example, high reliance on short-term wholesale unsecured funding); and (iii) institution-specific and market-wide confidence effects, over and above those generated by solvency concerns or weaknesses in liquidity positions. In the aggregation, we allow for the possibility that a run could be triggered either by extreme scores in any of the three areas, or by a combination of moderate scores across the different areas. The judgements underpinning more specific aspects of the calibration and weighting schemes were informed by analysis of a range of case studies.¹¹

¹¹ Currently, the danger zones are incorporated into RAMSI in a simplified way. In later drafts of this paper, the model will include model-consistent expectations, but at the moment, the current Tier 1 capital ratio is used instead of the expected future capital ratio and the past profitability indicator is ignored as it is not possible to identify unanticipated losses. We also intend to define banks scoring less than five points as ‘safe’ and allow them to receive funding withdrawn from troubled banks; as such, they will help to close the system by capturing flight-to-quality effects. If there are no ‘safe’ banks, we will assume that funds end up as increased reserves at the central bank. Finally, we plan to extend the framework to allow for closure of secured funding markets, though, in reality, this is likely to lead to immediate failure. For simplicity, we do not consider a more detailed breakdown of funding markets (for example, we do not distinguish between foreign and domestic funding markets).

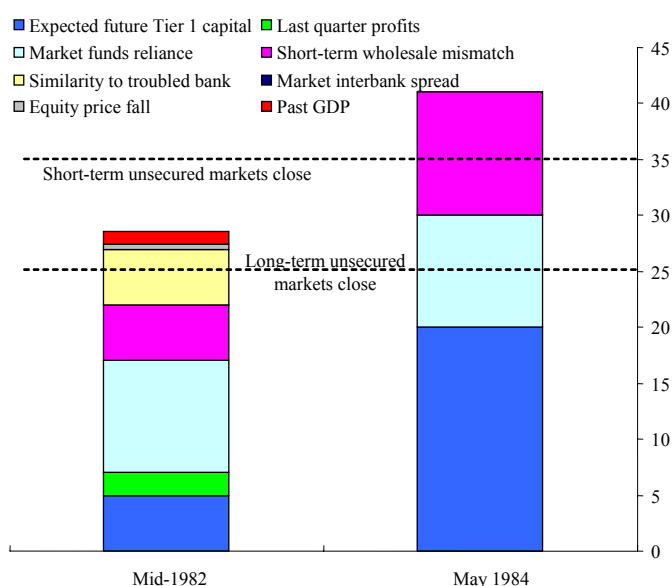
Figure 5: Danger zones – basic structure



4.1 Examples of a danger zone calibration: Continental Illinois

Case studies indicate that the danger zones approach performs relatively well, especially in terms of capturing the ranking of institutions under most stress. We have considered case studies beyond the very recent crisis. An example is the case of Continental Illinois, which, at least in terms of funding liquidity pressure, can be divided into two periods: the closure of longer-term domestic funding markets to it in July 1982 and the global run in May 1984. Chart 1 scores Continental Illinois in each of these periods.

Chart 1: Continental Illinois danger zone points



Before 1982, Continental is heavily reliant on market funds. The July 1982 run is triggered identified with mild concerns over future solvency stemming from anticipated losses on risky speculative loans to the energy sector. Many of these loans had been originated by Penn Square, a much smaller bank which failed earlier that month. Aside from rising solvency concerns, Continental scores points following Penn Square’s failure both because of its similarity and because of a significant unanticipated loss due to a direct exposure. Overall, Continental scores enough points for the first danger zone threshold to be crossed.

After 1982, Continental had greatly reduced access to long-term funding markets. Therefore, increased reliance on short-term funding then serves to increase Continental’s score over the next couple of years. But the final trigger for the second run is the fallout from the Latin American debt crisis – this substantially raised future solvency concerns during the first part of 1984 so that by May, Continental exceeds the second danger zone threshold.

5 Quantifying Systemic Liquidity Feedbacks

In this section we discuss how we quantitatively assess the systemic implications of distressed banks being shut out of funding markets, including both the implications for the bank in question, and though its defensive actions, systemic implications. A score of 25 or more Danger Zone (DZ) points triggers the closure of long-term unsecured funding markets to the bank. We refer to this as ‘Phase 1’ of funding market closure. There is no default during this phase since

the bank is able to refinance in short-term unsecured funding markets and banks are assumed to have access to an infinite supply of short-term unsecured funding.¹² Once the DZ score reaches 35, short-term funding markets close to the bank, and the bank enters ‘Phase 2’ of funding market closure. Ultimately, if the bank’s capital falls below regulatory minimum or the bank is unable to meet its cash flow constraint, the bank fails. The anatomy of these phases is described below.

