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The systemic implications of bail-in: a multi-layered network approach

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Abstract

We present a tractable framework to assess the systemic implications of bail-in. To this end, we construct a multi-layered network model where each layer represents the securities cross-holdings of a specific seniority among the largest euro area banking groups. On this basis, the bail-in of a bank can be simulated to identify the direct contagion risk to the other banks in the network. We find that there is no direct contagion to creditor banks. Spill-overs also tend to be small due to low levels of securities cross-holdings in the interbank network. We also quantify the impact of a bail-in on the different liability holders. In the baseline scenario, shareholders and subordinated creditors are always affected by the bail-in, senior unsecured creditors in 75% of the cases. Finally, we compute the effect of the bail-in on the network topology in each layer. We find that a bail-in significantly reshapes interbank linkages within specific seniority layers.

Keywords: *Bail-in, resolution regimes, financial networks, policy simulation, systemic risk.*
JEL: *G01, G18, G21, C63.*

Non-Technical Summary

The global financial crisis led to distress at a number of systemically important financial institutions which were considered too big to fail (Laeven and Valencia, 2013). In many cases, this led to public bail-outs, despite the fact that bail-outs may have negative consequences for the economy at large. A credible resolution framework mitigates these negative externalities, by shifting the costs of bank failures from taxpayers to, first and foremost, the shareholders and creditors of the failing bank. In Europe, the EU Bank Recovery and Resolution Directive (BRRD) and the Single Resolution Mechanism (SRM) Regulation came into force on 1 January 2016. One of the key objectives of the new bank resolution framework is to enable an orderly resolution of a bank without causing severe systemic disruptions to the financial system's ability to provide financing to the real economy (Financial Stability Board, 2013).

An important element of the bank resolution framework is the bail-in tool, which provides the resolution authority with the statutory power to write down and to convert into equity the claims of a broad scope of creditors. To credibly remove the implicit state guarantee upfront for all banks, it must be possible to effectively resolve banks without public support and to do so without significant contagion risk. Indeed, the bail-in tool may also have consequences for the wider financial system to the extent that other financial institutions which hold securities of the bank being resolved could face losses that may in turn impair their own viability. The analysis presented in this paper focuses on the potential direct contagion risks related to the bail-in of securities held by other banks in the system. While potentially systemically important, the costs such contagion may entail should however be weighed against the benefits of the new bail-in arrangements aiming at correcting some of the externalities related to pre-crisis (implicit) bail-out arrangements. Such net benefit assessments, however, go beyond the scope of the analysis presented here.

The model developed in this paper is able to inform the policy discussion on both the composition and level of loss absorbing capacity of banks and the mitigation of direct contagion following a bail-in. To this end, we construct a multi-layered network model using European System of Central Banks (ESCB) proprietary data on the securities holdings of the 26 largest euro area banking groups. Each of the four network layers represents the securities cross-holdings of a specific seniority among these 26 banking groups, namely equity, subordinated debt, senior unsecured debt and secured debt. These 26 banking groups represent 59 percent of total euro area banking sector assets, so despite having few banks in our sample, we cover a large fraction of bank assets. Beyond the network of 26 banks, we are also able to capture the impact of a bail-in at one of these 26 banks on individual euro area banking sectors. To the best of our knowledge, this is the first paper to study the systemic implications of a bail-in.

Within the multilayer network, bail-in is simulated at each of the 26 banks in turn. In the baseline scenario, a bank suffers a 5% shock to total assets and is then recapitalized to 10.5%

Common Equity Tier 1 (CET1) capital via a bail-in. We study three main effects within this framework. First, we estimate the direct contagion effect to creditors. There is no direct contagion to creditors in the sense that no creditor bank defaults due to a bail-in at one of its counterparties. Spill-overs also tend to be small due to low levels of securities cross-holdings in the network of 26 banks. Spill-overs outside the network of 26 banks to individual euro area sectors are also contained. Second, we estimate the balance sheet effect, where we quantify up to which seniority layer banks require bail-in in order to fulfill prudential requirements. In the baseline scenario, subordinated creditors are always affected by the bail-in, senior unsecured creditors in 75% of the cases. Third, we compute the effect of the bail-in on the network topology in each layer. We find that a bail-in at one bank leads to the rewiring of links within specific seniority layers. The bank under resolution becomes more central within the equity network layer after the bail-in and less central in the subordinated debt layer. In this context, the multilayer network structure becomes particularly important, as such an analysis could not be carried out in an aggregate single-layer network.

Of special relevance to regulators is the result that in a significant amount of cases some senior unsecured debt (and in certain configurations even a fraction of the deposit layer) will be bailed in following a shock of for instance 5 percent to total assets. This shows that resolution authorities will need to carefully consider the level of loss absorbing capacity - to avoid that certain creditors such as depositors or perhaps even senior unsecured creditors are hit - as well as the composition of loss absorbing capacity. In some cases, requirements to issue additional subordinated debt to increase loss absorbing capacity and decrease the probability that senior unsecured debt or even deposits are bailed in may be called for. Furthermore, low interbank cross-holdings of bank bail-inable debt in the network appear to prevent direct contagion. Resolution authorities also need to carefully monitor the effect of the bail-in on the systemic relevance of the bank under resolution, since on average banks become more central and more interconnected when exiting resolution.

1 Introduction

The global financial crisis led to distress at a number of systemically important financial institutions which were considered too big to fail (Laeven and Valencia, 2013). In many cases, this resulted in large-scale public bail-outs, despite the fact that bail-outs are generally assumed to have negative consequences for the economy at large. First, the mere probability of a bail-out for failing systemically important banks creates the wrong incentives for internal risk management and a moral hazard problem (Dam and Koetter, 2012), as the cost of failure is not borne by those who have taken the risks but by taxpayers. Second, it creates an uneven playing field among banks as large and complex banks, which are perceived as more likely to be bailed out, can fund themselves more cheaply than smaller banks (Ueda and di Mauro, 2013). Third, it creates a negative feedback loop between banks and their sovereign (Cooper and Nikolov, 2013; Fratzscher and Rieth, 2015; Merler and Pisani-Ferry, 2012). A credible resolution framework mitigates these negative externalities, by shifting the costs of bank failures from taxpayers to, first and foremost, the shareholders and creditors of the failing bank.

Notwithstanding the benefits of bail-in compared to the pre-crisis implicit bank bail-out arrangements, bank bail-ins may also give rise to costs affecting the banking system and other economic sectors. Those costs could in particular derive from the financial consequences for bank shareholders and creditors being bailed in, which if large enough could endanger their financial situation and potentially entail systemic implications. This paper focuses on the possible direct contagion risk related to the bail-in of other banks holding securities issued by banks entering resolution. If banks' cross holdings of bail-inable debt are sufficiently large a bail-in of one bank in the system could endanger the soundness of other banks. The analysis presented here thus considers one specific element of costs related to bank bail-in, with a special focus on the new recovery and resolution framework recently introduced in the European Union (described more in detail below). Eventually, it is important that the potential contagion costs emphasised in this paper are weighed against the benefits of bail-in arrangements. Such net benefit assessments, however, go beyond the scope of the analysis presented in this paper.

