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EXTERNALITIES IN INTERBANK NETWORK: RESULTS FROM A DYNAMIC SIMULATION MODEL

by Michele Manna* and Alessandro Schiavone*

Abstract

In this paper we conduct a simulation run on a sample of Italian banks where a trigger shock, a one-off event fairly large in size, spreads through the interbank network in a set-up featuring among the actors both commercial banks and the authorities. The banks deleverage to comply with a regulatory capital (leverage) ratio, roll off interbank loans, bid for central bank liquidity, seek help within their own group and dispose of assets. As the shock spreads, borrowers who lack liquid assets may be forced to undertake fire sales, letting their capital position deteriorate. A vicious circle arises in which capital and liquidity risks amplify the crisis. When authorities intervene, unconventional monetary policies smooth the contagion over but these measures become less effective when the shock is very large, when the situation is best addressed by policies aiming at strengthening banks' capital. In a theoretical scenario, in which authorities do not enact specific measures, a small fraction of the banking system (in terms of total assets) may be in default at the end of the simulation, while a larger share of banks would need to be recapitalized.

JEL Classification: E58, G01, G21, G28.
Keywords: banking crises, contagion, leverage, interbank market, central bank operations.

Contents

* Bank of Italy, Central Bank Operations.

1. INTRODUCTION AND LITERATURE[1]

In this paper we simulate the spreading of shocks using a set-up in which banks manage balance sheets actively in reaction to the direct and indirect effects of a shock and are subject to capital requirements (and, in an alternative set-up, liquidity requirements as well). Banks exchange funds in the interbank market, trade in securities, package their loans in securitised products and borrow liquidity from the central bank. Governance plays a role, in that some of our banks are co-linked in banking groups – through which they can seek mutual support – while others are stand-alone.

The paper builds on an established literature which includes Sheldon and Maurer (1998), Blåvarg and Nimander (2002), Wells (2002), Furfine (2003), Upper and Worms (2004), Lublóy (2005), Lelyveld and Liedorp (2006), Mistrulli (2007), Degryse and Nguyen (2007). The basic simulation that they run is as follows: a first bank defaults due to an exogenous shock; this credit event causes losses to other banks via exposures in the interbank market and one or more additional banks may default as well; if this happens, a new round of losses is triggered. The simulation ends when no further bank defaults.[2]

A good summary of the results of this literature is in Upper (2007): "The simulations published so far suggest that contagion due to lending in the interbank market is likely to be rare. However, if contagion does take place, the costs to the financial system could be very high [..] it is not clear whether some of these more extreme results are the consequence of the very strong assumptions underlying the simulations". Notably, the worst results come when the authors adopt a very high loss-given-default on interbank loans. However, in simulations using conventional levels of this parameter, in the region of 60% in accordance with the industry standard, the contagion is usually reckoned to affect at most 5-8% of the banking system (Table A.1 at the end of this paper[3]). For instance, Furfine (2003) concludes that "federal funds exposures are neither large enough nor distributed in a way to cause a great risk of contagion" while Sheldon and Maurer (1998) note that "the chances of a bank failure propagating through the banking system via the network of financial loans are quite low". Such relatively benign views are even more striking considering that what triggers the simulation is a rather extreme event: the abrupt collapse of possibly the largest bank in the country. Moreover, more often than not, the simulation does not exploit an important buffer, namely the transfer of resources within banking/financial conglomerates (Mistrulli 2007 is an exception). Finally, these simulations do not assign any role to government support interventions.

Coherently with this literature, this piece of research falls under the heading of 'what-if analyses'. As such, this is not an enquiry on the likelihood of a shock hitting the banking system but rather an attempt to rehearse the actions that a diversified set of players could undertake if the shock does occur. The empirical part of the paper is run on Italian banks' data (not unlike the aforementioned papers which typically deal with data from a single country). However, the simulation embodies fairly ordinary actions in an interbank network including the response by the authorities; in this light, the lessons we wish to draw from the exercise are meant to be of a broader and more international content. Furthermore, the reader should bear in mind that in order to yield non-trivial results, the trigger to the simulation is a credit shock purposely designed not only large in size but also one which hits the banks as a sudden, virtually overnight blow.

So long about the commonalities between our work and other relevant papers. On the other hand, as a first relevant deviation from the published literature, we wish to put forward a simulation whose actors are not confined to commercial banks but include also the authorities (central bank and banking supervisor). Secondly, after the first loop of losses as described above, in our scenario

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1 The authors would like to express their thanks to the participants to an internal seminar. The views expressed in this paper are the authors' own and do not necessarily reflect those of the Bank of Italy.

2 While this is the common basic pattern, the various papers differ in a number of details. For instance, in some simulations the exogenous shock brings about the default of two banks at once.

3 The reader will find selected key tables and charts throughout the main text; the others are in the annex and are coded with a capital A ("Table A.1").

banks do not just sit idle but undertake a number of actions (an *adjustment process*), mainly to deleverage and ensure compliance with the regulatory capital ratio (throughout this paper we measure it as a leverage ratio, namely the ratio between own funds and total assets). As a result, the credit shock which sets off the simulation turns into a liquidity problem for some banks and emerges later as a loss due to fire sales by other banks. All together, these features enable us to assess how capital and liquidity management interact in a systemic crisis and how they can intensify the propagation mechanism. Thirdly, we adopt a more general structure of the shock itself, featuring both an aggregate and an idiosyncratic component (in contrast with the previous literature, which posits a strictly idiosyncratic shock).[4]

Within such a framework, the game is played both within the interbank market, by commercial banks, but also outside it, as authorities deal with the commercial banks themselves. A banking supervisor enforces balance-sheet ratios while a central bank undertakes ordinary monetary policy operations and, when appropriate, extraordinary liquidity support (in the literature to date the authorities have no explicit role). Significantly, this addition enables us to test a number of support policies. For instance, the results we obtain lend support to the choice made by central banks to widen the pool of eligible collateral for refinancing.

Moreover, we wish to go beyond the end-simulation dichotomy between banks that are "up and running" and those that are "broke". Thus, in addition to those in default we identify the banks that have turned illiquid and those that are left with limited capital, insufficient to meet regulatory requirements and thus need to be recapitalised.

Finally, let us specify the most important assumptions adopted. While we exploit a unique dataset of actual gross bilateral interbank positions reported by Italian banks to the Bank of Italy, we do not have a comparable international dataset, so our set-up does not yield endogenous solutions to the cross-border spread of a crisis.[5] Nor, at this stage of research, do we attempt an endogenous solution to the change in the price of securities as the crisis unfolds (where this could have a significant impact insofar banks mark their holdings to market). Finally, our banks act only when the crisis materially affects their balance sheet. In the real world, however, banks may act simply on the basis of an expectation of such an effect, and this risk-aversion behaviour could contribute to the deepening of the crisis. An agenda for future research in this field would include running simulations that can eliminate one or more of these assumptions.

The rest of the paper is organised as follows. Section 2 gathers empirical evidence about the deleveraging process deployed by Italian banks, which underpins the adjustment process embedded in our simulation model. Section 3 introduces the trigger shocks and then describes the structure of the simulation. Section 4 presents the results, under the baseline scenario and some alternatives. Section 5 concludes.

2. How banks react to systemic shocks: adjustment process and propagation mechanism

2.1 Insights from the recent literature on deleveraging

As banks are highly leveraged, an exogenous shock to their assets can have major repercussions on capital and profitability, forcing an overhaul of investment and funding decisions. The magnitude of the effect is reckoned to be so great that the ensuing deleveraging has often been seen as a key factor in the propagation mechanism of the recent financial crisis (Brunnermeier 2009 and Tressel 2010).

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4 While the demise of Barings, a UK bank, in 1995 proves that fully idiosyncratic shocks may occasionally occur, this seems to be largely the exception; the rule is that crises are nurtured by a more widespread weakening of banks' balance sheets (Borio and Lowe 2002 and Hoggarth, Reidhill and Sinclair 2004).

5 Lack of suitable data affects most of the other relevant papers as well, which accordingly deal with the contagion in a domestic context. Tressel (2010) attempts to overcome the problem using aggregate data on cross-border interbank exposures.

The underlying intuition is fairly straightforward. A shock that reduces the value of assets depletes capital and increases leverage. Banks may not stand passively by but rather take corrective action, usually reducing their assets so as to bring the leverage multiple back down to the starting level or even lower. At the same time banks can deleverage by recapitalisation. An example may help. Consider a bank whose assets are worth 100, liabilities 70 and capital is therefore 30, so that the leverage multiple is 3.33. Now suppose the value of the assets falls to 90 (e.g. because the securities portfolio records a fall in market prices); as a result capital decreases to 20 and the multiple goes up to 4.50. The bank could restore the previous multiple by shrinking its liabilities by 23.3 units and curtailing investment assets by the same amount. Alternatively, to keep the leverage multiple at the target the bank may increase its capital endowment to cover the losses without shrinking its assets.

The two options have different systemic implications. By increasing their capital, banks avert the need to contract lending, whereas curtailing loans reinforces a pro-cyclical mechanism that can spread the shock to the economy at large. The same mechanism works during booms: when the value of assets increases, banks are encouraged to take on more debt for a given endowment of capital in order to exploit the new business opportunities. The result is an increase in leverage and an expansion of credit to the economy.

The pro-cyclicality issue is documented empirically by a stream of papers by Adrian and Shin (2010), who find a positive and significant correlation between leverage and total assets for major Wall Street investment banks. Conversely, they find mixed evidence on commercial banks, an outcome compatible with a leverage-targeting policy.[6] Partly similar results are obtained by IMF (2008), which in a survey of leading banks in a number of countries finds that pro-cyclicality is stronger in investment banks than in commercial banks, although this latter finding seems to be highly country-dependent.[7] This may explain why in a study on the Italian banking system, the correlation between total assets and leverage appears not to be very close when measured by national financial accounts data (Panetta et al., 2009). In Europe too, when more countries are sampled, as in ECB (2009), the data suggest that beginning in the second quarter of 2009 leverage multiples declined among large and complex institutions, reflecting either recapitalisations or attempts to limit the size of the balance sheets. If this behaviour were maintained over a long enough period, the result would be a positive correlation of the type mentioned above.

The unfolding of the crisis highlights how more leverage banks tend to be more exposed to the dry out of market liquidity. Dudley (2008) suggests that banks with tight capital were forced to curtail interbank lending to avoid overleveraging. Hence, if during the downturns banks 'target' their leverage, reducing credit to other banks, then even a moderate credit shock can 'transmute' into liquidity crisis with systemic repercussions. The BIS Committee on the Global Financial System pointed out how deleveraging and the liquidity squeeze triggered a vicious circle: 'The significant and rapid tightening of the secured lending terms which took place in 2008 led to a contraction of the supply of secured financing and exacerbated deleveraging pressures' (CGFS, 2010). Furthermore, the interaction between credit and liquidity risks can be intensified by two-tier interbank structures. Since systemic intermediaries play a crucial role in redistributing liquidity, a credit shock to the capital position of first-tier banks may dramatically reduce the liquidity available to other intermediaries. In fact Adrian and Shin show that the pro-cyclical behaviour of Wall Street investment banks depends mainly on the variation in their repo activity; that is, most of the balance-sheet fluctuations are accounted for by collateralized borrowing and lending .[8] The

6 Repeating the previous numerical example, assets decrease from 100 to 66.7 if the bank holds its leverage multiple constant at 3.33; if this goes up, say to 3.75, assets decrease less to 75 while if it goes down, say to 3.00, assets decrease more to 60.

7 "..commercial banks tend to be more pro-cyclical when operating in more-arm's-length financial systems, where a greater share of intermediation occurs through financial markets.." (IMF, 2008).

8 We carried out an econometric exercise on data for a sample of Italian banks and got results consistent with Adrian and Shin: large Italian banks do tend to behave pro-cyclically. In upturns, they let their leverage multiple increase mainly through the expansion of loans, while in downturns the multiple shrinks with the contraction of interbank credit (Annex 1).

relevance of a deleveraging channel from a liquidity perspective at systemic level has been underscored by Tressel (2010). To explain the retrenchment of cross-border interbank activity following the demise of Lehman Brothers, Tressel quantifies the contagion effect assuming that following a negative asset shock banks adjust the size of their balance sheet to maintain a minimum capital-asset ratio; in addition, the effect is amplified if one posits an interbank funding shock channel, whereby liquidity funding shocks originating within the interbank market and coupled with fire sales amplify the initial losses and deleveraging.