5.1 Phase 1: Withdrawal of long-term wholesale funding

In this section we consider the implications of a bank losing access to long-term wholesale funding markets. We use illustrative simulations to illustrate the marginal impact of snowballing and liquidity hoarding on wholesale maturity mismatch. Our aim is to illustrate clearly the properties of these modules by running them in isolation of the other complex transmission channels contained within RAMSI. To simplify the analysis, we hold balance sheets constant in aggregate (there is no reinvestment of profits), and also hold all other danger zone (DZ) scores constant apart from the short-term maturity mismatch score. Details of how the mismatch score is calculated are presented in Appendix 1. In short, mismatch (MM_t) is calculated as follow

$$MM_t = \frac{LA_t + WA_t^{0-3} - WL_t^{0-3}}{TA_t}, \text{ where}$$

- LA_t are liquid assets at time t.
- WA_t^{0-3} are wholesale assets at time t of less than three months maturity
- WL_t^{0-3} are wholesale liabilities at time t of less than three months maturity
- TA_t are total assets at time t

We present results from three scenarios relative to a baseline in which there is no effects are switched on. The results are based on stylised balance sheets. We focus on three banks. The ‘distressed’ bank is the bank that we calibrate to have a Danger Zone score exceeding 25, implying it is shut out of long-term funding markets. We also show the impact on two other banks (Banks A and B). Both are connected to the distressed bank through the interbank network and we shall demonstrate how the degree of connectivity affects the magnitude of the spillovers impact

¹² Here, short-term is defined as less than three months, given the constraints of RAMSI’s balance sheet structure. Ideally, we would embellish the model with a more granular maturity split of liabilities but the same key dynamics and feedbacks would apply.

(i) *Snowballing into shorter-term maturities (Chart 2.1)*: Once the distressed bank loses access to long-term unsecured wholesale funding markets, it substitutes lost long-term unsecured wholesale funding for short-term wholesale unsecured funding. This is the snowballing effect. It worsens the bank’s short-term wholesale maturity mismatch position and thus serves to increase its danger zone points score in the next quarter. Chart 2.1 illustrates that the snowballing increases the distressed bank’s maturity mismatch (expressed as a percentage of total assets according to the equation above) score each quarter as more of its liabilities mature and are rolled over only at short-term maturity. The distressed bank’s maturity mismatch as a percentage of total assets worsens by around 4 percentage points over the 12 quarters (shown in Chart 2.1 as a decline in maturity mismatch). The chart illustrates how much of the increase in maturity mismatch impact of snowballing occurs in the first four quarters, with the effect tailing off over time, reflecting the concentration of assets in the shorter maturity buckets. By design there is no impact on the other banks.¹³