In Europe, the EU Bank Recovery and Resolution Directive (BRRD) and the Single Resolution Mechanism (SRM) Regulation came into force on 1 January 2015. An important element of the bank resolution framework is the bail-in tool (applicable since 1 January 2016), which provides the resolution authority with the statutory power to write down and to convert into equity the claims of a broad scope of creditors. To credibly remove the implicit state guarantee upfront for all banks, at least two conditions must be met. First, it must be possible to effectively resolve banks without public support. This is only possible if banks have sufficient capacity to absorb losses and be recapitalized via a bail-in. Second, as mentioned above, resolution must be possible without generating significant contagion risk.

The model developed in this paper is able to inform the policy discussion on both the composition and level of loss absorbing capacity of banks and the mitigation of direct contagion following a bail-in. To this end, we construct a multi-layered network model using European System of Central Banks (ESCB) proprietary data on the securities holdings of the 26 largest euro area banking groups. Each of the four network layers represents the securities cross-holdings of a specific seniority among these 26 banking groups, namely equity, subordinated debt, senior unsecured debt and secured debt. These 26 banking groups represent 59 percent of total euro area banking sector assets, so despite having few banks in our sample, we cover a large fraction of bank assets. Beyond the network of 26 banks, we are also able to capture the impact of a bail-in at one of these 26 banks on individual euro area banking sectors. To the best of our knowledge, this is the first paper to study the systemic implications of a bail-in.

Within the multilayer network, bail-in is simulated at each of the 26 banks in turn. In the baseline scenario, a bank suffers a 5% shock to total assets[1] and is then recapitalized to 10.5% Common Equity Tier 1 (CET1) capital[2] via a bail-in. We study three main effects within this framework.

First, we estimate the direct contagion effect to creditors. There is no direct contagion to creditors in the sense that no creditor bank defaults due to a bail-in at one of its counterparties. Spill-overs also tend to be small due to low levels of securities cross-holdings in the network of 26 banks. Spill-overs outside the network of 26 banks to individual euro area sectors are also contained. The absence of direct contagion is in line with the empirical and simulation literature on contagion in financial networks (see the surveys of the field by Cabrales et al. (2015), Glasserman and Young (2015b) and Hüser (2015)). We are however the first to provide this insight in the context of the simulation of the financial stability implications of a resolution tool. Furthermore, our results were generated without resorting to exposures data generated from simulations, as is frequently done in the field for lack of granular data (Glasserman and Young, 2015a; Hałaj and Kok, 2013; Upper, 2011). We are able to overcome these data limitations since we have access to the actual securities cross-holdings detailed by seniority of the security. Hence we can describe the topology of the securities cross-holdings among large euro area banking groups and we can accurately compute the direct effect of a shock on the network structure.

Second, we estimate the balance sheet effect, where we quantify up to which seniority layer banks require bail-in in order to fulfill prudential requirements. A bail-in, as defined by the BRRD, comprises two steps: (i) liabilities are written down in proportion to the losses; (ii) the bank is

[1] A 5% shock to total assets was the maximum loss taken by global systemically important banks (G-SIBs) in the recent financial crisis (Financial Stability Board, 2015). We perform a sensitivity analysis in Section 5.5, where we vary the shock size from 1 to 12% of total assets.

[2] The 10.5 percent are based on the average of the CET 1 requirements of Significant Institutions published in the Supervisory Review and Evaluation Process (SREP) which is around 10 percent, see the Single Supervisory Mechanisms' SREP methodology under https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm_srep_methodology_booklet.en.pdf

recapitalized via a debt-to-equity conversion. In the baseline scenario, shareholders are always affected by the write-down, in 15% of the cases subordinated creditors are also hit and in 10% of the cases senior unsecured creditors also incur losses. This is consistent with the findings of Conlon and Cotter (2014), who retrospectively study the proportion of liabilities that authorities would have needed to write down in order to cover losses at European banks during the global financial crisis. Their results suggest that equity and subordinated bondholders would have been the main losers from the impairment losses realized by failing European banks. Losses attributed to senior debt holders would, on aggregate, have been proportionally small. The present analysis goes further. Indeed, Conlon and Cotter (2014) only evaluate the impact of a write-down of losses borne by the bank's shareholders and creditors. But this is only the first half of the resolution procedure, since a bail-in may also involve a recapitalization of the impaired institution. We find that following a bail-in comprising both write-down and recapitalization according to our baseline scenario, subordinated creditors are always affected by the bail-in and senior unsecured creditors in 75% of the cases. We thereby contribute to the (currently scarce) literature on bail-in[3], since we are the first to quantify the potential impact of both a write-down and subsequent recapitalization on shareholders and creditors.

Third, we compute the effect of the bail-in on the network topology in each layer. We find that a bail-in at one bank leads to the rewiring of links within specific seniority layers. The bank under resolution becomes more central within the equity network layer after the bail-in and less central in the subordinated debt layer. In this context, the multilayer network structure becomes particularly important, as such an analysis could not be carried out in an aggregate single-layer network. We therefore contribute to the nascent literature on multilayer networks[4], where we are the first to distill such a granular seniority structure based on actual exposures. Other breakdowns in the literature include for example maturity, instruments as well as the secured or unsecured nature of the transaction (Aldasoro and Alves, 2015; Langfield et al., 2014; Montagna and Kok, 2016). The main takeaway from the multilayer networks literature at this stage is that it is important to differentiate the layers of the network, since both topology and contagion processes can be different between layers. Our analysis of the security cross-holdings broken down by seniority layers confirms that finding: topological properties do differ across layers.

In additional simulation scenarios, we modify one aspect of the baseline scenario. In order to see what happens when a bank is hit by a shock in an already weakened financial system, we first apply an adverse scenario to the banking sector and then apply the baseline scenario to individual banks

[3] Contributions to the bail-in literature come from a variety of fields. Klimek et al. (2015) employ an agent-based model to compare bail-in, bail-out and the closing of a distressed institution. Chen et al. (2015) develop a capital structure model to analyze the incentives created by contingent convertibles and bail-in debt. Faia and di Mauro (2015) build a model of optimal design of resolution regimes and compare different regimes. Empirical studies investigate the market reactions to the recent bail-in cases in Europe (Schäfer et al., 2016) and the impact of new resolution regimes in the US on bank risk-taking (Ignatowski and Korte, 2014).