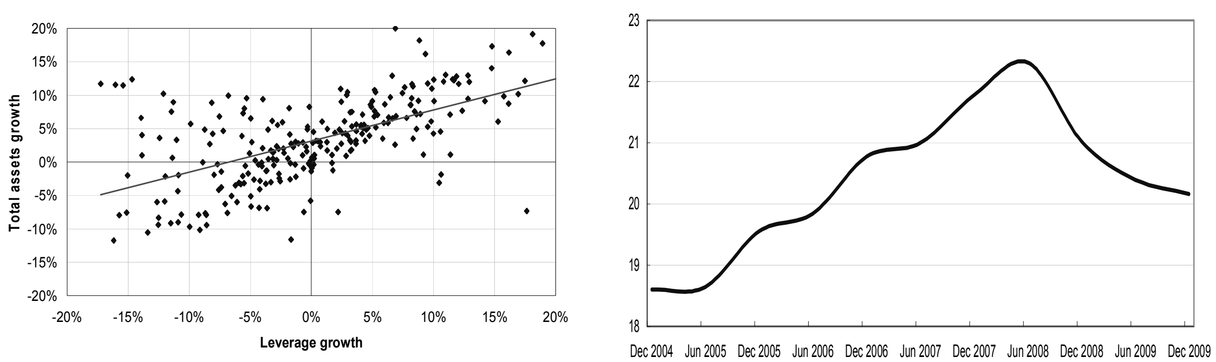
2.2 A look at the Italian banking system through the cycle

Throughout this paper, the empirical analysis is run on a sample of 40 Italian banks, selected on the basis of their ranking in interbank activity. They account for 59% of the assets and 68% of the capital ('own funds') of the Italian banking system (including branches of foreign banks).[9] Each of these banks is 'Italian' in the sense that it is incorporated in Italy and if it belongs to a banking group, the group is headquartered in Italy. For the more specific purpose of gauging the relevance of the deleveraging process, we carved out a sub-sample of 30 banks, operating from December 2004 to December 2009 to keep the panel balanced.[10] The mean leverage multiple is 20.2 in December 2009, and interbank loans account for 18.9% of total assets, compared with system-wide figures of 13.2% and 14.1% respectively. From 2005 through 2009 the changes in the leverage multiple and in total assets (growth rates over six-month periods at the level of each bank in the sample) are positively correlated: when the balance sheet increases, the leverage multiple rises (Chart 1, left side). That is, in economic upswings capital grows less than total assets. Overall, leverage moves pro-cyclically, peaking in the first half of 2008 before falling significantly mainly due to recapitalisation (Chart 1, right side).

Chart 1

Pro-cyclicality in the leverage of the main Italian banks (1-2)

(*2004 – 2009*)



Source: Based on Bank of Italy data.

(1) Growth rates are calculated on a half-yearly basis. – (2) The sample includes 30 banks, selected on the basis of their ranking in interbank activity, that are present throughout the period.

For a more analytical description of the adjustment process when leverage declines, we look in greater detail at how balance-sheet structures evolved from the last quarter of 2008 to the first quarter of 2010, using the wider 40-bank sample. By far the single largest item is loans to non-

9 This sample reduces the number of bilateral exchanges of interbank deposits to be tracked in the simulation to less than one per cent of those that would have been involved had we included all the banks headquartered in Italy. This choice (to our knowledge, a recurrent one in the literature on contagion) greatly simplifies the simulation.

10 In this regard our analysis differs from Panetta et al. (2009), in which the pro-cyclicality of the Italian banks is investigated on the basis of aggregate data for the entire banking system.

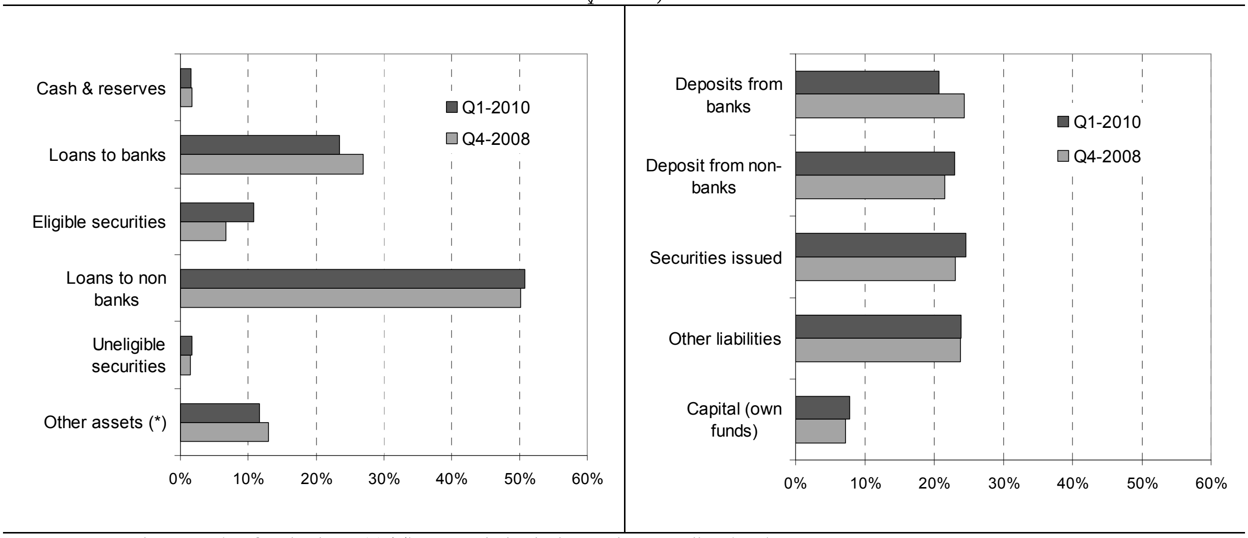
banks, accounting for around 50% of aggregate assets (Chart 2, left side). The distribution of the items on the liabilities side is more uniform: deposits from banks, deposits from non-banks, securities issued, and other liabilities count for each between 20% and 25% each, with capital between 7% and 8% (Chart 2, right side).[11]

Over the period under observation the main changes on the asset side include the reduction in interbank claims (from 27% to 23.4%) and the increase in eligible securities (from 6.7% to 10.8%); on the liabilities side the fall in deposits from banks is offset by the increase in retail deposits and the surge in bonds outstanding. The capital endowment also rose, contributing to the decline in leverage. These changes help to indicate the way in which Italian banks carried out the adjustment process. As the financial environment deteriorated, banks became more reluctant to lend to each other and tried to hoard high-quality securities in order to face possible future liquidity strains. Consistent with this empirical evidence, our simulation model assumes that when banks face capital losses, to avoid excessive leverage they first call back their interbank loans. This leads to a funding shock for borrowers; those with sufficient liquid assets are better placed to overcome the liquidity strains; the others, in order do avoid becoming illiquid, are forced to take a series of actions that could worsen their capital position, setting off a vicious circle in which capital and liquidity risks tend to strengthen the mechanism by which the crisis is propagated.

Chart 2

The adjustment of Italian banks' balance sheets(1)

(*per cent*)



Source: Based on Bank of Italy data. (1) The sample includes 40 large Italian banks.

3. The structure of the simulation and its calibration

3.1 The structure and magnitude of the shock

We consider a very general class of shocks whose algebra is

$$\varepsilon_{i,t} = \beta \xi_{i,t} + (1-\beta) \frac{K_{i,t}}{\sum_{i=1}^{n} K_{i,t}} \sigma \qquad \sigma > 0,\ \xi_{i,t} \geq 0,\ \beta \in [0,1],\ i = 1,..,n \tag{1}$$

[11] Of course, aggregate statistics mask heterogeneity across individual banks: for example, in 13 banks the ratio of capital to total assets is less than half the reported average (8 banks using consolidated data at group level).

where the shock $\varepsilon_{i,t}$ hitting bank *i* (from 1 to *n*) at time *t* is a linear combination, according to weights β and (1- β), of the random outcome $\xi_{i,t}$ and the product of a constant σ multiplied by the share of bank *i*'s capital in the total capital of all the banks. While the former acts as the idiosyncratic component of the shock, the latter can be read as a macroeconomic factor that hits banks across the board, such as rising loan losses during a recession. The backbone of the simulation is a Monte Carlo exercise where in each of 200 runs a new set of *n* values of the ξ's are drawn, from a Poisson distribution (with parameter one). Given a choice of σ and β, this yields the ε's whose sum within each run is referred to in this paper as the 'magnitude of the shock'.[12]

The higher β, the less even the distribution of the shock. If β < 1 each bank is hit by the shock while if β = 1 we have $\varepsilon_{i,t} = 0$ when $\xi_{i,t} = 0$, which is to say that some banks are not hit by the shock. The literature cited in section 1 relies on the special case of β =1, where, for a given bank *i*, $\xi_{i,t}$ is set equal to the capital of that bank while $\varepsilon_{j,t} = \xi_{j,t} = 0$ for $j \neq i$. Hence, we label this as the 'deterministic shock' given that ξ is fixed by the researcher; it was then natural to refer to the more general structure [1] as the 'stochastic shock'.

3.2 The balance-sheet identity and the capital ratios

We consider a population of *n* = 40 banks, all headquartered in the same country. For the purpose of the simulation, this implies that they are regulated by the same supervisor and deal with the same central bank, which runs open market operations and may decide to act as lender of last resort. As in real life, the banks' business is quite diversified and entails transactions both in wholesale and in retail markets. The balance-sheet identity of the generic bank *i* at time *t* (t = 0 identifies the starting position, t = T the end of the simulation) is:

$$[2] \qquad DA_{i,t} + R_{i,t} + G_{i,t} + U_{i,t} + L_{i,t} + SA_{i,t} + OA_{i,t} \equiv A_{i,t} \equiv DL_{i,t} + C_{i,t} + B_{i,t} + M_{i,t} + SL_{i,t} + OL_{i,t} + K_{i,t}$$

where $DA_{i,t}$ ($DL_{i,t}$) is the sum of bilateral interbank loans or deposits[13] granted or received by *i* to or from other banks in the sample. R stands for the reserves held with the central bank, G for the securities eligible as collateral in the central bank's open market operations, and U for securities actively traded in financial markets[14] but not eligible. L is the portfolio of loans. SA/SL are sundry items including interbank loans/deposits to/from banks outside the sample and, on the asset side, the margins in refinancing operations (the difference between the assets pledged and the liquidity obtained). Finally, OA is any other asset, such as property. On the liabilities side, C represents retail deposits and B the stock of securities issued, M is refinancing from the central bank and OL any other liabilities. The difference between assets and liabilities is the capital K, while A is the size of the balance sheet (assets ≡ liabilities plus capital).[15]

Of our 40-bank sample, seven banks are stand-alone and 33 belong to one of five banking groups.[16] Being a member of a group brings advantages but also obligations. A bank that cannot comply with the capital requirement or reimburse its creditors may seek help from other group

12 We set σ so that the magnitude of the shock meets, on average over the 200 tries, the intended target, say 2.5% of the banks' total assets (more on this in section 3.4). Since the Poisson distribution (with parameter one) yields zero in 35% to 40% of the draws, quite a number of banks are hit only by the macroeconomic component.

13 Throughout the simulation, we use 'interbank loan' to refer to the exchange of funds seen from the point of view of the lender, 'interbank deposit' to the same transaction from the borrower's perspective.

14 We include here securities denominated in any of the four leading international currencies other than the euro (US dollar, yen, pound sterling and Swiss franc) whose issuer is investment grade.

15 One could easily envisage balance sheets either more detailed or more simplified than [1]. Overall, we felt that for the purposes of this research such an identity allows accurate registration of the actions banks can take throughout the simulation – to deleverage; to roll-off interbank loans; to raise liquidity through central bank refinancing, repos in the market, and loan securitisation – but not more complex than that.