Chart 2.1 Impact of Snowballing only

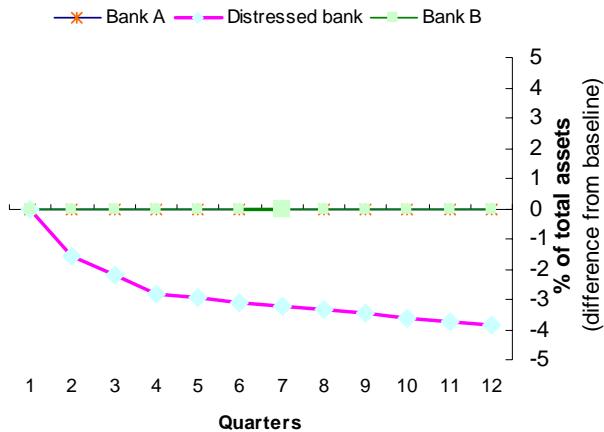


Chart 2.2: Impact of Liquidity Hoarding only

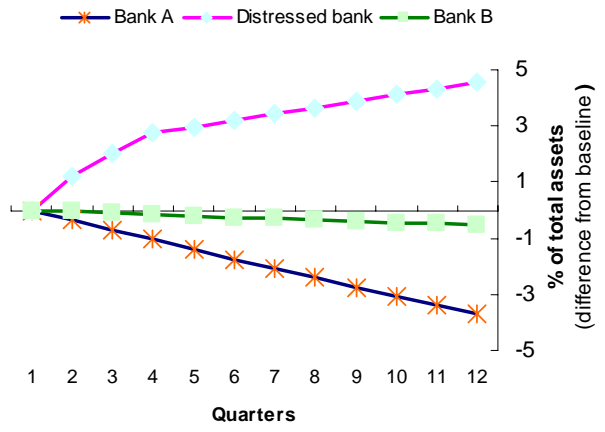
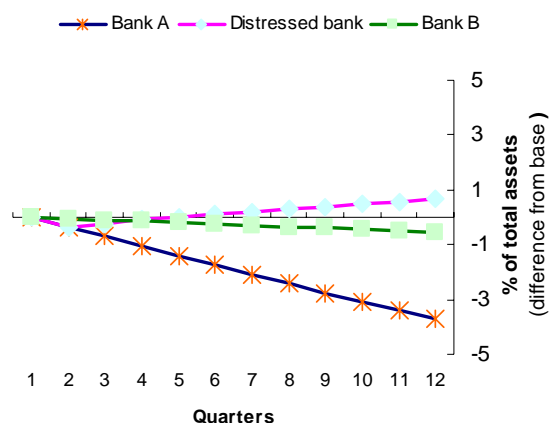


Chart 2.3: Impact of snowballing and liquidity hoarding

¹³ At this stage we have made the simplifying assumption that there is no corresponding shortening of the maturity of assets of other banks, since this is likely to be of only second order importance in its impact on funding conditions.



(ii) *Liquidity Hoarding by Shortening Lending Maturities (Chart 2.2)*: A bank that is unable to access longer-term wholesale funding starts to hoard liquidity by maturity ie. it only rolls over maturing wholesale assets at short-term maturities (ie less than three months in our setup). This has two effects. First, the additional short-term wholesale assets improve the bank’s short-term wholesale maturity mismatch position in the next period as extra liquidity will be available on demand if needed. This serve to improve its maturity mismatch in the next quarter. Chart 2.2 illustrates how the maturity mismatch of the distressed bank improves by nearly five percentage points over the simulation. Second, this behaviour leads to a shortening of the interbank liabilities of other banks to which the distressed bank is lending, and as it hoards liquidity, a fraction of all other bank’s interbank liabilities effectively snowball. The fraction of other banks’ interbank liabilities that snowball is calibrated to correspond to the ratio of that bank’s interbank borrowing from the distressed bank to its total interbank borrowing. This is higher for bank A so its position deteriorates by more than bank B. This worsens the other banks’ short-term wholesale maturity mismatch position and thus serves to increase their danger zone points scores.

(iii) *Snowballing and Liquidity hoarding (Chart 2.3)*: Allowing for both snowballing and liquidity hoarding is represented as a combination of (i) and (ii) above. In this case the distressed bank improves its maturity mismatch overall as the impact of hoarding liquidity outweighs the impact of snowballing. Other banks maturity mismatch worsens, since there there is only the negative impact of the distressed bank’s liquidity hoarding, the effect of which is identical to case (ii) since the amount of liquidity hoarded by the distressed bank is the same in each case.

(iv) *Outflow of retail deposits:* After long-term unsecured funding markets close to the bank, the bank experiences gradual retail deposit outflows (0.5% for every danger zone point above 25) such that the outflow reaches 5% of retail deposits by the time short-term unsecured markets close. This is intended to reflect behaviour of well-informed investors rather than representing a widespread run akin to that suffered in 2007 by Northern Rock. The bank replaces lost retail deposits with short-term wholesale unsecured funding. Similar to the impact of snowballing, this worsens their short-term wholesale maturity mismatch position and thus serves to increase its danger zone points score in the next quarter.

In most circumstances a stressed bank will survive this phase of a funding crisis, since it can still access short-term funding markets. Unless it suffers devastating counterparty losses as a result of another bank failing, the stressed bank proceeds to the following period.

5.2 Phase 2: Removal of short-term funding options

The second phase of liquidity crisis occurs when funding conditions deteriorate to such a point that the bank is frozen out of both short- and long-term funding markets. In our model this occurs when a bank's DZ score exceeds 35 (see Figure 5). The bank's insolvency is not inevitable at this point (unlike in previous versions of RAMSI when a DZ score of 35 points triggered failure). But in the absence of short- and long-term wholesale funding, it becomes increasingly difficult for a bank to meet its flow constraint. The bank may need to take further defensive actions to meet its constraint, some of which may imply further systemic feedbacks.