[4] See the survey by Hüser (2015) for an overview of the multi-layer financial networks literature.

in turn. In very rare cases, there is direct contagion in the sense that a bank fails its prudential requirement after a bail-in at its counterparty. In a third scenario, we change the recapitalization level such that the bank under resolution is recapitalized at the same level as the average of its peer group. We define one peer group as the global systemically important banks (GSIBs) and the second peer group as the non-GSIBS in the sample. In the recapitalization at the level of the peer group, the senior layer is always affected, compared to the baseline scenario where subordinated debt is sometimes the highest layer to take the hit. In a further scenario, we vary the shock size from 1 to 12 percent of total assets in increments of 1 percentage point. For shocks up to 4 percent deposits are not affected. Starting with a shock size of 5 percent, for an increasing number of banks the deposit layer would be hit.[5] The change in topology of the network is also affected by the shock size. The average change in centrality ranking of the bailed-in bank increases with the shock size, implying that larger bail-ins potentially also create more systemically relevant institutions.

Of special relevance to regulators is the result that in a significant amount of cases some senior unsecured debt (and in certain configurations even a fraction of the deposit layer) will be bailed in following a shock of for instance 5 percent to total assets. This shows that resolution authorities will need to carefully consider the level of loss absorbing capacity - to avoid that certain creditors such as depositors or perhaps even senior unsecured creditors are hit - as well as the composition of loss absorbing capacity. In some cases, requirements to issue additional subordinated debt to increase loss absorbing capacity and decrease the probability that senior unsecured debt or even deposits are bailed in may be called for. Furthermore, low interbank cross-holdings of bank bail-inable debt in the network appear to prevent direct contagion. Efforts by regulatory authorities, such as the Financial Stability Board, to strongly dis-incentivize such cross-holdings therefore seem to go in the right direction.[6] Resolution authorities also need to carefully monitor the effect of the bail-in on the systemic relevance of the bank under resolution, since on average banks become more central and more interconnected when exiting resolution.

The paper is structured as follows. Section 2 describes the bail-in framework in the European Union. Section 3 describes the data. Section 4 presents the multi-layer network model and descriptive statistics on the topology of the network. It also quantifies the potential direct contagion channels. Section 5 explains the simulation scenarios and presents the simulation results. Section 6 concludes with a discussion of policy implications.

[5]Deposits covered by the deposit guarantee scheme (DGS) are excluded from the scope of the bail-in tool. The DGS, however, contributes to funding the resolution process by absorbing losses to the extent of the net losses that it would have had to suffer after compensating depositors in normal insolvency proceedings.

[6]Principles on Loss-absorbing and Recapitalisation Capacity of G-SIBs in Resolution: Total Loss-absorbing Capacity (TLAC) Term Sheet, 9 November 2015, see http://www.fsb.org/wp-content/uploads/TLAC-Principles-and-Term-Sheet-for-publication-final.pdf.

2 Bail-in framework in the banking union

Focusing on the banking union context[7], the bail-in tool is first described. Second, the measures that authorities may take to ex ante reduce contagion in case of a bail-in are explained. Third, we elaborate on the conditions for considering a bank as failing and putting it into resolution. Finally we cover the expected level of capitalization following a bail-in. The policy measures described here inform the calibration of the failure threshold and the recapitalization level for the bail-in simulations performed in Section 5.

2.1 Description of the bail-in tool

The legal basis for the bail-in tool is provided by the Single Resolution Mechanism (SRM) Regulation.[8] Based on the powers provided by the SRM Regulation, the Single Resolution Board can convert to equity or write down the principal amount of a wide range of unsecured liabilities of a bank that is considered failing-or-likely-to fail (FLTF). The bail-in tool aims to recapitalize a FLTF bank or to provide capital for a bridge institution in case a liquidation of the FLTF bank is not possible because it would create negative externalities for the financial system.

The SRM Regulation provides a hierarchy for the bail-in of creditors and also excludes certain liabilities from the scope of the bail-in tool. The SRM Regulation thus follows the approach that all liabilities of a bank are bail-inable, unless they are specifically excluded, as opposed to defining the list of bail-inable liabilities. Secured or collateralised liabilities including covered bonds are excluded. In order to protect deposits guaranteed by Deposit Guarantee Schemes (DGS) and reduce the risk of systemic contagion, the bail-in tool also excludes covered deposits[9] and interbank liabilities with an original maturity of less than seven days.[10] Additionally, under exceptional circumstances certain liabilities may be fully or partially excluded on a case-by-case basis from the bail-in tool for financial stability reasons and to avoid widespread contagion.[11] Furthermore, the Single Resolution Fund (SRF) may contribute to the recapitalization of the failing bank subject to a number of strict conditions including the requirement that losses totalling not less than 8 percent of total liabilities including own funds have already been absorbed by creditors of the failing bank through the use of the bail-in tool.

[7] We focus on the banking union/euro area context as our model uses proprietary Eurosystem data. For the legal references provided to the Single Resolution Mechanism (SRM) Regulation, similar provisions can be found for the European Union in the Bank Recovery and Resolution Directive (BRRD).

[8] See article 27 SRM Regulation.

[9] Deposits covered by the deposit guarantee scheme (DGS) are excluded from the scope of the bail-in tool. The DGS, however, contributes to funding the resolution process by absorbing losses to the extent of the net losses that it would have had to suffer after compensating depositors in normal insolvency proceedings.

[10] See article 27 (3) SRM Regulation for the full list of liabilities excluded.

[11] See article 27 (5) SRM Regulation for the precise conditions under which liabilities can be excluded from the bail-in tool in exceptional circumstances.

The hierarchy for the bail-in of creditors is explicitly provided for by the SRM Regulation[12] and follows a creditor waterfall whereby the most junior liability is bailed in first, followed by the next tranches upon depletion of each previous liability (see Figure 1 for a stylized example of a bail-in and Figure 3 for an illustration of the detailed creditor hierarchy).[13] Thanks to the availability of information on seniority levels of the individual securities in our dataset, we are able to follow that hierarchy in our bail-in simulation.

2.2 Measures to prevent negative spill-over effects

In response to a call in 2013 by G20 Leaders for the development of standards on the adequacy of loss-absorption and recapitalisation capacity of global systemically important banks (G-SIBs), the Financial Stability Board (FSB) has introduced in November 2015 the total loss-absorbing capacity (TLAC) standard.[14] The aim is to ensure that GSIBs have sufficient capacity to absorb losses and recapitalize via a bail-in of their private creditors, both before and during resolution. The FSB TLAC standard defines a requirement for instruments and liabilities that should be readily available for bail-in in case of resolution of a G-SIB, without prejudice to the possibility to apply the bail-in tool to other non-TLAC liabilities.

Prior to the FSB TLAC standard, a similar requirement already existed in the EU - the Minimum Requirement for Eligible Liabilities (MREL).[15] There are however some significant differences between the final TLAC standard and the original EU MREL standard.[16] For one, TLAC applies as a minimum requirement for G-SIBs, whereas MREL is applicable on a discretionary case-by-case basis for all banks. Both standards avoid that banks structured their liabilities in a manner that undermined the effectiveness of the bail-in tool (e.g. by moving from an unsecured funding basis to a secured funding basis) and establish a minimum level of loss absorbency for G-SIBs, respectively EU banks.