16 As explained in section 2.2, the selection was based on an objective criterion (ranking in interbank activity). It was a pleasant extra to find that the process yielded both banks belonging to groups and stand-alone institutions, so that we could seek to gauge the role of the group in weathering the simulated shock.

members; but a bank that disposes of spare resources is bound to lend support, when asked. However, such mutual support is not unlimited: bank *i* will transfer to the illiquid bank *j* only an amount of its reserves R that does not endanger its own paramount objective of continuous reimbursement of creditors.

Within the simulation, banking groups matter also because they are the focus of supervision, which enforces a capital constraint in terms of a capital ratio:

$$k_{i,t} \equiv \frac{K^*_{i,t}}{A^*_{i,t}} \qquad [3]$$

The symbol * signals that we use amended definitions of capital K and total assets A, which net out for intra-group interbank loans and cross-shareholdings. This allowed us to derive what can be termed consolidated balance sheets, since it is at group level that compliance with the capital ratio is checked. Referring, for instance, to group G1, the supervisor monitors whether

$$k_{G1,t} \equiv \frac{\sum_{i\in G1} K_{i,t}}{\sum_{i\in G1} A^*_{i,t}} \geq k^* \qquad [4]$$

holds true, where k* is the regulatory capital threshold.

3.3 How the simulation is structured: the adjustment process

The simulation may be seen as a sequence of three main stages (for a graphical representation of the unfolding of the crisis, see the diagram at the end of this section).

In the first stage an exogenous shock causes a write-down/write-off of loans L and 'other assets' OA hits the banks. As a result, some of them can end up recording negative capital. At this point, a state of default is declared unless the banks in question get enough support from within their group.[17] Such support needs to be qualified in two ways. First, this is not an option available to stand-alone banks in our sample. Second, the troubled banks do not necessarily raise enough resources within their group (not least because other group members could also be seeking support, drawing necessarily on the same pool of resources). For either of these reasons, notwithstanding this form of support one or more banks may actually default. If this happens, their creditors bear losses on interbank loans, which may in turn trigger additional defaults. The process continues until no further bank collapses.

Broadly speaking, this first stage is basically the same as in the papers running such simulations to date (although intragroup support is the exception rather than the rule in these scenarios, and we solve the loss-given-default parameter endogenously). Hereinafter, we add new steps.

The second stage is the heart of the contagion mechanism. Banks that no longer meet the capital requirement owing to the losses suffered in the previous stage set out to deleverage. Their first move is to roll off interbank loans, planning to use the funds so raised to increase their reserves R, which can then be used to liquidate enough liabilities. If the plan is carried out, the balance sheet shrinks and the capital ratio *k* is restored to the required level.

Calling in an interbank loan requires the borrower to raise sufficient funds to repay (unless it pays back in kind, through another loan[18]). This can be achieved in a number of ways. First, the

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17 The bank seeking help issues new shares, to be underwritten by the banks of the group that have positive capital. The accounting is such that at a group level neither K* nor A* – nor consequently, the *k* ratio – changes.

18 The design of the simulation allows either bilateral or multilateral clearing of deposits. In the former, bank *i* rolls off a deposit of X euros with bank *j*, which pays by reducing its own loan to *i* by the same amount. In multilateral clearing, the algorithm checks out if there are chains in which bank *i* cancels a loan of X euros to bank *j*, bank *j* cancels a loan of X euros to bank *l*, …, and bank *z* cancels a loan of X euros to bank *i*, under the condition that all the banks are interested in deleveraging.

borrower can dispose of its reserves R. Second, it can bid for central bank credit, provided it can pledge enough eligible securities G (a hair-cut α_G is applied). Third, it can undertake repos in the market against the marketable-but-not-eligible securities U or an ABS backed by its loans L (hair-cuts α_U and α_L respectively are applied). Fourth, if there is still a funding shortfall, the bank may turn to its fellow group members for transfers of reserves R (a mechanism of intragroup support as above applies again here[19]). Finally, if worse comes to worst, a bank still short of liquidity must take an extreme measure: the sale of any remaining assets it holds (barring residual interbank loans and sundry items). The downside is that such sales are made at a discount from their balance-sheet value and give rise to capital losses. The crux of the matter is that the lender seeking reimbursement cannot be sure the borrower is able to repay in full. Any partial repayment implies that the lender gets less liquidity than planned, while the illiquid borrower is suspended by the authorities. A further by-product is that because of these 'fire sales', some borrowers could record losses severe enough to end up with negative capital (before default is declared, a new round of intragroup capital transfer applies; see footnote 17).

In the third stage, the banks still in business carry out the required deleveraging. For this they use the available R – or if need be any additional reserves that can be raised through central bank refinancing and market repos – to liquidate their liabilities, starting with outstanding securities, B. If they achieve their objective only in part, they are classified as undercapitalised.

Here the simulation ends, and each of the *n* banks is classified in one of the four following states: default (S1); liquid with capital that is positive but insufficient to comply with the regulatory *ratio* k* (S2); illiquid, i.e. unable to reimburse its interbank deposits when requested (S3); in business, i.e. liquid and compliant with *k** (S4). Accordingly, we report the results of the simulation identifying the share of total assets as of time t = 0, of the banks in the first three categories, designated by L1, L2 and L3 (L stands for loss):

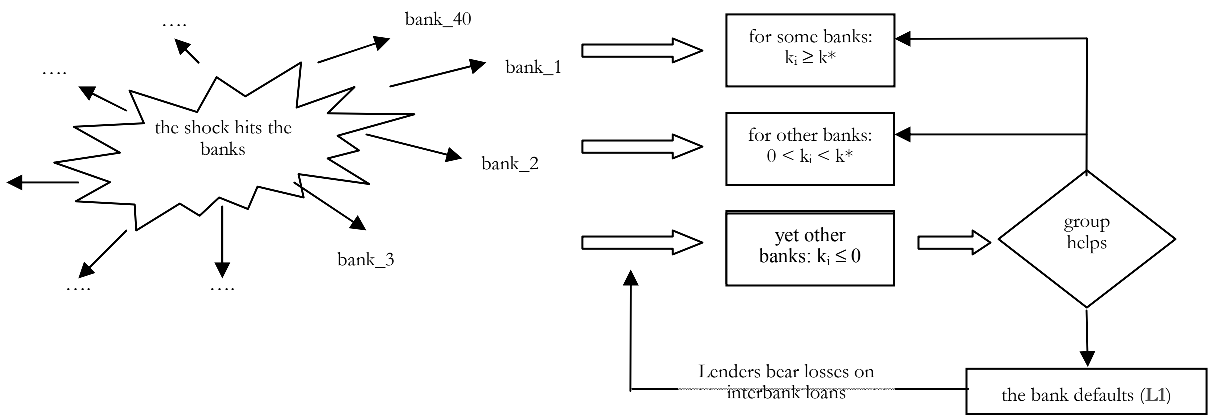
$$[5] \quad L1 = \frac{\sum_{i \in S1} A_{i,o}}{\sum_{i=1}^{n} A_{i,o}} \qquad L2 = \frac{\sum_{i \in S2} A_{i,o}}{\sum_{i=1}^{n} A_{i,o}} \qquad L3 = \frac{\sum_{i \in S3} A_{i,o}}{\sum_{i=1}^{n} A_{i,o}}$$

Arguably, any given numerical result for L1 carries a much greater weight than the same numerical result for L2 or L3. It is one thing to say that banks accounting for 10% of the banking system are undercapitalised, quite another to say that this percentage of the system is in default. With this obvious caveat, we nevertheless occasionally present some results in terms of the sum of L1, L2 and L3 to produce a single measure of stress. In this case, we speak loosely of the percentage weight of the banks affected. More details on the simulation and its algebra are given in Annex 2.

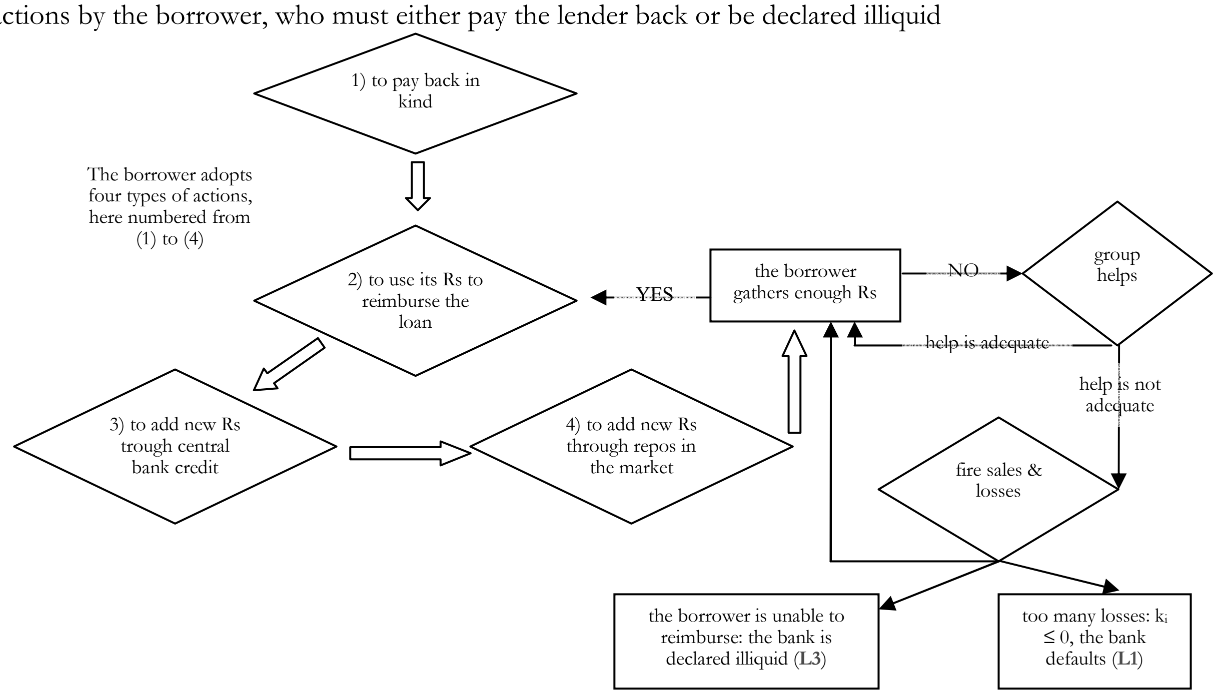
[19] Those banks with excess R may lend the difference to liquidity-strapped members of the group. In terms of [1], this gives rise to an interbank loan DA from the former to the latter. Since the scope for fire sales is restricted to some asset items, a bank might be unable to reimburse its creditors in full even when technically it still holds assets and its net capital is positive.

Simulation diagram (version in which authorities do not intervene)

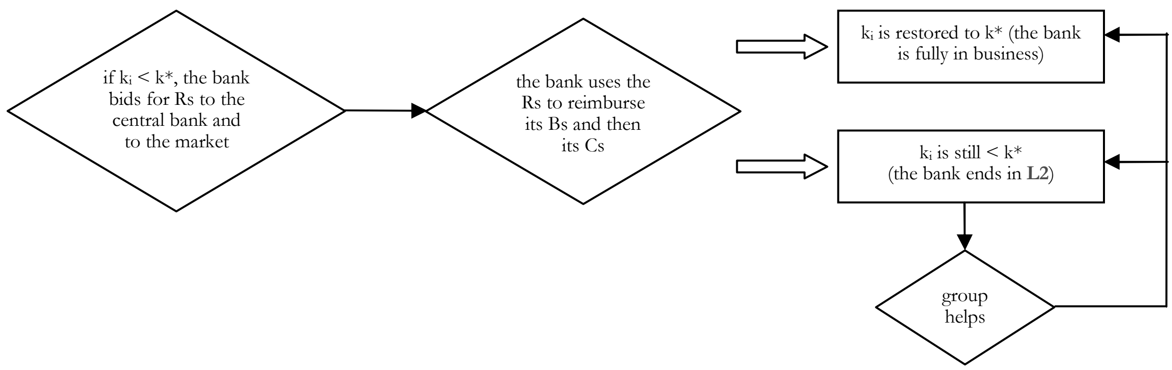
The shock hits the banks; those in need (could) get support from within their group



When banks need to deleverage, their first action is to roll off interbank loans. This triggers a sequence of actions by the borrower, who must either pay the lender back or be declared illiquid



Banks that are in business (i.e. neither in default nor illiquid) deleverage, if required.