There are various funding options available to a distressed bank with a DZ score greater than 35, and below these are assessed according to various steps.

Step 1: Is the bank still able to meet its flow constraint in the complete absence of wholesale funding?

At this point it is useful to simplify the notation for the cash flow constraint used in Section 2. Abandoning the distinction between interbank and other financial assets and liabilities, ignoring off-balance sheet items (which could be considered in an extended model), and excluding net income (reinvestment funds) and liquid assets, the cash flow constraint, which accounts for all balance sheet items in the 0-3 month maturity bucket, may be written as:

$$WL_{Due} + OL_{Due} + WA_{New} + OA_{New} < WL_{New} + OL_{New} + WA_{Due} + OA_{Due}$$

where:

1. WL_{Due} is the sum of all wholesale liabilities due to mature.
2. RL_{Due} are retail liabilities due to mature.
3. WA_{Due} is the sum of all wholesale assets due to mature, excluding liquid assets.
4. RA_{Due} is the sum of all most granular assets minus WA_{Due} and liquid assets.
5. WL_{New} is the sum of all new Wholesale liabilities is set equal to zero (see above).
6. RA_{New} is the sum of all new retail assets is set equal to OA_{Due} .
7. RL_{New} is the sum of all new retail liabilities is set equal to OL_{Due} .
8. WA_{New} is the sum of all new Wholesale assets is set equal to WA_{Due} .

We make some further important simplifying assumptions at this point. We assume that the bank's funding problems do not cause it to deleverage. So it continues to replace maturing retail assets with new retail assets. Thus we omit important feedbacks from banks to the macroeconomy (a bank lending channel). Ongoing work aims to incorporate such feedbacks (see conclusions). We also assume that all retail liabilities can be refinanced beyond the 5% outflow already captured between 25 and 35 points. This assumption may be relaxed in future work. Finally, we assume that at this stage, the bank continues to roll over wholesale funding (of other banks). Such funding may, however, be withdrawn as a defensive action (see below).

If, given the above assumptions the constraint is satisfied if not (Step 1), then they can proceed to the next quarter. If not, then we consider how banks may take a series of defensive actions to help them meet the constraint (steps 2-5). As discussed above, the ordering of these actions reflects the pecking order from actions observed during the crisis, from published contingency planning documents, and from our own judgement. Any bank that does not satisfy the constraint after Step 5 is defined as defaulted (step 6).

Step 2: Using profits to repay liabilities. Instead of reinvesting profits as normal (see Section 2), banks are assumed to use some or all of their reinvestment funds to pay off some of their short-term liabilities. Balance sheet expansion is dampened and short-term interbank liabilities decrease as reinvestment funds are used to pay them back. If the flow constraint still does not balance, we proceed to step 3.

Step 3 Liquidity Hoarding by Withdrawal (step 2 and set WA_{New} equal to zero). In this case a stressed bank completely withdraw their maturing wholesale assets and use them to repay maturing wholesale liabilities. Their balance sheet shrinks as a result (next quarter, they will only have 0-3 months wholesale assets from those assets that cascaded down from being 3-6 months). This has no direct impact on counterparties since we assume that these are below 35 points and can replace the lost funding with new short-term interbank liabilities in the interbank

market (if they are above 35 points they will already be going through the flow constraint process). In the example

Step 4 Adding unencumbered liquid assets to the inflows. If the cash flow constraint still cannot be met, we assume that banks encumber a fraction of their liquid assets to obtain repo funding to repay liabilities due. The size of the balance sheet does not change in this step but banks' liquid assets are recorded as encumbered rather than unencumbered and remain as encumbered for the next quarter, meaning that they can no longer be counted in as a positive in the danger zone indicators and can no longer be used in a defensive way if the bank experiences further outflows in the next quarter.

Step 5 (Asset Fire Sales). Step 4 and adding fire sales to the inflows. Banks raise liquid assets by selling assets in a fire sale, obtaining the price that would prevail once the assets have been sold, which will reduce shareholder funds. Asset receipts are reinvested in a safe asset (such as government bonds). Banks then encumber these liquid assets as in step 4.