In addition to including requirements to increase the loss absorbing capacity of G-SIBs, the FSB TLAC standard includes measures to mitigate the risk of contagion upon the bail-in of creditors. Specifically, the FSB TLAC standard includes a requirement that provides strong dis-incentives for banks to hold liabilities that are likely to be bailed in at the point of resolution. G-SIBs must deduct exposures to eligible external TLAC liabilities issued by other G-SIBs from their own TLAC or regulatory capital exposures in a similar manner to the existing provisions for the

[12]See article 17 SRM Regulation.

[13]This waterfall is without prejudice to the liabilities explicitly excluded from bail-in and the possibility for authorities to exempt from bail-in certain liabilities under the aforementioned exceptional circumstances.

[14]Principles on Loss-absorbing and Recapitalisation Capacity of G-SIBs in Resolution: Total Loss-absorbing Capacity (TLAC) Term Sheet, 9 November 2015, see http://www.fsb.org/wp-content/uploads/TLAC-Principles-and-Term-Sheet-for-publication-final.pdf.

[15]See article 45 BRRD. For banking union, see article 12 SRMR.

[16]See Box 6 of the ECB Financial Stability Review (November 2014) for the key differences between TLAC and MREL.

deduction of regulatory capital of other banks in Basel III. Further provisions, also for non-G-SIBs are envisaged.[17] The FSB TLAC proposal does not further specify this provision for non-GSIBs and leaves further specifications to the Basel Committee on Banking Supervision (BCBS). Similarly, the BCBS proposes that internationally active banks (both G-SIBs and non-G-SIBs) be required to deduct their net TLAC holdings that do not otherwise qualify as Basel III capital from their own Tier 2 capital.

The SRM Regulation or the BRRD do not contain a similar deduction requirement for holdings of MREL by other G-SIBs. Noticeable is however in this respect that the Single Resolution Board can instruct national resolution authorities to limit the extent to which other institutions hold liabilities eligible for the bail-in tool, save for liabilities that are held at entities that are part of the same group.[18] This power is part of the set of powers at the disposal of resolution authorities to mitigate any impediments to resolvability of a bank.[19] In Europe, pending the transposition of the FSB standard in EU legislation, the legislator thus prefers a discretionary case-by-case approach by the Single Resolution Board or national resolution authorities over a general requirement across all banks. The difference in approach between TLAC and MREL is to a certain extent understandable, as TLAC applies to a relatively homogeneous group (G-SIBs), whereas MREL applies to all banks.

2.3 Conditions for resolution

In order for the bail-in tool to be used in a resolution, resolution authorities should consider that all three conditions for resolution are met. These include (i) that there is no reasonable prospect that any alternative private sector measures would prevent the failure within a reasonable timeframe and (ii) a resolution action is necessary and in the public interest and (iii) the assessment by the supervisor or resolution authority that the bank is failing-or-likely-to-fail (FLTF).[20]

Regarding the last condition, which is particularly relevant for our simulation exercise, EU legislation does not provide for quantitative thresholds to determine whether a bank is failing or likely to fail (FLTF). Instead such determination is left to the supervisor or resolution authority. For our network model, a benchmark is needed to assess at which capital level a bank would be considered to be failing or likely to fail. One possible threshold would be the minimum requirement of 4.5 percent CET1, reflecting that buffers and other capital to meet minimum (Pillar 1) and additional supervisory (Pillar 2) capital requirements are depleted.[21] A more conservative assumption would be that a bank is determined as failing or likely to fail when a bank has depleted its buffers and

[17] See section 15 of FSB Term sheet dated 9 November 2015.

[18] See article 27 (4) SRM Regulation, last subparagraph. For the EU, see article 44 (2) last subparagraph BRRD.

[19] See article 10 SRM Regulation, and article 17 of the BRRD.

[20] See article 18 (1) of SRM Regulation and article 32 (1) of the BRRD.

[21] Part Two of the CRR establishes the own funds requirements (Pillar 1 capital requirements) with which institutions are required to comply. In accordance with Article 104(1)(a) of Directive 2013/36/EU5 (Capital Requirements Directive CRD), Member States must ensure that competent authorities are empowered, inter alia, to require institutions to hold additional own funds requirements (Pillar 2 capital requirements) on a case-by-case basis.

half of its Pillar 2 capital add-on, reflecting that breaches of an additional supervisory (Pillar 2) capital requirement may be grounds for a withdrawal of authorization and a Failing-or-Likely-to-Fail-Assessment. For these reasons, this is the threshold we adopt in the bail-in simulations below. Based on SSM averages, this would put the threshold at 7% CET1.[22]

2.4 Level of recapitalization

The EU BRRD or the SRM Regulation do not provide for a specific level of recapitalisation. Instead, the EU framework relies, as for the FLTF assessment, on a more qualitative assessment of the recapitalisation level. Resolution authorities apply the bail-in tool to recapitalise a FLTF bank to a level sufficient to restore its ability to comply with the conditions for authorisation and to continue to carry out the activities for which it is authorised, and to sustain sufficient market confidence in the institution or entity.[23] Further criteria for the level of recapitalisation are provided by draft Regulatory Technical Standards (RTS) of the European Banking Authority (EBA)[24] for the determination of the level of MREL. These RTS prescribe that as a baseline resolution authorities should aim to set a level of MREL sufficient to ensure that following a bail-in, the institution can i) absorb losses sufficiently to exhaust capital requirements and buffers; ii) satisfy capital requirements applicable after the implementation of the preferred resolution strategy and iii) match average capitalisation levels for a defined peer group in order to restore market confidence[25].

In particular, the last two conditions provide an indication at what level a bank is expected to be capitalized after a bail-in. First, it is reasonable to assume that capital requirements applicable after the preferred resolution strategy are lower or equal to the capital requirements prior to the resolution: the assets of the entity following resolution should in principle be less risky than prior to the resolution. In the bail-in simulations in Section 5, we recapitalize banks under resolution to 10.5 percent CET1. The 10.5 percent are based on the average of the CET1 requirements for the euro area banks under direct SSM supervision (the so-called Significant Institutions) published in the Supervisory Review and Evaluation Process (SREP) which is 9.9% and which we round to 10%.[26] We add 50 basis points on top of the 10 percent since banks typically operate with a margin above their prudential requirements. Based on the conditions outlined in the previous paragraph, another

[22]To be precise, this would put the threshold at 4.5%+1/2*(9.9%-4.5%) = 7.2% CET1, which we round to 7%. The 9.9% refer to the average of the CET1 requirements for the euro area banks under direct SSM supervision (the so-called Significant Institutions) published in the Supervisory Review and Evaluation Process (SREP), see the Single Supervisory Mechanisms' SREP methodology under https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm_srep_methodology_booklet.en.pdf.