3.4 *The calibration of the model*

A relatively complex set-up like this requires choices on a number of parameters, two of which are especially important: the magnitude of the trigger shock and the regulatory leverage threshold (capital ratio) k^*. The latter is set equal to the minimum value of the k's within the five banking groups and seven stand-alone banks in our sample.[20] It was less straightforward to make an educated guess on the magnitude of the initial shock. One reference is the financial statement assessment carried out by IMF on the Spanish banking system (2012) aimed at assessing the banks' capital needs (output of the model) stemming from a deterioration of the macroeconomic and market conditions (input). By using a contingent claim approach, they estimate that under severe adverse scenario the total expected loss would be tantamount to around 6% out of total assets of the banks comprising the sample.[21] Differently from this approach, what we need in order to trigger our simulation is to make some hypothesis about the magnitude of the initial shock in terms of aggregated losses borne by the banking system. Given this different perspective we tried out a range of shock magnitudes from 1% to 4% (of banks' total assets) which allow us to consider multiple scenarios and to gauge consequently the extent of the contagion in the interbank market. To avail of an order of dimension of how such percentages rank against real world data, new bad debts recorded in a given year by Italian banks (a concept similar to our simulated shock) amounted to 0.9-1.0% of their total assets in the rather exceptional years of 2009 through 2011 while in a more "ordinary" year such as 2008 the corresponding percentage was 0.6%.[22] Hence, the lowest end of our scale of shock is close to actual losses in fairly extreme circumstances. Plus, the reader should bear in mind that we posit the shock as a one-off, basically overnight event, while these statistics refer to new bad loans accrued throughout a whole year.

Other parameters are: (i) the hair-cuts α_G, α_U and α_L and the degree of losses in fire sales of OAs; (ii) the extent to which available units of items U and L can actually be repoed in the market to raise liquidity; (iii) the recovery ratio on interbank loans to banks that default; (iv) the weight β of the idiosyncratic component of the shock [1]. Our choices on these parameters are set out below:

(i) We set α_G = 5%, the round number closest to the mid-point in the 2.5-11.5% range of hair-cuts applied by the Eurosystem at our main reference date (March 2010) depending on the type of security and its maturity, if this is between 3 and 10 years. Drawing again from the Eurosystem operational framework, we set α_L = 25%. Lacking any more obvious intuition, we adopted the same percentage for α_U[23] and for the degree of losses in the fire sales of OAs.

(ii) At several points the simulation envisages that banks may liquidate their *U*s and *L*s (once these are packaged in an asset-backed security). Experience suggests that this option is not unlimited, as the markets could eventually ration banks. We accordingly assumed that banks can liquidate no more than 33% of their loans, which in any case is three times the figure of 11% reported by the Association for Financial Markets in Europe (AFME 2010) on the securitisation of loans to households and non-financial corporations at the end of 2009 in 11 euro-area countries. As far as we know, no comparable reference is available on the share for the *U*s; we set this at 50% as an intermediate position.

(iii) When a bank defaults, the recovery ratio was derived endogenously on the basis of the balance sheet at the time of the default, with a cap at 40% (the industry standard).[24]

(iv) We set β = 50% to start with a balanced type of shock.

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20 This choice was due to two facts: first, there was no regulatory capital ratio requirement on Italian banks at the time of our snapshot of data; second, we deliberately chose to start from a state in which all groups and stand-alone banks were compliant.

21 This figure is computed at a statistical probability of 5% or less in order to capture tail risk.

22 We obtain these results by multiplying the ratio (new bad debts / loans) times the ratio (loans / total assets); the two sets of data are from the Bank of Italy Annual Report, 2011, tables a17.1 and a17,9.

23 As the *U*s account for only 0.6% of the whole balance sheet, within a reasonable range any choice would have made little difference to the final results.

24 The cap was introduced to prevent quirks in the data from producing an unrealistically high recovery ratio.

It is fair to note that if some parameters are based on fairly objective elements, such as the hair-cut α_G on eligible assets, others can be considered educated guesses if not outright arbitrary choices. Where lack of data precluded finding an obvious benchmark, we preferred to err, if anything, on the side of caution, by selecting values that ought to enable the banks with more resources to weather the crisis, rather than the contrary. The idea is to increase the likelihood that if our simulation eventually yields loss estimates that are on the high side compared to the literature, this would be due to the way we designed the trigger shock and the game played by the banks, not to some ill-chosen parameter values. The same principle was behind our decision to start with a well capitalised banking system – the ratio *k* for the entire sample is almost four times higher than the required minimum *k** and no banking group or stand-alone bank fails to fulfil this minimum – and to preclude extremely severe yet still realistic shocks, on the order, say, of those experienced by Irish banks.

4. The results

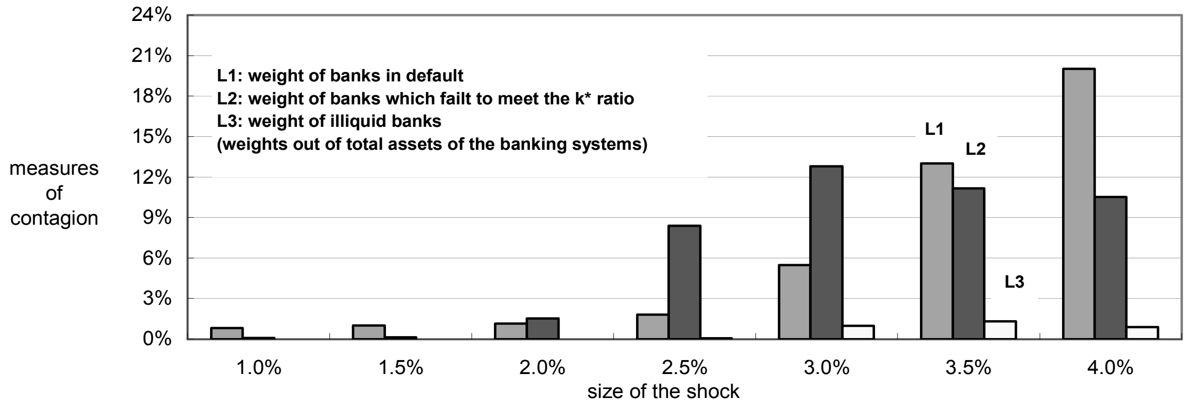
4.1 The main results

In the baseline scenario, both the size and the ranking in loss statistics L1 (banks in default) and L2 (undercapitalised banks) change as the magnitude of the shock increases. For relatively small shocks, the damage remains limited. For shock magnitudes on the order of 2.5%, the results are less reassuring: at the end of the simulation banks accounting for 2% of the assets of our 40-bank system would be in default and another 8% would be undercapitalised (Chart 3). As the shock is made stronger still, L1 rises rapidly and eventually overtakes L2. For a shock of 4.0%, the strongest one we tested, 20% of the banking system is in default and an additional 11% undercapitalised. Smaller figures are associated with the L3 statistics on illiquid banks, an issue that is explored further below using a second dataset, referring to March 2009. [25]

Chart 3

Measures of contagion, baseline scenario (1)

(*per cent of total assets of the banking system at the start of the simulation; March 2010 data*)



(1) Averages over 200 replications of the simulation, where each time a new pool of the ζ component in [1] is drawn from a Poisson distribution (with parameter one). The baseline scenario is defined by the following parameters: hair-cut on G, L and U at 5%, 25% and 25% respectively; percentage of loss on fire sales at 25%; weight β of the idiosyncratic shock at 50%; degree of tradability in the repo market of the *Us* at 50% and of securities backed by *Ls* at 33%.

Below we discuss how these results compare with the previous literature and their robustness to the assumptions made on the parameters. First, however, let us discuss several additional technical

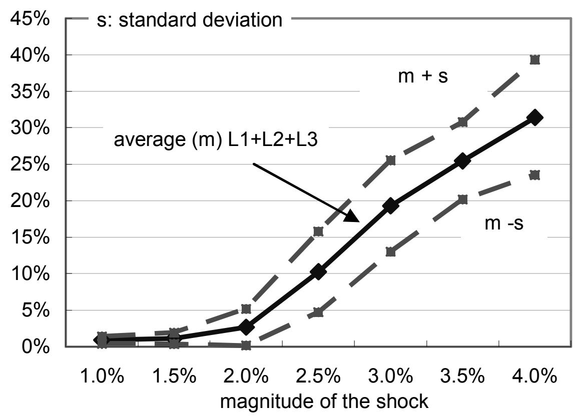
[25] This result is not surprising, given that throughout the simulation banks have unlimited access to central bank refinancing provided they post adequate collateral (and are willing to pay the required interest rate). In the Eurosystem's operational framework, this is the rule because of the working of the marginal lending facility.

elements in our set-up. The results presented in Chart 3 are averages over 200 runs of the simulation, each based on a set of 40 random draws of the idiosyncratic component ζ in [1]. Chart 4 suggests the way in which the results vary between runs (here, for simplicity we alter our rule and refer to the sum of L1, L2 and L3). The basic pattern is confirmed; notably the portion of banks affected rises sharply when the magnitude of the shock reaches 2.0% of total assets. At the same time, the chart strengthens the intuition that the outcome of a contagion is predictable only up to a point (see also Chart A.1 on the dispersion of results). Moreover, it is worth double-checking whether 200 runs are necessary sufficient: actually, the results look fairly stable already from the 80^{th} replication onward (Chart 5).

Chart 4

Variability of results across the 200 replications of the simulation (1)

(*per cent of total assets of the banking system at the start of the simulation; March 2010 data*)

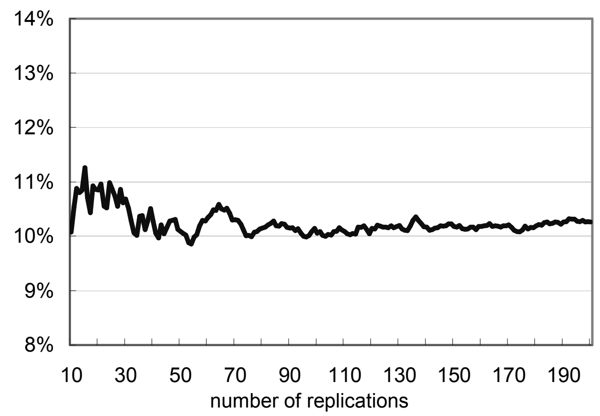


(1) Results for the sum of the L1, L2 and L3 statistics over 200 replications of the simulation under the baseline scenario. See notes at the bottom of Chart 3 for further details.

Chart 5

Average of L1+L2+L3 as a function of the number of replications of the simulation (1)

(*per cent of total assets of the banking system at the start of the simulation; scenario with shock of 2.5%; March 2010 data*)



(1) The horizontal axis specifies the number of replications of the simulation on the basis of which the average of L1+L2+L3 is worked out. Results are referred to the baseline scenario for a shock of 2.5%.

On the face of it, the losses are larger than those found in the previous literature. As observed in section 1, other authors concluded that for conventional values of loss-given-default, contagion could affect banks accounting for at most 5%-8% of system assets, whereas we find a portion greater than 10% with the intermediate 2.5% shock and 31% with the 4.0% shock. Even restricting the measurement to L1 statistic alone (banks in default), the figures in our simulation range from 2% to 20%.

In principle the difference in results could be due to the underlying balance-sheet data, the nature and magnitude of the shock, or the structure of the simulation. To determine which of these elements is most important, we ran the whole exercise again, this time positing the type of shock most commonly used in the literature.[26] Here, the simulation is run n=40 times, with the shock knocking down one bank each time. The results are the average of L1 loss statistics over the n replications, and are also presented as the average over the runs in which contagion occurs (that is, at least a second bank fails after the first), and are measured also at the end of the first loop of losses, where most of the simulations published end. On average, over all 40 replications, at the end of the first loop L1 is 3%, an outcome close to the lower bound of the range of results of previous works (Table 1). However, much greater losses emerge if the analysis is restricted to the runs involving cases of contagion, as Upper (2007) anticipated in his survey. This is rare: in only 5 of the 40 runs does the default of the first bank trigger that of a second or more. These findings

[26] We also assumed the absence of intragroup links; that is, we treated all 40 banks as stand-alone entities, again in line with the majority of the previous literature.

suggest that our results are comparable to those presented in the literature, when same type of shock and set-up are adopted.[27]

What actually determines the difference, however, is the adjustment process embedded in the simulation model. To gauge this impact, let us compare L1 at the end of the entire simulation with L1 at the completion of the first loop. The ratio between these two loss statistics is just above 1 using the 'deterministic shock' drawn from the literature and well above 2 taking our 'stochastic shock' [1]. Our intuition is that simulations using simple triggers – such as the collapse of one bank while the others remain unscathed – gain relatively little from more elaborate simulations (which might explain why other authors, having chosen the 'deterministic shock', also saw less need to design complex set-ups). Conversely, when a more general type of shock is adopted, ignoring the adjustment process can lead to a severe underestimation of the contagion.