Such fire sales create asset-side feedbacks that cause remaining banks to suffer temporary (intra-period) mark-to-market losses. The fire sale discount lasts for one quarter, and the resulting fall in asset prices may lead other banks to incur mark-to-market losses; hence in extreme circumstances these banks may then also fail. The associated price impact given by equation (1) is applied to other banks' AFS assets. Consistent with Duffie *et al* (2007), we take the relationship between prices and the magnitude of fire sales to be concave. For asset j , the fire sale equation is:

$$P'_j = \max \left\{ 0, P_j \left(2 - \exp \left(\theta \frac{S_{ij}}{M_j + \varepsilon_j} \right) \right) \right\} \quad (1)$$

The price of asset j following the fire sale, P'_j , is the maximum of zero and the price before the fire sale, P_j , multiplied by a discount term. The discount term is a function of value of assets sold by bank i in the fire sale, S_{ij} , divided by the depth of the market in normal times, M_j , and scaled by a parameter θ that reflects frictions, such as search problems, that cause markets to be less than perfectly liquid. Market depth can also be shocked by a term ε_j to capture fluctuations in the depth of markets as macroeconomic conditions vary. There are three types of assets that can be affected by fire sales: equities, corporate debt securities, and asset and mortgage-backed securities. Each has a different value of market depth.

Calibration is guided both by this empirical evidence and a top-down judgement regarding the plausible impact of a fire sale on capital.¹⁴ The calibration for θ is based on the results presented in Mitchell *et al* (2007). Given θ , a value of market depth M_j is chosen for each of the asset types so that when the UK bank with the largest holdings of an asset class in its trading portfolio and AFS assets sells all these assets, it generates price falls of 2% for equities, 4% for corporate debt, and 5% for asset and mortgage-backed securities.

Step 6 (Failure). If a bank still cannot meet its flow constraint, it is assumed to default in the network. When a bank defaults, counterparty credit losses incurred by other banks are determined using a network model. A matrix of interbank exposures for the major UK banks, along with some smaller UK institutions and a selection of large complex financial institutions (LCFIs) is built using reported large exposure data where available. Since we also have information on total interbank asset and liability positions, we then use maximum entropy techniques to fill in missing gaps in the network, ensuring that none of the estimated entries exceed the reporting threshold for large exposures.¹⁵ If any interbank assets or liabilities are unallocated following this procedure, we assume that they are associated with a residual sector which cannot default.

Both fire sale and network feedback effects affect other banks' danger zone points scores. If any of the banks cross 25 as a result, then they are flagged as snowballing and liquidity hoarding by maturity, and this affects balance sheets in the next quarter as outlined under Phase 1. If the score of any bank crosses 35 points, then that bank enters Phase 2 needs to be gone through for those banks in the same quarter as part of a loop, until the system clears.

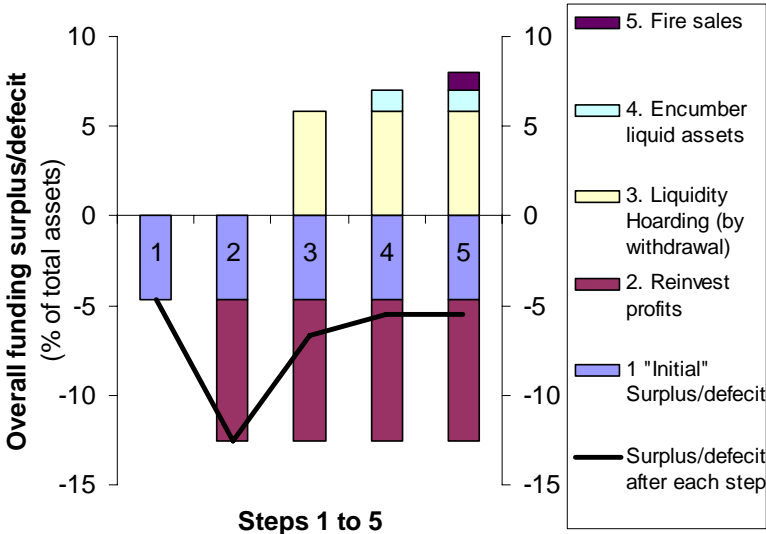
Chart 3 illustrates with a simulation representing an outcome for one bank that – following a bad draw in RAMSI – does not initially meet the flow constraint once it has been excluded from short- and long-term funding markets. In the example the bank has a shortfall of around five percent of total assets (the first bar in the chart). Hence the bank moves to Step 2 (see below). In the simulation example, the bank is not able to ameliorate its funding position through reinvestment since it makes *losses* in step 2 and it is further away from being able to meet its

¹⁴ The impact is likely to be stronger when the financial system is under stress and markets are less deep (Pulvino (1998)).