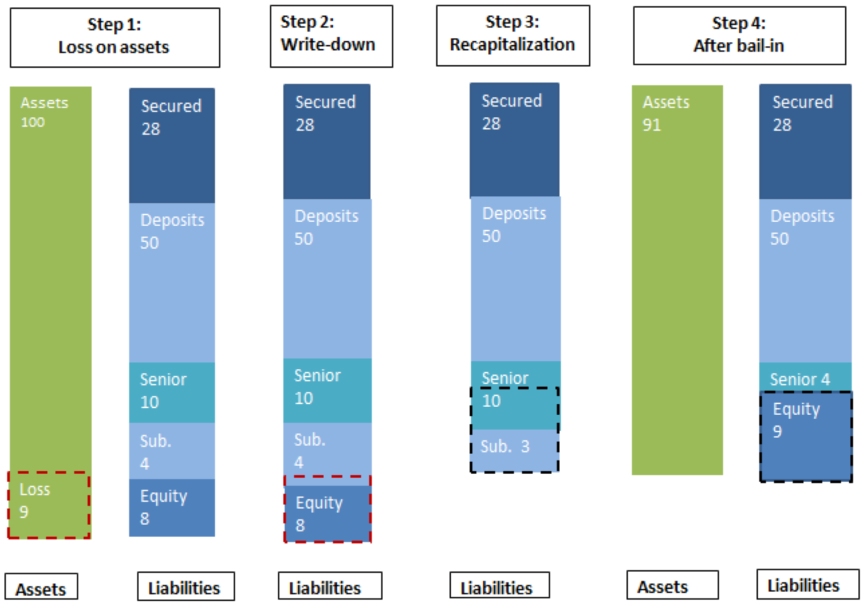
[23]See article 43 (2) of the BRRD.

[24]See EBA FINAL Draft Regulatory Technical Standards on criteria for determining the minimum requirement for own funds and eligible liabilities under Directive 2014/59/EU (EBA/RTS/2015/05 dated 3 July 2015).

[25]Resolution Authorities may adjust this baseline up or down on the basis of either: i) changes to the institution's capital requirements identified in the resolution plan whose impact can be quantified and which are assessed as feasible and credible; or the degree of confidence they desire.

[26]See the Single Supervisory Mechanisms' SREP methodology under https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm_srep_methodology_booklet.en.pdf.

Figure 1: Stylized example of loss absorption and recapitalization after a bail-in



Note: Block sizes are not to scale. For ease of exposition, AT1 and T2 capital have been omitted.

possible recapitalisation threshold would be to match average capitalisation levels of the peer group. Whilst a peer group may be difficult to define for certain banks given the variety of business models in the European banking system, a natural peer group for a failing G-SIB is the one consisting of all other G-SIBs in the system.[27] Simulation results for this alternative recapitalisation level are presented in Section 5.4.

Figure 1 presents a stylized example of loss absorption and recapitalization after a bail-in. In the first step, a bank experiences a loss of 9 units on its asset side. In a second step, its liability side is written down to absorb the losses. In this example, the entire equity is lost and a part of the subordinated debt. In a third step, the bank will be recapitalized to 10.5 percent CET1 capital, as explained in the above paragraph.[28] This means recapitalization requires new equity of roughly 9 units; the entire subordinated debt and a fraction of the senior unsecured debt need to be bailed in to achieve that. The final step illustrates the balance sheet of the bank after the bail-in.

[27]See also article 2(9) of EBA FINAL Draft Regulatory Technical Standards on criteria for determining the minimum requirement for own funds and eligible liabilities under Directive 2014/59/EU (EBA/RTS/2015/05 dated 3 July 2015).

[28]For simplicity we assume in this figure that the average risk-weight is 100% such that total risk-weighted assets is equal to total assets.

3 Data

We make use of two micro-financial datasets namely the European System of Central Banks' (ESCB) Securities Holdings Statistics by Group (SHSG) and the ECB Centralised Securities Database (CSDB). The first one contains data on security-by-security holdings of debt securities, listed equity and fund shares covering the largest 26 euro area banking groups by total assets[29] (i.e. holder-by-holder information). These 26 banking groups represent 59 percent of total euro area banking sector assets. The second one is an individual security reference database having detailed information at a monthly frequency on the issuer and the issuance characteristics for the above-mentioned financial instruments.

From the SHSG data we can identify all the holdings of debt securities and quoted shares reported by the 26 banking groups. The individual security holdings are reported at a non-consolidated level but intra-group holdings are flagged in the dataset. We use precisely this intra-group holdings flag to identify all the individual entities belonging to a group. Thus, we derive the group structure from this flag assuming a cross-holding of instruments between entities belonging to the same group. In case there are no cross-holdings of securities between two entities belonging to the same group or this relationship is not flagged in the dataset, we might not be able to identify all entities belonging to a banking group.

We use the International Security Identification Number (ISIN) to merge the SHSG data with the CSDB. In so doing we obtain information on the type of debt[30] and the seniority[31] which, in turn, permits us to accurately assess the exposure[32] of the groups to bail-inable instruments were an entity to default. Based on these datasets, four securities cross-holdings networks differentiated by the seniority of the security are built. The four network layers include equity, subordinated debt, senior unsecured debt and secured debt.

We complement the analysis with the use of quarterly balance sheet data from the ECB Supervisory statistics.[33] More specifically, we use the reporting of own funds and capital requirements

[29] The selection of the banking groups included in SHSG is subject to the Governing Council decision, which is taken at least once a year (the groups are then called reporting banking groups, or shortly RBGs). The SHS Regulation indicates the use of a quantitative threshold (0.5% of consolidated balance sheet of the EU banking Groups), combined with other quantitative and/or qualitative criteria (e.g. to keep certain groups in the sample even if they fell below the threshold over time), to identify banking groups of particular relevance for monetary policy, financial stability or other ESCB tasks. Banking Groups are (parent) credit institutions and all their financial subsidiaries or branches, other than insurance undertakings which have received official authorisation in accordance with Art. 6 of Directive 73/239/EEC or Art. 4 of Directive 2002/83/EC.

[30] This attribute provides a broad range of categories in which debt securities are classified in e.g. straight bond, medium term note, commercial paper, asset backed security, hybrid instrument etc.

[31] This attribute classifies debt instruments into senior/subordinated, secured/unsecured and guaranteed/unguaranteed.

[32] We do not have information in SHS with respect to which part of the bank's portfolio these instruments are allocated in (i.e. available-for-sale, trading or held-to-maturity). Thus, we consider the holdings of debt and equity recorded at book value as we are interested in assessing the nominal cross-holding exposure.

[33] These data are based on the Implementing technical standards (ITS) defined by the European Banking Authority which set out a uniform reporting framework for credit institutions domiciled in EU countries rendering the

(COREP) and the reporting of financial information (FINREP). The granularity of these data is crucial in order to compute the size of the equity and debt layers for all the banking groups in the network. Therefore, these data are central for evaluating the loss absorbing capacity of the different entities in case of defaults inside the network.