Table 1

Results of the simulation using the 'deterministic shock' (1)

(*per cent of total assets of the banking system at the start of the simulation; March 2010 data*)

	(a) end of first loop	(b) end of simulation	(b) / (a)
Average over 40 runs	3.0 %	3.2 %	1.06
Average over runs with contagion	13.3 %	13.9 %	1.04
(number of contagion runs: 5)			
Memorandum item: baseline scenario with 'stochastic' shock [1], with $\beta = 0.50$			
Magnitude of the shock = 2.5%	1.8 %	10.3 %	5.73
Magnitude of the shock = 4.0%	11.7 %	31.4 %	2.68

(1) The results in the main part of the table refer to averages over 40 runs of the simulation (in each run a different bank defaults while initially the other 39 do not suffer losses). 'Contagion' is defined as a run in which at least a second bank defaults. For further details on the baseline scenario under the 'stochastic shock', see the notes to Chart 3.

4.2 *Sensitivity to changes in the parameters*

In view of the number of our choices on parameters, a series of robustness checks are certainly in order. A first set of checks involved replication of the basic simulation but changing one parameter at a time (the percentage of loss in fire sales; the degree to which securities in the U item can be pledged in the repo market to gather liquidity; the corresponding degree on securities backed by loans L; the cap on the recovery ratio). Subsequently we ran the simulation making all the changes simultaneously. On the whole our baseline scenario appears to be fairly robust to the various assumptions, for low or intermediate magnitudes of the shock (Table A.2). One notable exception comes when the cap on the recovery ratio is reduced from the reference level of 40% to 30% and then 20%. This significantly increases L1 (banks in default) and L2 (undercapitalised banks) for a shock of magnitude 4.0%. This confirms the inverse correlation between the extent of contagion and the recovery ratio found in much of the literature.

Another area for double-checking is how sensitive the results are to the reference date for the simulation. To inquire into this, we repeated our entire simulation exercise using data at March 2009. In the year from that date to March 2010, the overall capital ratio k for our sample banks rose from 6.0% to 6.6%; at the same time, interbank loans contracted both by amount (their ratio to total assets fell from 14.5% to 11.4%) and by number (outstanding bilateral relationships fell from 416 to 377). Both trends should have made the banking system more resilient: the banks became better capitalised in proportion to total assets, while the interbank market, the conduit for contagions, became smaller.[28] Thus, it is no surprise to find that the March 2010 dataset yields a

27 This also suggests that our particular dataset is not the source of significant differences in results.

28 This is not to say that we advocate a smaller interbank market, which could have negative consequences in terms of efficiency in the allocation of funds.

much lower L1 statistic, 1.9% as against and 4.5% of total assets (Table 2). The difference in L3 (illiquid banks) is even more dramatic, 0.1% and 5.1% respectively for March 2009 and March 2010. This certainly suggests that a large interbank market, which is a positive element in good times, can become the catalyst for damage in a crisis.

To disentangle what was caused by what, given that in the year intervening between our two simulation dates the banks both increased capital and reduced interbank loans, we run a counterfactual exercise, taking the balance-sheet data at March 2010 but using the 2009 data on interbank positions. This simulation yields a result for L1 close to that obtained using the March 2010 dataset in full. This implies that the decrease in banks in default between the March 2009 and the March 2010 data ought to be associated with the increase in the capital ratio (and thus of capital, at least in relative terms). But the story on L2 and L3 is different, with results that are if anything even higher for the mixed dataset than for the March 2009 (not to mention the March 2010) data. In other words, the fact that we found few illiquid banks (and also not so many undercapitalised ones) at our main reference date likely owes more to the relative smallness of the interbank market at that time than to the strength of their capital base.

Table 2

Measures of contagion as a function of the balance-sheet reference date (1)

(per cent of total assets of the banking system at the start of the simulation; March 2010 data)

	L1	L2	L3
March 2010 data	1.8 %	8.4 %	0.1 %
March 2009 data	4.5 %	10.3 %	5.1 %
March 2010 data (March 2009 for the interbank market)	2.4 %	12.7 %	5.7 %

(1) Results of loss statistics L1, L2 and L3, under the baseline scenario for a magnitude of the shock equal to 2.5% of total assets of the banking system. The balance-sheet data used in the simulations are as at March 2010, March 2009 and again March 2010 except for the interbank market where March 2009 data are used.

A close look at the weight β of the idiosyncratic component of the shock is also worthwhile. As β rises from 0.25 to 0.50 (this is the baseline scenario) and then to 0.75 and finally to 1.00, L1 increases visibly, especially when the shock magnitude is 3.0% (Chart 6).[29] Note, however, that when β goes from 0.75 to 1.00 (and already from 0.50 to 0.75 for the 3.0% shock), the increase in L1 is offset to a large extent by a reduction in L2.

What happens is that when the impact of the shock is more heterogeneous (higher β), more banks are likely to end up not just undercapitalised but in default (which may be obvious). But the overall impact (the sum of L1 and L2) does not necessarily increase so greatly (perhaps less obvious; the extreme case of Barings (see footnote 4) is an excellent example of an extremely concentrated shock that is lethal to one bank but basically innocuous for the rest of the banking system). Findings like these add a further challenge to the policy maker. An adequate response to the crisis depends on accurately gauging not only the magnitude but also the nature of the shock that triggered it.

[29] Even when β =1, the results of Chart 6 are not directly comparable to those of Table 1 for the deterministic shock, since in the former we restore group links and the idiosyncratic component ξ is again drawn randomly.

4.3 The authorities intervene

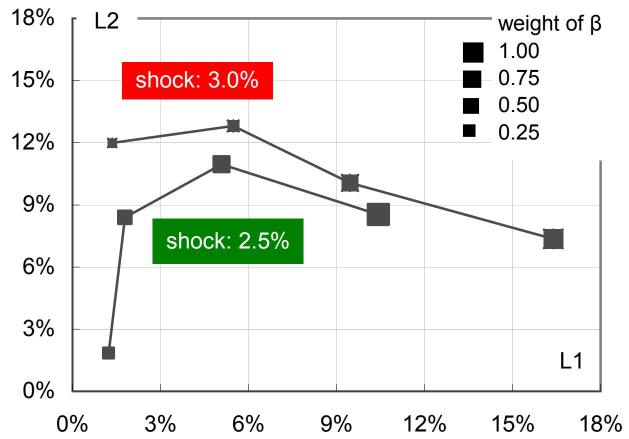
We don't really know what would have happened to banks had the authorities in the advanced countries adopted a more laissez-faire attitude in recent years. One welcome consequence might be that the results discussed in the previous section could largely be regarded as nothing but an intellectual game, since the simulation posited the lack of any support policy when the crisis breaks out.

Here, we remove this assumption and let the authorities play the game. First, we test the central bank's widening of the pool of assets accepted as collateral in monetary policy operations to including any marketable security classified under item U and any loan L (with a 25% hair-cut for both items). It is fair to measure the effectiveness of such policy by deducting from the loss statistics the weight of the banks in default as immediate result of the shock: this is because no change, however great, in the supply of liquidity could prevent this type of credit event (at least as far as the simulation is concerned). The results are shown in Chart 7 as the percentage difference in the sum of L1, L2 and L3 (minus the aforementioned weight) between the baseline scenario and the scenario with a larger pool of eligible assets; the difference is also worked out not counting the L3 statistic on illiquid banks in both terms. The improvement is impressive: widening the pool of eligible assets would reduce contagion by half under the 1.0% shock, by around one third under intermediate shocks and close to one fifth when the shock is 3.0% or higher. In policy terms, the lesson appears to be straightforward: the central bank's action is quite effective, although at the margin its support is less pivotal the larger the credit loss that triggers the crisis initially, when banks need capital more than fresh liquidity support. Note that the reduction in losses is smaller when the comparison between the two scenarios is run only on the L1 and L2 statistics than when the L3 statistic on illiquid banks is added (in the chart the two lines overlap for relatively small shocks since in those instances L3 was zero or close to zero already in the baseline scenario). This offers an empirical gauge to assess how the central bank is best equipped to fight banks' illiquidity at the outset of a crisis, whereas remedying undercapitalisation is more of a by-product of this policy since it saves prevents otherwise illiquid banks required to reimburse funds from having to make fire sales.

Chart 6

The contagion as a function of the magnitude and the nature of the shock (1)

(per cent of total assets of the banking system at the start of the simulation; March 2010 data)

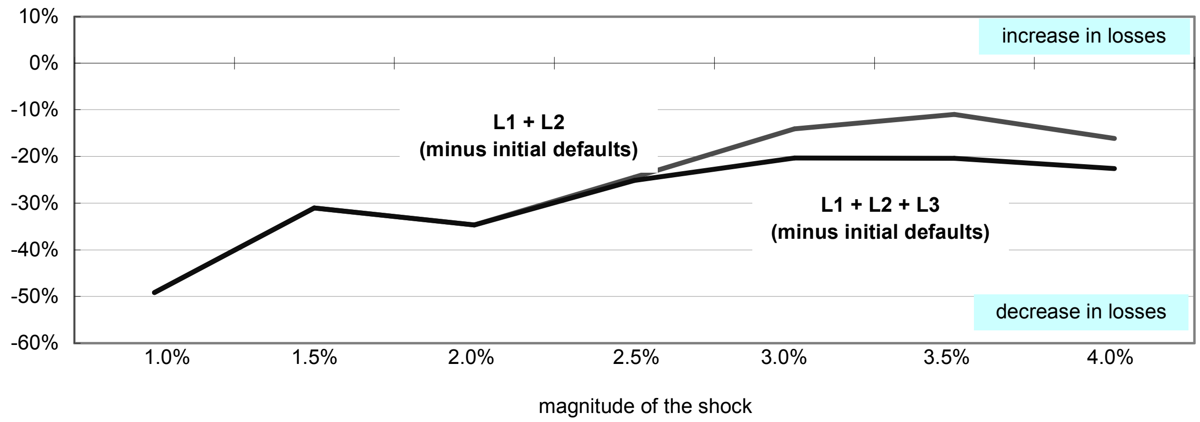


(1) Results based on various weights β of the idiosyncratic component of the shock. See also notes to Chart 3.

Chart 7

Change in loss statistics when unconventional monetary policies are enacted, compared to the baseline scenario (1)

(*per cent of total assets of the banking system at the start of the simulation*; *March 2010 data*)



(1) Results shown are changes in the specified loss statistics between the baseline scenario (see chart 3 for further details) and the scenario where the central bank widens the pool of eligible collateral accepting any U and L.

Alternatively, the central bank may decide to extend its support to a few selected banks rather than to the banking system across the board – essentially, traditional lending of last resort, i.e. fully discretionary support provided to troubled banks. In this simulation, we assume that 35 banks are offered liquidity under the standard conditions of the baseline scenario and the other 5 banks are allowed to post as eligible collateral any U and L (as above). The results are presented in Table 3; note that as selecting the set of five banks that yields the most promising results requires considerable computation,[30] we took only shocks of 2.0%, 2.5% and 3.0% of total assets rather than the usual range from 1.0% to 4.0%. For the 2.0% shock, under the 'lending-of-last-resort scenario' the central bank achieves half of the gain obtained under the more generous policy of widening the pool across the board, the unconventional monetary policy scenario (-16% and -35% respectively in the sum of the three loss statistics). The former policy is highly cost-effective, in that it would require a much smaller increase in total central bank refinancing (€14 billion under the baseline scenario, €16 billion with lending-of-last-resort and €22 billion with unconventional policy measures). The results are less impressive for the 3.0% shock – which may serve as a reminder that stepping up liquidity supply can do only so much when the trigger shock becomes very strong – as the loss reduction vis-à-vis the baseline scenario shrinks to one third (7% under lending of last resort and 20% with unconventional measures), while refinancing must be significantly increased even under the more selective last-resort-lending policy.