¹⁵ The techniques adopted are similar to those discussed by Wells (2004), Elsinger *et al* (2006b) and OeNB (2006).

funding constraint (see solid line in Chart 3). The solid line illustrates that the bank gets closer to meeting its flow constraint by withdrawing all maturing wholesale assets and using them to pay off liabilities due (step 3); by encumbering its liquid assets (Step 4) and by increasing its liquid asset holdings through fire-selling its illiquid assets. But in this extreme example, the combined effect of these actions is insufficient for the bank to meet its flow constraint and the bank fails.

Chart 3: Steps in flow constraint when wholesale funding withdrawn



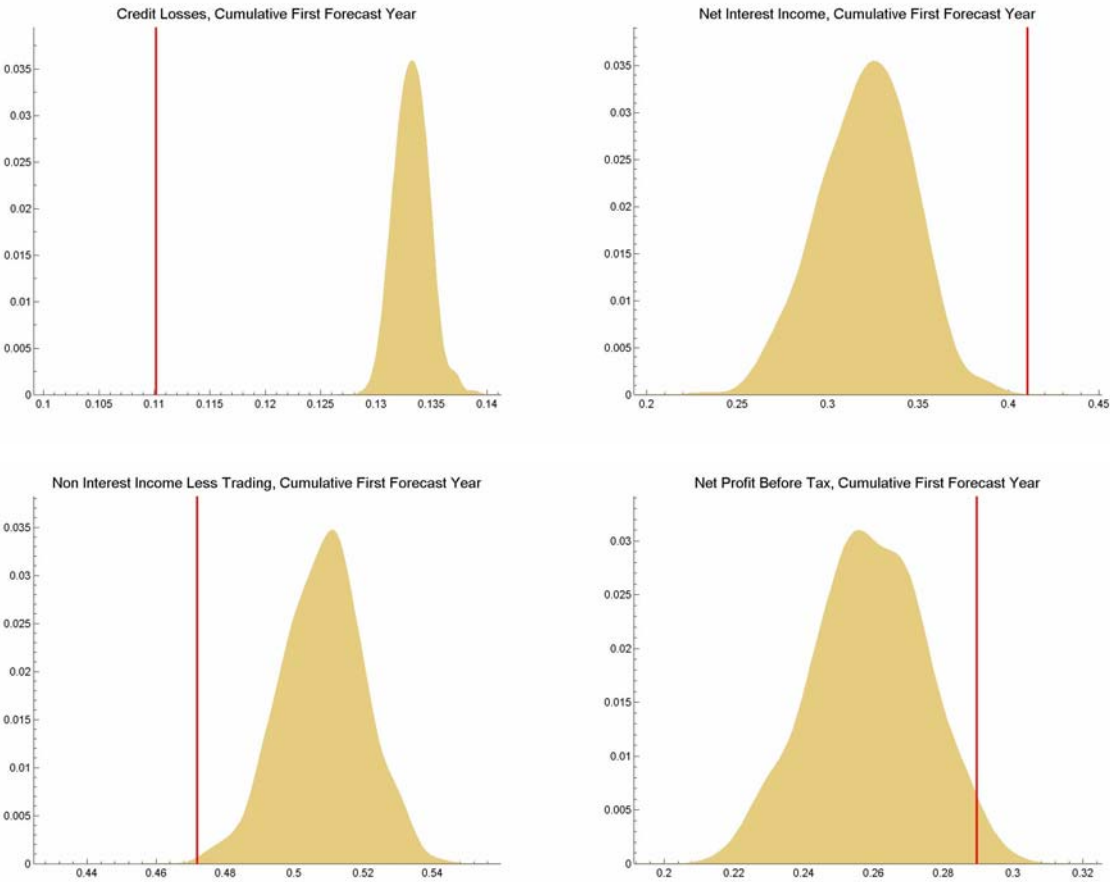
6 Simulation Results

In this section we reveal model properties through stochastic simulations, and focus on the marginal impact of introducing systemic feedbacks. We use data up to 2007 Q4 (so that all balance sheet information is on the basis of end-2007 data) and run 500 simulations on a three-year forecast horizon stretching to the end of 2010. The BVAR is the only source of exogenous randomness in the stochastic simulations; each simulation is thus driven by a sequence of macroeconomic shocks drawn from a multivariate normal distribution.¹⁶ The results are illustrative, reflecting model properties in this preliminary version rather than being the authors' view of the likely impact on the banks in question.