To evaluate the impact of a bail-in on national banking sectors in the euro area, we also use the ESCB Securities Holdings Statistics by Sectors (SHSS) and the ECB Consolidated Banking Database (CBD). We use SHSS data to estimate the amount of debt securities and listed shares issued by the 26 banking groups in our sample which are held by the different euro area countries and sectors. In order to identify all the individual securities which have been issued by a banking group, we include all the securities issued by the individual entities belonging to each of the 26 banking groups. In addition, we use the CBD which contains a broad set of banking indicators aggregated at the country level covering all EU countries. Thus, we obtain from the CBD the nominal amounts of CET1 capital and risk-weighted assets in the aggregated banking system of each euro area country. For all the descriptive statistics and the simulation results displayed below we use data for the first quarter of 2015.

From the data described above, we are able to construct four detailed seniority layers for the 26 banks: CET1 capital, subordinated debt, senior unsecured debt and secured debt. Table 1 shows the cross-holdings by layer in percent of total cross-holdings. Crossholdings of total unsecured debt make up half of all the securities cross-holdings, of which nearly all is senior debt. Secured debt makes up over a third of total cross-holdings and equity accounts for 14 percent of the total.

Table 1: Cross-holdings by layer out of total cross-holdings for Q1 2015

	Relative cross-holdings
CET1 capital	14.1 %
Subordinated unsecured debt	1.3 %
Senior unsecured debt	48.3 %
Secured debt	36.1 %
Total cross-holdings	100 %

Table 2 shows the average funding structure of the banks in the sample in percent of total funding.[34] Averaging across all 26 banks, deposits represent nearly 60 percent of total funding, whereas they represent only half of the average GSIB's balance sheet. Secured debt is the second largest category, representing a quarter of total funding for the average bank. For the average GSIBs in our sample, secured debt is a third of total funding whereas for the average non-GSIBs it is only a fifth. For the other balance sheet items, the differences among GSIBs and non-GSIBs are much less pronounced. On average, banks issue senior unsecured debt worth a tenth of their balance sheet and issue equity of around 4 percent of total funding.

information reported comparable across entities.

[34] Total funding is the sum of equity and debt and equivalent to total assets.

Table 2: Average funding structure of the banks in the sample in percent of total funding for Q1 2015

	All banks	GSIBs	non-GSIBS
Secured debt	24.33	32.85	19.05
Deposits	57.18	50.97	60.17
Senior unsecured debt	11.1	10.12	12.59
Subordinated unsecured debt	1.68	1.19	1.83
T2 capital	1.07	0.7	1.29
AT1 capital	0.22	0.3	0.23
CET1 capital	4.42	3.87	4.83

4 Multilayer network of securities cross-holdings

4.1 Structure of the multi-layer network of securities cross-holdings

We consider an economy populated by n banks constituting a financial network. Banks may issue debt securities or equity to other banks in the network. These nominal obligations have different levels of priority called seniority classes. Different liabilities are in the same priority class if - in case of default - repayment is rationed proportionally between them. Different capital instruments are in the same priority class if they are written down together in proportion to the losses, meaning their principal amount is reduced proportionally to the loss incurred. The seniority class is denoted by s, where seniority class 1 has the lowest priority. The structure of the interbank securities cross-holdings is represented by an $n \times n$ matrix L^s where L^s_{ij} represents the nominal obligation of bank i to bank j in seniority class s. Liabilities to creditors outside the network in a specific seniority class are denoted by D^s_i. Furthermore, banks may hold shares of other banks which are denoted by the matrix $S^1 \in [0,1]^{n \times n}$ where S^1_{ij} is the share of bank i held by bank j and the superscript 1 stands for seniority class 1. E^1 is a vector of nominal equity values, where E^1_i is the equity issued by bank i. The equity cross-holdings matrix is denoted by C^1 where $C^1_{ij} = S^1_{ij} \times E^1_i$ is the nominal amount of equity issued by bank i and held by bank j. The equity cross-holdings matrix C^1 as well as the interbank securities cross-holdings matrices L^s represent the different layers of the multi-layer network.

The liability side of bank i's balance sheet is divided into seven seniority classes (see Table 3). The capital layer is divided into three seniority classes, which are Common Equity Tier 1 (CET1) capital, Additional Tier 1 (AT1) capital and Tier 2 (T2) capital (in the order of increasing priority). The liabilities are divided into four seniority classes: subordinated unsecured liabilities, senior unsecured liabilities, deposits and secured liabilities (also in the order of increasing seniority).

The asset side of bank i's balance sheet is composed of equity cross-holdings, which are the nominal amounts of equity bank i holds of other banks in the system, interbank debt holdings, which are the debt securities bank i holds of other banks in the network, and other assets, which is a residual category.

Table 3: Balance sheet of bank i

Assets	Liabilities and capital
Other assets	**Secured debt issued**
(Total assets - (Interbank assets + Equity cross-holdings))	$(\sum_j L^7_{ij} + D^7_i)$
	Deposits (D^6_i)
	Senior unsecured debt issued
	$(\sum_j L^5_{ij} + D^5_i)$
Interbank debt holdings	**Subordinated unsecured debt issued**
$(\sum_i (L^7_{ij} + L^5_{ij} + L^4_{ij} + L^3_{ij} + L^2_{ij}))$	$(\sum_j L^4_{ij} + D^4_i)$
	T2 $(\sum_j L^3_{ij} + D^3_i)$
	AT1 $(\sum_j L^2_{ij} + D^2_i)$
Equity cross-holdings $(\sum_i C^1_{ij} = \sum_i S^1_{ij} \times E^1_j)$	**CET1** (E^1_i)

4.2 Topology of the network

We populate the above model with the data described in Section 3. Table 4 presents the following network measures: mean geodesic[35], average degree[36], density[37] and diameter.[38] The aggregate layer shows a highly dense network where each bank is at most two edges away, on average each bank is just 1.2 edges away. The breakdown by layers reveals more diversity, the secured and the senior unsecured debt layer are also very dense, with roughly two thirds of existing edges out of all possible edges. The equity and the subordinated layer only have a third of existing edges out of all possible edges and at least two nodes are not connected by a path, since the mean geodesic and diameter are infinity for both layers. Figure 2 shows the degree distribution for the different network layers.

4.3 Quantifying the potential for direct contagion

From the multi-layer network we can compute descriptive statistics on the size of the loss absorbing capacity of the issuer of bail-inable securities and the potential contagion channels to the holders of these securities. Overall, we find that the potential direct contagion channels are small due to the

[35]The distance between two nodes in a graph is the number of edges in a shortest path (also called a geodesic) connecting them. If there is no path connecting the two nodes, then conventionally the distance is defined as infinite and hence the mean geodesic of the network is also infinity.

[36]The degree of a node in a network is the number of links the node has to other nodes. The network built here is directed, meaning that links point in one direction from one node to another node. For, example bank 1 might hold a security of bank 2, but not vice versa. In that case, nodes have two different degrees, the in-degree, which is the number of incoming links, and the out-degree, which is the number of outgoing links. The average degree computed here is the average of the total degree, which is the sum of the in-degree and the out-degree.