Table 3

Loss reduction under unconventional monetary policies and lending of last resort vis-à-vis the baseline scenario of no support (1)

(*per cent of total assets of the banking system at the start of the simulation and billions of euros; March 2010 data*)

Magnitude of shock	Change in loss statistic L1+L2+L3 (minus first losses), in %		Amount of central bank refinancing, billions of euros		
	UMP scenario – baseline scenario	LOLR scenario – baseline scenario	Baseline scenario	UMP scenario	LOLR scenario
2.0%	-34.7 %	-15.8 %	14	22	16
2.5%	-25.1 %	-13.0 %	42	71	55
3.0%	-20.3 %	-7.3 %	58	111	81

(1) Unconventional monetary policy = UMP; lending of last resort = LOLR. Under the UMP scenario, the central bank widens its pool of eligible collateral to accept any asset classified under items U and L from any bank; under LOLR it makes this offered to 5 of the 40 banks.

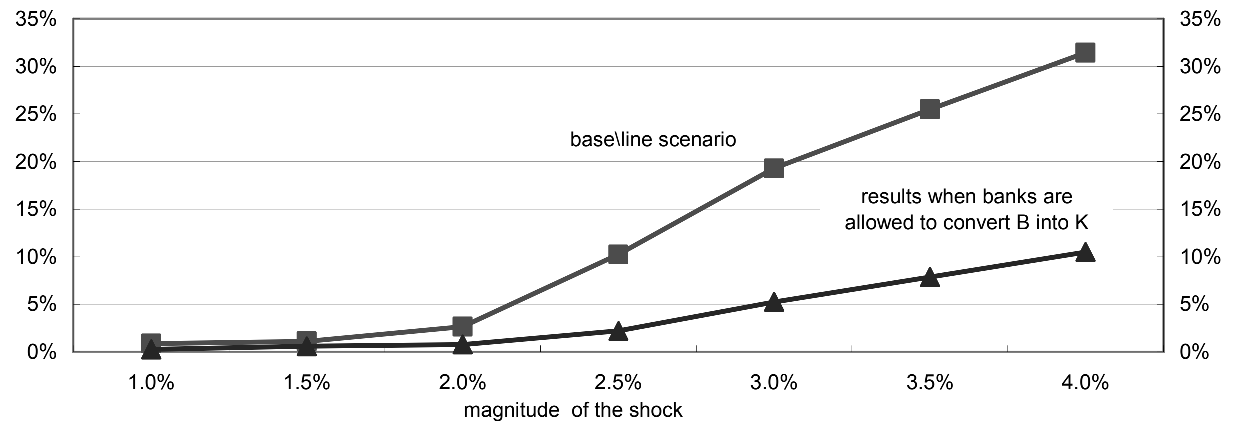
[30] There are more than 650,000 possible combinations of 5 units out of a sample of 40.

Apart from liquidity support, banking supervisors may attempt to manage the crisis with measures to strengthen banks' capital. Here, we test the case where the banks are required to alter the composition of their stable funding sources, counting up to one fifth of their outstanding securities issues into regulatory capital.[31] According to the simulation, this would improve the banks' resilience to the external shock quite significantly. The percentage of bank assets affected, measured by the sum of the L1, L2 and L3 statistics, falls from 10.3% to 2.3% when the shock magnitude is 2.5% of total assets, from 31.4% to 10.5% when the shock is 4.0% (Chart 8). This outcome will not be a surprise to those who call for contingent convertible debt requirements. Calomiris and Herring (2011), for one, argues that if a mechanism of conversion of debt in capital had been in place in 2007, the systemic repercussions of the sub-prime crisis could have been avoided. Note, however, that for smaller shocks the gains are modest, suggesting that the supervisor should not be too quick to implement this measure after any shock.

Chart 8

Reduction in L1+L2+L3 when banks are allowed to count up to one fifth of their issued securities as capital (1)

(*per cent of total assets of the banking system at the start of the simulation*; *March 2010 data*)



(1) B= Bonds; K=Capital. Results referred to the sum of the statistics L1, L2 and L3 over 200 runs of the simulation under the baseline scenario. See notes to Chart 3 for further details.

4.4 *The future landscape given a compulsory liquidity ratio*

As a final exercise, we run a simulation in which the capital ratio is flanked by a compulsory liquidity ratio (again, at a group level):

$$[6] \qquad l_{i,t} \equiv \frac{R_{i,t} + G_{i,t}}{\max\{[DL_{i,t} - DA_{i,t}]; 0\} + \lambda_C C_{i,t} + \lambda_B B_{i,t}}$$

The capacity to cope with liquidity outflows in the short term (the denominator of the ratio) is estimated as the excess of interbank deposits over interbank loans plus a fraction λ_C of customer deposits C and a fraction λ_B of outstanding bond issues B (for the meaning of R, G, DA and DL see section 3.2). This is a simple but fair representation of the forthcoming Basel 3 liquidity ratio (see BSBC 2009).

31 In the simulation, the option is activated by those banks whose capital would otherwise turn negative. Our experiment is relevant to the concept of "contingent capital" developed in the literature. De Martino et al. (2010) suggest the introduction of countercyclical contingent capital based on a double trigger: a) an aggregate shock to the banking system; and b) the individual bank's capital adequacy ratio below a predefined threshold, higher than the minimum.

In considering the results, the reader should bear in mind that for most groups the balance-sheet data at March 2010 do not yield a value of ratio [6] above 1 (no surprise given that the Basel 3 liquidity coverage ratio does not go into effect until 2015). Hence, to start the exercise with a fully compliant banking system, we manipulated the balance-sheet data by adopting either of two admittedly extreme options: (1) the size of the balance sheet remains the same, while banks sell 'other assets' OA and use the proceeds to purchase eligible bonds G; and 2) banks expand the balance sheet by adding capital and use all the new available resources to add further G. We do not attach any specific probability to either of these two paths to compliance with the liquidity coverage ratio when it goes into force. Presumably, they may demarcate a range of possible intermediate solutions.

As was to be expected, under either option, the fact that in the 'modified' balance sheet banks have more G available than in the original balance sheet lowers the L3 statistic on illiquid banks (Chart A.2). However, under option 1 there is hardly any change in the likelihood of banks being in default or undercapitalised. This outcome is not wholly intuitive, in that greater G should reduce the need for fire sales, hence capital losses. A possible interpretation is that the liquidity ratio requirement offsets liquidity shocks but also reduces flexibility in exploiting the added strength of the balance-sheet (via the increase in G), which could weaken the response to credit shocks. Clearly, more reassuring results are obtained under option 2, but based also on the results presented in Chart 8, the improvement is likely to be due mainly to the capital strengthening.

5. Conclusion

We simulate the spreading of shocks through the banking system in a set-up that posits banks' active balance-sheet management, intra-group support, and regulatory constraints, principally a capital adequacy ratio (or leverage ceiling). As an important caveat in assessing the data, the reader should bear in mind that, coherently with previous literature on the resiliency of interbank networks, this is not an enquiry on the likelihood of a shock hitting the banking system but it is rather an attempt to figure out the actions that a diversified set of players could undertake if the shock does occur. Furthermore, to yield non-trivial results, the trigger to the simulation is a shock purposely designed not only large in size but as one which hits the banks as a sudden, one-shot blow (in terms of losses on banks' loans to non financial customers).[32]

In an adverse scenario, assuming no intervention by policy authorities, we reckon that banks accounting for 2% of total assets would be in default at the end of the simulation, while an additional 8% would need to be recapitalised to meet the requirements if the trigger shock is put at a magnitude of 2.5% of total assets; if the shock strengthens to 3.0%, these two loss statistics increase to 5% and 13%. The assumption in this simulation is that the authorities stick to their ordinary policy course and do not engage in any specific support actions, even when contagion spreads. (Quite clearly, these percentages are derived from the simulation and may fall short of describing what happened in the real world in recent years or what or could have happened had the authorities taken a laissez-faire attitude.)

In a second simulation, we assume the authorities are more active, following one three possible policies: (i) extension of the pool of eligible assets to include all marketable securities and all loan assets; (ii) eligible asset extension only for selected banks (5 of 40 in our exercises), not across the board; (iii) option for banks to count up to one fifth of their outstanding bond issues as regulatory capital. The results of the simulation help to pinpoint the most suitable context for each of these crisis management policies. Lending of last resort works best against crises triggered by small-to-medium shocks (up to 2% of total bank assets); unconventional monetary policy, where liquidity is

[32] The simulated shock ranges from 1 to 4% of total assets of banks in our sample, while based on data for Italian banks actual new losses on loans could amount to some 0.6% of total assets in a relatively ordinary year such as 2008.

supplied on a tap procedure against a wider-than-usual pool of collateral assets, may the contagion by as much as half but is relatively less effective when the magnitude of the shock is 3.0% or greater; when the shock is very strong, policies of capital strengthening support are quite effective in curbing the crisis.

Our loss estimates are larger than those found by most of the previous simulations of banking crises (for comparable levels of the loss-given-default parameter and no support policies by the authorities), even though we explicitly allow for intragroup help to individual distressed banks . A counterfactual exercise suggests that the difference is due both to our design of the shock and to the fact that we let banks undertake actions to shelter themselves and their group.[33] Our shock design comprises a fairly general structure with both an aggregate and an idiosyncratic component, with varying weights. (The literature usually adopts a fully idiosyncratic shock to one or sometimes two banks, leaving all the others unscathed.) On banks' countermeasures, the downside is that action by individual banks or groups could contribute at aggregate level to spread the contagion. The credit shock that initiates the simulation may become a liquidity problem for some banks and emerge later as a fire-sale loss for other banks. In our view the results shed some light on how a banking crisis can deepen due to severe problems of coordination.

Our set-up is flexible enough to test a number of alternative scenarios. A fairly large shock, say 3.0% of total bank assets, with a prevailing idiosyncratic component can substantially increase the share of banks in default. We also tried different underlying balance-sheet data (March 2009 instead of March 2010). We find that the 2010 data result in a substantially lower share of banks in default, which presumably depends on the higher capital/asset ratio at that date. The number of illiquid and undercapitalised banks also diminishes, mainly because of a contraction in the interbank market between March 2009 and March 2010.

Finally, let us suggest a tentative agenda of future research. In this paper, for simplicity we allow banks to take countermeasures only when their own balance sheets are affected. Ideally, however, one would want to test a set-up allowing for preventive measures simply on the basis of the expectation of crisis, depending on the banks' risk attitude. A more complex set-up could also provide endogenous solutions for the price of the securities held by banks, so as to mark their balance sheet assets to market. A more daunting task would be to design a simulation that finds solutions where markets eventually ration out one or more banks, regardless of their credit rating, without imposing external caps as we did. Finally, we cannot help but observe that none of the support policies tested substantially mitigates the original coordination problem. It could be rewarding to devise simulations in which banks have an incentive to undertake the required deleveraging in a more coordinated way, which means avoiding the roll-off of interbank loans and possibly also the rush to sell some securities, which could worsen the final outcome when balance sheets are marked to market.

[33] The results do not appear to be greatly affected by the use of Italian bank data or by the date chosen (March 2010).