¹⁶ In other words, we draw 1000 realisations of the macroeconomic risk factors in the first quarter. In subsequent periods, we draw a single set of macroeconomic risk factors for each of the 1000 draws. In some cases we only run 500 simulations.

Chart 2 shows the simulated distributions of some key profit and loss items, which apply irrespective of whether or not systemic liquidity feedbacks are included. For each variable, we calculate aggregate cumulative figures for the first year by adding over banks and quarters, and normalise by aggregate 2007 ('beginning of period') capital. The vertical line represents the corresponding figures from the 2007 published accounts, normalised by 2006 capital levels.

Chart 2: Simulated distributions for profit and loss items (per cent of aggregate 2007 capital): no liquidity effects



The top left-hand panel shows that credit risk is projected to increase in 2008, reflecting a worsening of the macroeconomic outlook. Net interest income is projected to be weaker than 2007, reflecting contractual frictions that prevent banks from instantaneously passing on higher funding costs to their borrowers. The variance of net interest income may be unrealistically high as the model does not currently incorporate hedging of interest rate risk.¹⁷ Non-interest income (bottom left-hand panel) remains high, with a median projection above the reported

¹⁷ Banks can be penalised under the second pillar of Basel II for not hedging interest rate risk in their banking book. Hedging of interest rate risk will be introduced in later drafts of this paper.

2007 level; this variable is procyclical but adjusts relatively slowly to macroeconomic changes. The net impact on banks’ profitability is summarised in the net profit chart (bottom right-hand panel). As can be seen, profits were projected to be weaker than in 2007.

Chart 3 shows the distribution of total assets in the last quarter of the simulation and the average aggregate return on assets (RoA) over the whole horizon with funding liquidity risk and systemic liquidity feedbacks excluded from the model. This implies that institutions can only default if they become insolvent because their capital falls below the regulatory minimum. It also implies that there is no contagion. As can be seen, the ROA chart has negative skew and some observations in the extreme tail. The negative skew reflects cases where one or more institutions are defaulting for pure solvency reasons; the extreme observations reflect cases where more than one institution defaults for pure solvency reasons.

Chart 3: Total system assets – final quarter (no liquidity effects)

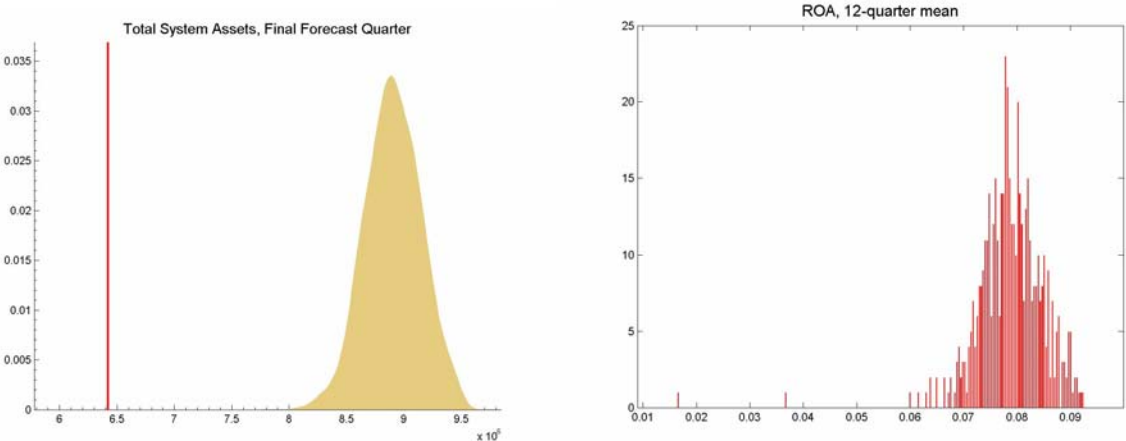
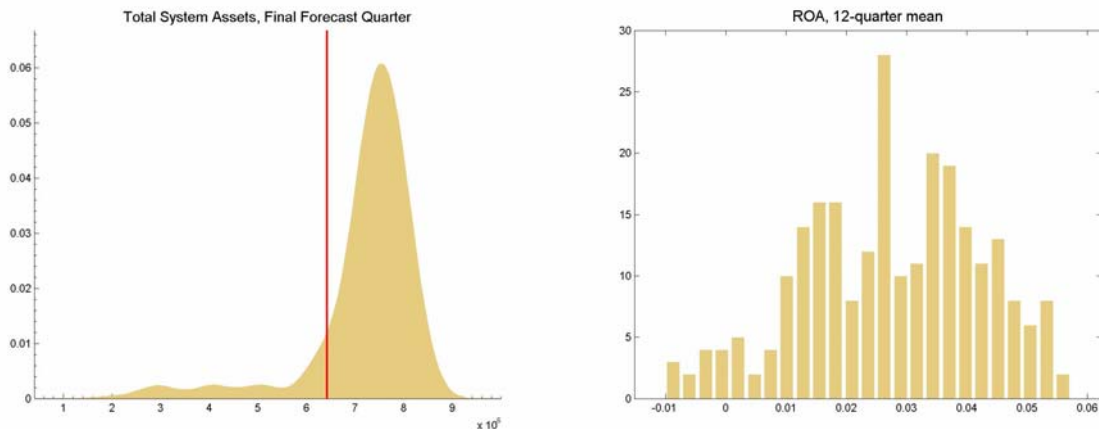