[37]The density of the network is the number of existing edges over the number of possible edges.

[38]The diameter of a network is the longest of all the calculated shortest paths in a network. If there is no path connecting two nodes, then conventionally the distance is defined as infinite.

Figure 2: Degree distribution of each network layer

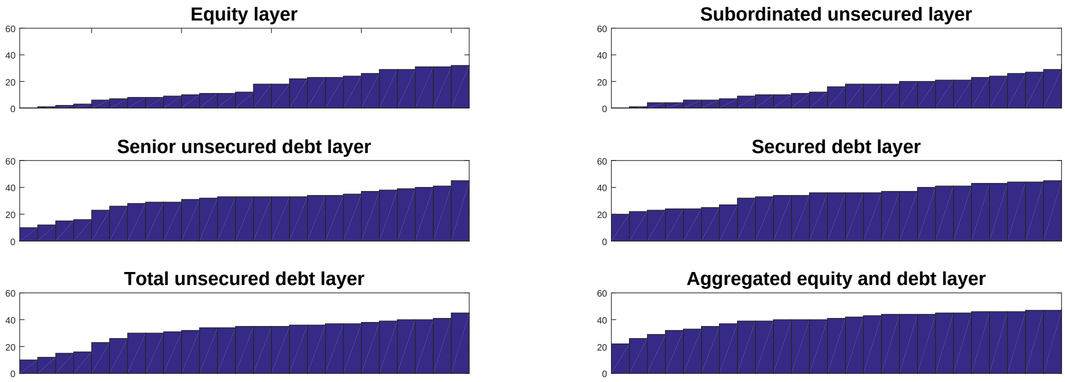


Table 4: Network measures for the individual layers for Q1 2015

	Mean Geodesic	Average Degree	Density	Diameter
Equity	Inf	16.38	0.33	Inf
Subordinated unsecured debt	Inf	15.15	0.3	Inf
Senior unsecured debt	1.4	30.92	0.62	3
Total unsecured debt	1.38	32	0.64	3
Secured debt	1.34	34.69	0.69	3
Total cross-holdings	1.2	40	0.8	2

low level of cross-holdings in the network. From there, we can conclude that most of the bail-inable debt and equity of these banks are held outside the network. The Securities Holdings Statistics by Sector can provide an indication of whom might hold these bail-inable securities. Over a third of the bail-inable debt and equity issued by the 26 banking groups and held by euro area residents is held by the banking sector. The household sector, the insurance sector as well as money market funds (MMF) and non-MMF investment funds all hold between 10 and 15% of that debt and equity issued.

4.3.1 Loss absorbing capacity of the issuer

Indices I^s_{1i} and I^s_{2i} show the relative potential for loss absorption of equity and bail-inable debt cross-held in the network for bank i. Thereby, they show the size of potential contagion channels should these debt layers be bailed in. Index I^s_{1i} measures the proportion of nominal liabilities issued by bank i in layer s to banks in the network out of the total liabilities issued by bank i in that seniority layer. For the equity layer, the index is computed the following way[39]:

$$I_{1i}^1 = \frac{\sum_j C_{ij}^1}{E_i^1}.$$

For the debt layers, the formula is:

$$I_{1i}^s = \frac{\sum_j L_{ij}^s}{\sum_j L_{ij}^s + D_i^s}.$$

This shows how much the holders within the network are hit versus the external holders. Index I_{2i}^s is the proportion of liabilities s issued by bank i to banks in the network out of the total assets (TA_i) of bank i. For the equity layer, the index is computed the following way:

$$I_{2i}^1 = \frac{\sum_j C_{ij}^1}{TA_i}.$$

For the debt layers, the formula is:

$$I_{2i}^s = \frac{\sum_j L_{ij}^s}{TA_i}.$$

This shows how much funding the bank gets from other banks within the network relative to total liabilities (represented by total assets here). These measures are computed for each bank in the network. Table 5 shows the minimum, the mean and the maximum for these two measures. Should the senior unsecured debt be written down, on average 5.6 percent will be borne by counterparties in the network and the rest by external counterparties.[40] On average, senior unsecured debt internal to the system represents 0.6 percent of a bank's total assets. Both measures suggest that the losses will be mostly borne by outside holders. As an upper bound on the internal loss bearing we have the maximum of index I_1, which shows that at most 18 percent of losses of one particular bank on the total unsecured debt would be borne by the network in case of the default of this bank. The equity issued by banks in the network and held by banks in the network on average makes up a small fraction of total equity issuance by banks in the network.

Index I_{3i}^s is the proportion of equity or debt issued by bank i in seniority layer s out of the risk-weighted assets of bank i: $I_{3i}^1 = \frac{E_i^1}{RWA_i}$ or $I_{3i}^s = \frac{\sum_j L_{ij}^s + D_i^s}{RWA_i}$, where RWA are risk-weighted assets. The loss absorbing capacity (LAC) is the sum of index I_{3i}^s across seniority layers. In one instance it excludes the deposit layer (second to last row in Table 6):

[39] For the notation, see Section 4.1.

[40] We analyze the effect of a bail-in not only on direct counterparties in the network, but also on national euro area banking sectors. See Sections 5.2.3 and 5.3.2 for results.

Table 5: Nominal amount of securities issued by banks within the network and held within the network out of the total layer (I_1) or total assets (I_2) of the issuing bank, broken down by layer (in percent)

	min(I_1)	mean(I_1)	max(I_1)	min(I_2)	mean(I_2)	max(I_2)
Senior unsecured debt	0.15	5.62	19.96	0.02	0.59	3.16
Subordinated unsecured debt	0	0.63	2.74	0	0.01	0.07
Equity	0	1.91	9.31	0	0.09	0.49

$$\frac{E_i^1 + \sum_{s=2}^{5} \sum_i L_{ij}^s + D_i^s}{RWA_i} = \sum_{s=1}^{5} I_{3i}^s \tag{1}$$

In the other instance it includes the deposit layer (last row in Table 6):

$$\frac{E_i^1 + \sum_{s=2}^{6} \sum_i L_{ij}^s + D_i^s}{RWA_i} = \sum_{s=1}^{6} I_{3i}^s \tag{2}$$

These measures show the loss absorbing capacity of the total bail-inable debt issued by bank i (held both within and outside the network) by seniority layer relative to risk-weighted assets. The minimum, mean and maximum values are reported in Table 6. Deposits represent on average 163 percent of risk-weighted assets and are in theory the largest item in the loss absorbing capacity.[41] The second largest is total unsecured debt, which represents 38 percent on average. Equity represents 12 percent of risk-weighted assets on average. Without deposits, the loss absorbing capacity is 54 percent of risk-weighted assets, whereas if deposits are included it quadruples to 217 percent of risk-weighted assets.