Table A.1

Main results of selected papers simulating effects of contagion

Author (year)	Data	Main qualitative results	Banks affected, % of their assets out of total banking system; worst case scenario; loss rate = 60% (or closest available rate)
Furfine (2003)	US	Federal funds exposures are neither large enough nor distributed in a way to cause a great risk of contagion. Very few banks would fail as a direct result of the failure of an important federal funds borrower. Illiquidity however presents a greater threat to the banking system. Should the largest federal funds debtor become unable to borrow, illiquidity could spread to banks holding almost 9% of the US banking system assets.	(close to) 2%
Mistrulli (2007)	Italy	Even if the Italian interbank market is conducive to financial contagion it is unlikely to trigger a systemic crisis. Banking groups tend to improve the resilience of the banking system to shocks.	All banks: 7.9%; large banks only: 7.4%
Sheldon and Maurer (1998)	Switzerland	Although the likelihood of a bank insolvency in any given year is quite high, the chances of a bank failure propagating through the banking system via the network of interbank loans is quite low.	
Upper and Worms (2004)	Germany (estimated data)	In the absence of a safety net, there is considerable scope for contagion that could affect a large proportion of the banking system. The financial safety net (institutional guarantees for savings and cooperative banks) considerably reduces – but does not eliminate – the danger of contagion.	61.6% (loss rate = 0.50)
Lelyveld and Liedorp (2006)	Netherlands	Bankruptcy of one of the large banks will put a considerable burden on the other banks but will not lead to a complete collapse of the interbank market.	2% (large exposures data)
Degryse and Nguyen (2007)	Belgium	The risk of contagion varies substantially over time: it increased over the period 1993–97, decreased afterward, and flattened out at a very low level at the end of the sample period (end of 2002). The failure of some foreign banks could have a sizable effect on Belgian banks' assets, although the risk of contagion is currently low. Contagion is a low-frequency event but interbank exposures at some time periods may constitute a devastating contagion channel.	3.3%
Wells (2002)	UK (estimated data)	Although an idiosyncratic failure of one bank could cause multiple failures of other banks, this is the exception rather than the rule. Even if the loss-given-default were 100%, the insolvency of a single bank triggers additional failures in only 4 of the 33 cases. In the event of the failure of a large bank, there does appear to be the potential for a substantial weakening in the capital position of a number of other banks.	6.7% (multiple failures)
Blåvarg and Nimander (2002)	Sweden	In the event of default of one of the Swedish banks, there is a slight risk of a subsequent failure of another Swedish bank.	
Lublóy (2005)	Hungary	Even under unrealistic scenarios the contagion is fairly limited both in absolute and relative terms, which can be mostly explained by the limited interbank exposures of Hungarian banks.	

Table A.2

Change in loss statistics when parameters are changed compared to the baseline scenario (1)

(*per cent of total assets of the banking system at the start of the simulation*)

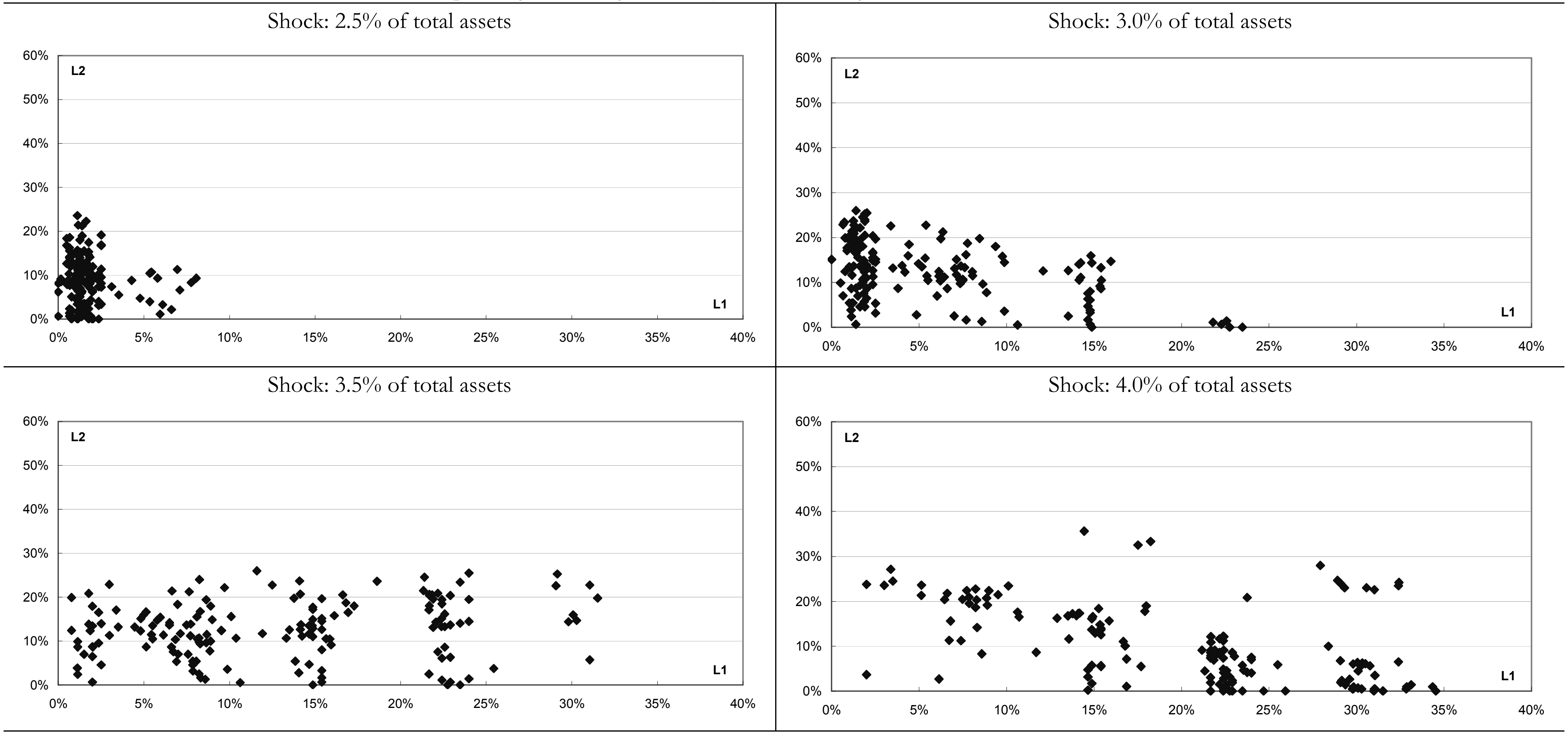
	Magnitude of shock = 2.5%			Magnitude of shock = 3.0%			Magnitude of shock = 4.0%		
	L1	L2	L3	L1	L2	L3	L1	L2	L3
Baseline scenario	1.8%	0.1%	8.4%	5.5%	1.0%	12.8%	20.0%	0.9%	10.5%
Changes in loss statistics compared to baseline scenario following changes in parameters									
A) parameter governing the loss in fire sales (25% in the baseline scenario)									
A1) 40%	=	=	+0.1	=	=	=	=	=	=
A2) 70%	=	=	=	=	=	=	=	=	=
B) percentage of liquidity of U (50% in the baseline scenario)									
B1) 30%	=	=	+0.1	=	+0.3	=	=	-0.2	+0.2
B2) 10%	=	=	+0.1	=	+0.2	=	=	-0.1	+0.1
C) percentage of liquidity of L (30% in the baseline scenario)									
C1) 20%	=	+1.5	=	+0.1	+0.8	=	=	+0.4	-0.1
C2) 10%	=	+8.4	-8.4	+0.1	+1.1	+0.3	+0.4	+0.1	-0.1
D) cap on recovery ratio (40% in the baseline scenario)									
D1) 30%	=	=	+0.1	+0.2	+0.5	-0.3	+4.4	-0.1	+7.5
D2) 20%	=	=	+0.2	+0.4	+0.4	+1.6	+18.9	+0.2	+7.6
Multiple changes									
A1+B1+C1+D1	=	+1.8	=	+0.2	+1.7	-0.5	+5.3	+0.1	+6.8
A2+B2+C2+D2	=	+2.0	+0.4	+0.4	+1.7	+1.8	+28.6	=	+1.7

(1) Based on data at March 2010. Results shown are averages over 200 replications of the simulation. The table shows the results for the baseline scenario – defined by the values specified in the table and a weight of 50% of the idiosyncratic shock – and the corresponding changes in percentage points.

Chart A.1

Distribution of results under the baseline scenario (1)

(per cent of total assets of the banking system at the start of the simulation; March 2010 data)

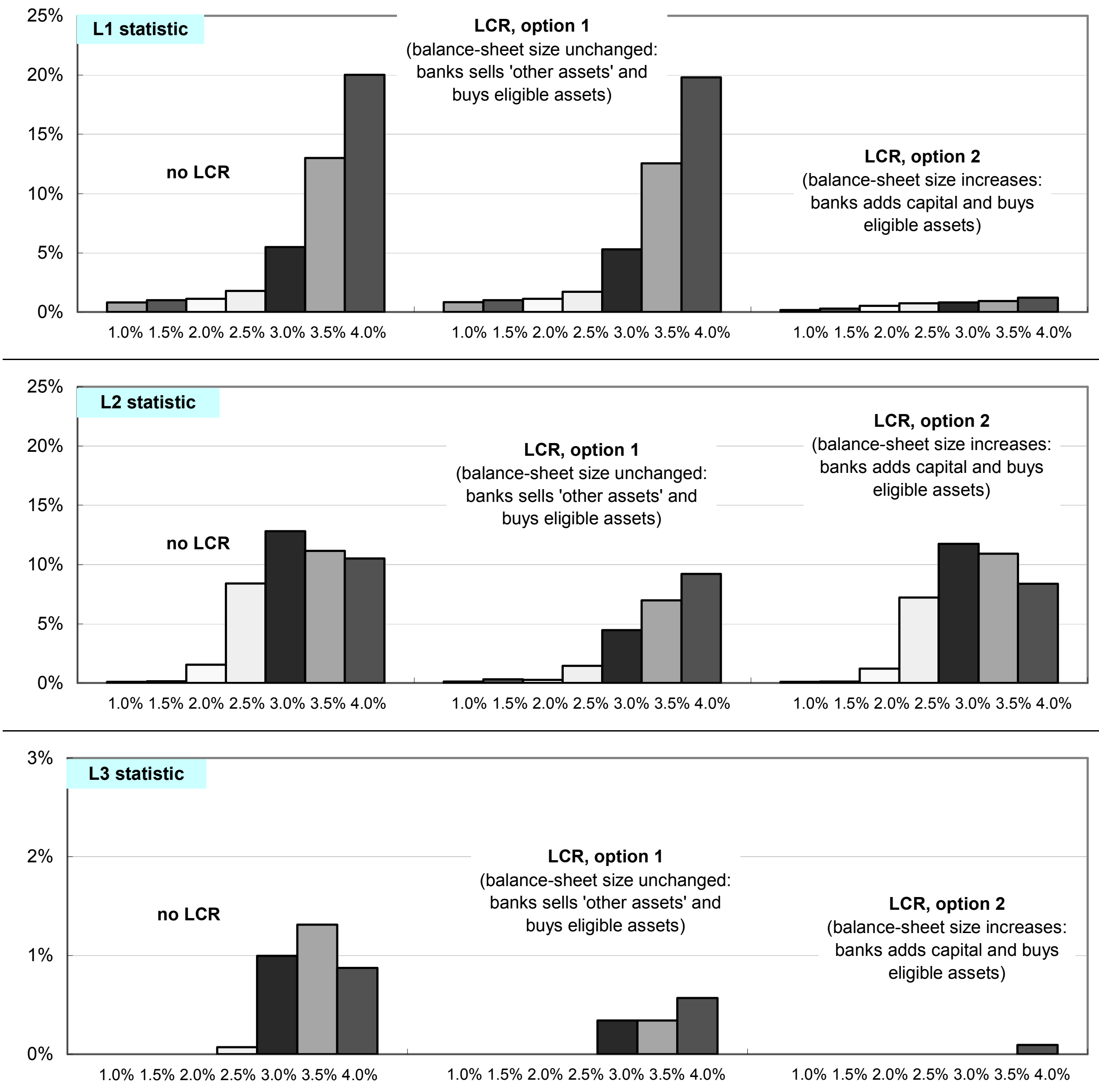


(1) Results over 200 simulations. See notes in Chart 3 for details on the baseline scenario.

Chart A.2

Losses in a set-up with liquidity coverage ratio requirement (1)

(per cent of total assets of the banking system at the start of the simulation)



(1) For each group of bars, moving left to right the histograms report the statistics in the baseline scenario (no LCR) using March 2010 data, in the scenario with LCR where the compliance at the beginning of the simulation is achieved by changing the March 2010 data through an increase in items G and K (central block) and through an increase in items G and decrease in OA (right-hand block).