Chart 4 presents the results incorporating funding liquidity risk and systemic liquidity feedbacks. It is immediately evident that the final projected outcomes are considerably worse. This is partly due to a higher incidence of failure due to the possibility that an institution may default because it is unable to meet its cash flow constraint. But the charts also highlight the role of contagion due to the systemic liquidity feedbacks. The distributions have a long left-hand tail, which is a direct consequence of liquidity feedbacks, which can, in some cases cause several institutions to default. These preliminary results point towards the importance of considering funding liquidity risk and systemic liquidity feedbacks in any quantitative model of systemic risk.

[Further analysis of results to be added]

Chart 4: Total system assets – final quarter (with liquidity effects)



7 Conclusions and future work

This main contribution of this paper has been to demonstrate how systemic risk may escalate as a bank’s funding conditions deteriorate, irrespective of whether the bank ultimately survives or fails. By applying the model to the UK banking system based on the balance sheet vulnerabilities that existed at the end of 2007, we have demonstrated how rising funding costs and liquidity concerns can amplify other sources of risk.

Several important transmission channels are introduced relative to previous published work on RAMSI. By imposing a cash flow constraint on each bank, we have assessed the onset and evolution of liquidity stress in various phases. As the distressed bank loses access to longer-term funding markets its liabilities snowball into shorter-maturities, further undermining confidence. Stressed banks take defensive actions in an attempt to stave off a liquidity crisis, which may in turn have a systemic impact. In particular, hoarding liquid assets shortens the wholesale liability structure of other banks; while selling assets at fire sales prices may affect the mark-to-market valuation of banks’ held-to-maturity assets, which in turn affects funding conditions.

A substantial area for further (ongoing) work is to incorporate feedbacks from the banking sector to the real economy. This is a focus of ongoing development work and could be done by

adding an aggregate lending measure to the BVAR and then treating changes in banks' supply of credit at a given point in time (in terms of either quantities or prices) as lending shocks for the subsequent period. Needless to say, such a mechanism needs to be carefully designed in order to preserve the internal consistency of the framework.

Appendix 1: Calculation of the maturity mismatch Danger Zone score

Short-term wholesale maturity mismatch (MM) score is calculated as

$$\text{MM} = [(\text{liquid assets} + \text{wholesale assets} < 3 \text{ months}) - (\text{wholesale liabilities} < 3 \text{ months})] / (\text{total assets})$$

The mismatch is constructed using wholesale assets and liabilities which have a remaining contractual maturity less than 3 months in order to capture the short-term position of the bank. Liquid assets are defined as: cash and balances at central banks; items in the course of collection; treasury and other eligible bills; and government bonds. Wholesale assets are defined as: loans and advances to banks; loans and advances to other financial companies; financial investments available for sale (investment securities) excluding items that are recognised as liquid assets; and reverse repurchase agreements and cash collateral on securities borrowed. Wholesale liabilities are defined as: deposits from banks; items in the course of collection due to other banks; deposits from other financial companies; and debt securities in issue (this includes commercial paper, certificates of deposit, securitisations, covered bonds and other securities issued by the institution).

The danger zone scores for the short-term maturity mismatch are shown in Appendix Table 1.1.

Appendix Table 1.1. Points score for short-term wholesale maturity mismatch:

Calculated maturity mismatch	Danger Zone Points
Less than -5%	0
-5% to -8%	0-3
-8% to 11%	3-6
-11% to -14%	6-9
-14% to -17%	9-12
-17% to -20%	12-15

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