DELEVERAGING. AN ECONOMETRIC ANALYSIS

The relevance of a deleveraging channel from a liquidity perspective in the case of Italian banks was checked carrying out a regression *à la* Adrian and Shin (2010). Our basic regression looks like

$$\frac{ML_{i,t}-ML_{i,t-1}}{ML_{i,t-1}}=\beta_{0,i}+\beta_1\frac{A_{i,t}-A_{i,t-1}}{A_{i,t-1}}+\beta_2 ML_{i,t-1}+\beta_3\frac{A_{i,t}-A_{i,t-1}}{A_{i,t-1}}d_t$$

where $ML_{t,i}$ is the leverage multiple of bank i at the end of the (six-month) period t, A is its total assets and d_t is a dummy variable that takes value 1 at 2007H2 and 0 otherwise. The regression with fixed effects was carried out using the intragroup estimator. In additional regressions, in order to detect which balance-sheet items contribute most to the deleveraging process, the change in total assets was replaced by the change in interbank loans (D), other loans (L), the securities portfolio (G)[34] and finally any other item on the asset side of the balance sheet (OA). The dummy (d) was included to capture the break introduced by the crisis, if any.

Table A.3

Leverage regression (a)

(*half-yearly changes; dependent variable: leverage growth rate*)

Leverage (log lag)	-0.350**	-0.356**	-0.384**	-0.392**
Total Assets (A)	0.459**	0.467**		
A × *d*		0.028		
Loans (L)			0.129**	0.187**
L × *d*				-0.068
Securities (G)			-0.010	0.020
G × *d*				-0.028
Interbank (D)			0.016	0.0014
D × *d*				0.130**
Other assets (OA)			0.075*	0.082
OA × *d*				-0.015
Constant	1.556**	1.550**	1.910**	1.838**
Observations	300	300	300	300
Number of banks	30	30	30	30
R^2 adjusted	0.27	0.28	0.23	0.26
F	38.89	27.70	14.18	23.40
sigma_e	0.148	0.147	0.153	0.150
sigma_u	0.163	0.165	0.179	0.182
Rho	0.547	0.556	0.579	0.596

(a) Regressions of half-yearly leverage growth rates on growth rates of total assets, loans and securities. All items are computed from the balance sheets of the banks included in the simulation exercise. */** denote significance at 5% and 1%. P-value accounts for heteroschedasticity and autocorrelation of residuals.
Date: from December 2004 until December 2009.

The sign of the estimate of β_1 in the basic set-up [6] is positive, in line with the results found by Adrian and Shin for investment banks, and is highly significant. When the other variables are tested and no dummy term is included, only non-interbank loans turn out to add some explanatory power. However, when each item may interact with the post-crisis dummy variable, the picture changes: the coefficient of loans is much larger in absolute value but the interaction is not significant, suggesting that loans contribute asymmetrically to capital

[34] In this section we include in G the value of all marketable securities.

pro-cyclicality. The estimates reveal also that the contraction of interbank flows is correlated with the decrease in leverage after the end of the financial crisis. Finally, the estimate of the coefficient β_2 is negative across the board, signalling that leverage is mean-reverting.

Table A.4

Descriptive statistics of banks included in the leverage regression (a)

(millions of €)

	Mean	Std. Dev.	Bottom quartile	Median	Top quartile
Total assets	46,012	78,788	8,688	19,758	38,183
Interbank	9,660	22,613	1,097	2,228	5,635
Securities	6,304	13,794	752	1,837	4,052
Other	17,839	28,236	3,118	10,677	16,667
Tier one	3,456	8,198	417	962	2,306
Leverage(c)	20.4	10.8	13.7	17.2	23.8

Source: Based on Banca d'Italia data.
(a) The leverage multiple is the ratio of total assets to tier one capital.

ANNEX 2

THE SIMULATION IN DETAIL

What follows is a description of the baseline scenario of the simulation, where the authorities follow the ordinary course of action with no specific anti-crisis measures. In reading these notes the reader should be aware of the following elements:

- the simulation is run on a sample of *n* banks *i*, *j*, .., scattered over N groups G_1, G_2, .., G_N (some groups consist of only one stand-alone bank). The notation i, j $\in G_1$ signals that both banks *i* and *j* belong to group G_1 while $\{i \in G_1; j \notin G_1\}$ specifies that *i* belongs to G_1 while bank *j* doesn't;
- the simulation consists of a sequence of steps, and the identity [1] as written out in the main text is updated at the beginning of each step. To keep notation simple, as a rule we do not explicitly specify the step *t* to which the formulae refer, as this should generally be clear enough from the context (*t* goes from 0, the start of the simulation before the shock occurs, to T, the end of the simulation). When we refer to item X as measured at the end of the previous step, we write $X_{i,-1}$. We use the change operator Δ, which applied to item X yields the difference between the stock of X in the current and in the previous step;
- the capital ratio *k* is obtained dividing K by A* where the latter is an amended version of total assets A, excluding both the cross share-holdings P generated through the simulation whenever there is a step of intragroup transfer of resources and intragroup interbank loans (some of which may exist from the beginning);
- an n×1 vector I is compiled to keep track of the state of each bank: in its *i*-th cell the vector holds value 0 if the *i*-th bank is fully active, 1 if it is in default (liabilities exceed assets), 2 if it is liquid and with positive capital but with a capital ratio *k* below the threshold k*, 3 if it is unable to reimburse in full all the interbank loans its creditors have called in.

This is the sequence of steps.

Step 1. The shock. Every bank bears losses amounting which for bank *i* amount to ε_i

$$\Delta L_i + \Delta OA_i = -\varepsilon_i$$

$$\Delta K_i = -\varepsilon_i$$

Step 2. Intragroup recapitalisation. Bank i transfers c units of its assets to j, where $\{i, j\} \in G_1$, under the conditions: $K_i > 0$, $K_j < 0$, with $c \leq \min(K_i, -K_j)$

$\Delta L_i + \Delta OA_i = -c = \Delta K_i$

$\Delta P_i = +c$

$\Delta L_j + \Delta OA_j = +c = \Delta K_j$

Note that: $\Delta A_i = 0$; $\Delta A_i^* = -c$; $\Delta A_i = +c$; $\Delta A_i^* = +c$. At a group level: $\Delta A_{G1} = \Delta A_{G1}^* = 0$.

Step 3. Spreading of losses. Banks bear losses on their interbank loans to banks now in default.

If $K_{j,-1} \leq 0$, bank j defaults $\Rightarrow I_j = 1$.

As there may be more than one such j, any bank l which is still active ($K_{l,-1} > 0$) will bear losses:

$$\Delta DA_l = -\sum_{I_j=1} DA_{l,j,-1}$$

$$\Delta K_l = -\sum_{I_j=1} \left[DA_{l,j,-1} \times (1 - r_j) \right]$$

where r_j is the recovery ratio (which applies equally to all j's creditors). In the balance-sheet identity, the difference between the interbank loan being written off and the reduction in capital is stored under the sundry item SA

$$\Delta SA_l = +\sum_{I_j=1} \left(DA_{l,j,-1} \times r_j \right)$$

As a result of this step, bank l may go under ($K_{l,} \leq 0$). If this is the case, the simulation repeats step 2 and, if necessary, step 3. The loop is repeated until no further bank goes under. Then, the simulation advances to step 4.

Step 4. Ingtagroup recapitalisation, up to $k > k^*$. This mirrors step 3, except that banks help each other within the group to bring each bank's capital ratio back up to the regulatory minimum k^*. Starting conditions change accordingly: $K_i > A_i^* \times k^*$, $K_j < A_j^* \times k^*$, $c \leq \min(K_i - A_i^* \times k^*, -(K_j - (A_j^* \times k^*))$.

Step 5a. Rolling off interbank loans, symmetric clearing. After step 4 some active banks may still have a capital ratio k too low to comply with the regulatory requirement. Hence, they deleverage, first by calling in interbank loans and using the funds transferred to them by their borrowers to liquidate some liabilities.

First, they define a target A* reduction (tAr) as

$tAr_i = \text{Min}(A_i^* \times k^* - K_i; 0)$

This can be implemented through the interbank loans (we expand the acronym into tArl)

$tArl_i = \text{Min}(tAr_i; ODA_i)$

Note that interbank loans to group banks are not called in. They do not count towards the regulatory requirement and would only amount to a zero-sum game of liquidity transfer within the group.

In this step, the loan by i to j (because of what we just said, if $i \in G_1$, $j \notin G_1$) is cancelled if, symmetrically, there exists a reverse loan by j to i and j as well is in the course of deleveraging.

Step 5b. Rolling off interbank loans, multilateral clearing. Clearing here is multilateral. In the simplest (triangular) case, bank i cancels its loan of c units to bank j, which cancels a deposit of the same amount with bank l, which finally cancels its interbank loan of c units to i. Necessary conditions for such clearing to be carried out are that not only the existence of the loans but also that the triplet i, j, l consists of banks whose target tArl has not been entirely fulfilled as a result of step 5a.

Step 6 Raising additional reserves by repoing G, L and U. To reimburse what remains of the interbank loans that have been rolled off after the clearing (steps 5a and 5b), banks use their reserves R with the central bank. If the current stock of R does not suffice, they increase it by central bank refinancing (which requires G to be pledged) and market repos (with U or securities backed by L as collateral). As an example, consider the monetary policy operation where g% units of the eligible bonds G held by bank i are posted as collateral and the central bank enforces the hair-cut α_G:

$$\Delta R_i = + \frac{g}{100} G_i \left(1-\alpha_G\right)$$

$$\Delta G_i = -\frac{g}{100} G_i$$

$$\Delta SA_i = + \frac{g}{100} G_i \times \alpha_G$$

$$\Delta AUP_i = + \frac{g}{100} G_i = \Delta M_i$$

Where the sundry item SA accommodates the hair-cut. With respect to U and L the hair-cuts α_U and α_L apply.

Step 7 Intragroup transfer of liquidity. If even after step the bank is still short of the required liquidity to reimburse its former lenders, it seeks support from the rest of its group (provided they have excess liquidity). If bank *i* receives *c* units of the reserves R held by *j*, where of course $\{i, j\} \in$ G1, then *j* records a credit towards *i* in the form of an interbank loan.

$\Delta R_i = + c = \Delta DL_{i,j}$

$\Delta R_j = -c = \Delta DA_{j,i}$

Step 8 Intragroup liquidity raising. If any of the active banks in the group is still short of the required reserves, its fellow group members raise additional liquidity as described under step 6. Then there is a new round of intragroup liquidity transfer takes place. This iterative process stops when additional reserves are still required but no further G, L or U is available within the group (in this case go to step 9) or else the reserves are sufficient for full reimbursement.

Step 9 Fire sale. As a last resort, banks may sell other assets, OA (say, property). But as this is done under the urgent for liquidity, these sales take place at a loss α_O. Say, bank *i* sells o units of its OA:

$\Delta R_i = + o \times \left(1-\alpha_O\right)$

$\Delta OA_i = -o$

$\Delta K_i = -o \times \alpha_O$

Because of the implied capital loss, some banks may go under and a new round of step 2 takes place. If this does not suffice, step 3 is also repeated. Banks cannot help conducting these fire sales, as otherwise they would default: instead, they take all feasible actions to reimburse their creditors. Note however that the fire sale is undertaken only by bank *i* individually; the other banks in its group are not bound to follow this path.

Step 10. Identification of illiquid banks. Banks whose capital is negative at the end of step 9 and even following a new round of transfer of resources within the group (step 2) default. Banks that are not able to reimburse their creditors in full are suspended by the supervisor ($I_j = 3$).

Step 11 Deleveraging. Banks that are still active at the end of step 10 set out to deleverage if their capital ratio *k* is lower than k*. To this end, they update their estimate on the target A* reduction tAr (see step 5a) and check whether their current reserves suffice for this, i.e. $R_i \geq tAr_i$. If not, they first seek to raise additional liquidity, through their G, U and L (see step 6). If this is not enough, additional funds may be provided within the group (see step 7). Then, if reserves R are sufficient, they use them to reduce their outstanding securities B and then retail deposits C. Otherwise, the banking supervisor declares that the bank is undercapitalised ($I_j = 2$).

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