Table 6: Size of the total layers relative to risk-weighted assets (I_3) (in percent)

	min(I_3)	mean(I_3)	max(I_3)
Deposits	89.21	163.06	248.03
Total unsecured debt	7.67	38.65	96.77
Senior unsecured debt	2.68	33.97	91
Subordinated unsecured debt	1.16	4.67	9
T2	0	2.9	5.64
AT1	0	0.68	2.83
Equity	8.14	12.6	20.44
LAC (without deposit layer)	21.89	54.83	118.09
LAC (with deposit layer)	152.15	217.89	318.89

[41] Deposits covered by the deposit guarantee scheme (DGS) are excluded from the scope of the bail-in tool. The DGS, however, contributes to funding the resolution process by absorbing losses to the extent of the net losses that it would have had to suffer after compensating depositors in normal insolvency proceedings.

4.3.2 Loss exposure of the holder

The following two indices measure the potential relative losses of holding bank j should the debt or the equity of all issuing banks i (other than j) be written down or bailed in in that seniority layer. They are thus the upper bound on the holder's loss exposure to the network. Index I^s_{4j} is the proportion of debt securities issued from banks within the network and held by bank j out of j's total assets by seniority class s: $I^s_{4j} = \frac{\sum_i L^s_{ij}}{TA_j}$. Index I_{5j} is the proportion of debt securities issued from banks within the network and held by bank j out of j's equity values by seniority class s: $I^s_{5j} = \frac{\sum_i L^s_{ij}}{E^1_j}$. Both indices are calculated for each holding bank j. For both measures, Table 7 lists the minimum, mean and maximum values.

Table 7: Total cross-holdings out of holding bank's total assets (I_4) or equity (I_5), broken down by layer (in percent)

	min(I_4)	**mean(I_4)**	**max(I_4)**	**min(I_5)**	**mean(I_5)**	**max(I_5)**
Total unsecured debt	0.01	0.67	3.92	0.15	16.92	105.44
Senior unsecured debt	0	0.65	3.92	0.03	16.68	105.44
Subordinated unsecured debt	0	0.01	0.07	0	0.23	1.6
Equity held	0	0.07	0.29	0	1.9	8.98

The final two indices represent the potential loss a holder j faces if an issuer i's equity or debt is written down relative to j's equity values or total assets, and thus represent the potential loss coming from a failing or failed single counterparty in the network. Index I^s_{6j} is the amount of equity or debt held by bank j of bank i out of j's total assets. In the case of equity cross-holdings, the index is computed as: $I^s_6 = C^1 * q^{-1}$, where q is a diagonal matrix such that $q \times x = TA$ and x is a unit vector of length n. In the case of debt cross-holdings the measure is computed analogously: $I^s_{6j} = L^s * q^{-1}$. Index I^s_{7j} is the amount of equity or debt held by bank j of bank i out of j's equity values. In the case of equity cross-holdings, the index is computed as: $I^s_7 = C^1 * p^{-1}$ where p is a diagonal matrix such that $p \times x = E^1$ and x is a unit vector of length n. In the case of debt cross-holdings the measure is computed analogously: $I^s_7 = L^s * p^{-1}$. See Table 8 for results.

Table 8: Securities issued by individual banks in the network and held by banks in the network out of holding bank's total assets (I_6) or equity (I_7), broken down by layer (in percent)

	min(I_6)	**mean(I_6)**	**max(I_6)**	**min(I_7)**	**mean(I_7)**	**max(I_7)**
Senior unsecured debt	0	0.02	1.15	0	0.64	32.1
Subordinated unsecured debt	0	0	0.03	0	0.01	0.85
Equity held	0	0.0029458	0.28	0	0.07	5.03

The maximum of index I_5 for total unsecured debt is slightly above one hundred percent, which means that there is at least one bank that would lose more than its CET1 capital should all of its counterparties in the network default on all their unsecured debt. This is a very extreme scenario for several reasons. First, because it would require the default on their total unsecured debt of all counterparties in the network. Second, because the mean of index I_5 for total unsecured debt is 17 percent, which means that on average such an extreme scenario would wipe out less than one fifth of the bank's equity. In the case where just a single counterparty defaults on all its unsecured debt, as measured by index I_7, the highest loss would amount to one third of the holder's equity. But this also seems to be an exceptional case, since the average of index I_7 is at 0.6 percent of the holder's equity.

5 Simulation of bail-in in the multi-layer network

Before presenting the simulation exercise, it should be highlighted that the presented simulation results are likely to underestimate the contagion risk for several reasons. First, the simulation exercise is isolated to the direct network effects; that is, any confidence driven contagion effects, such as fire sales of assets, that are likely to occur in the context of a bail-in of any of the 26 banks in the sample are not captured. Second, the analysis only considers one bank bail-in at a time; more pronounced direct contagion effects could be envisaged in cases where two or more banking groups are bailed in simultaneously. Third, due to data limitations regarding the exact structure of the 26 banking groups (see Section 3 on how we construct the banking groups from the data), we might not be able to identify all subsidiaries and hence might miss some cross-holdings, thereby again underestimating the potential direct contagion in the network.

Finally, the way we update the equity ratios is likely to underestimate their true decrease following asset losses at a bank. We update the equity ratios the following way. From the supervisory data, we have the initial risk-weighted assets as well as the total unweighted assets for each of the 26 banking groups. So we can compute the ratio of weighted to unweighted assets. We assume this ratio to be constant for each bank, since we do not have the risk weights for the individual asset catgeories and therefore cannot update the equity ratio in a more precise fashion. So each time a bank loses assets in the simulation, we calculate the new risk-weighted assets by multiplying the new unweighted assets by that constant ratio. Thereby, we lose the impact of the change in the asset composition on the equity ratio of the counterparties of the bank under resolution. Since, in the context of a bail-in, creditors may have their debt holdings converted to equity, which is more risky and thus carries a higher risk weight, this will have a further negative impact on equity ratios at counterparties. Since we cannot capture this additional negative impact, we may underestimate the impact of a bail-in on counterparties in the network.

As the underlying data are of a confidential nature, individual bank results are not shown. Charts show aggregated results for groups of at least three banks. To generate the charts, bank-level results were sorted in ascending order and then banks were grouped in groups of at least three, which leaves us with eight bank clusters for which we display average results. For the boxplot charts we sorted the scenarios by the median outcome and then grouped banks in groups of at least three. The sorting implies that clusters do not necessarily represent the same banks across charts.

5.1 Description of the baseline scenario

We simulate the effect of a bail-in within the multi-layer network of large euro area banking groups.[42] The simulations are performed 26 times, each time one of the 26 banks is hit by an idiosyncratic shock and then recapitalized.

First step: Idiosyncratic shock at bank i. Bank i is hit by an idiosyncratic shock with a size of 5 percent of total assets.[43] This loss is deducted from bank i's external assets.[44]

Second step: Write-down to absorb losses. In order to absorb the loss, equity and debt will be written down in accordance with the creditor hierarchy. Figure 3 illustrates the order of bail-in as well as the links from the liabilities of an individual bank to its creditors in the network. First, the total amount of funds necessary to absorb the cumulated losses is assessed. Then, we calculate up to which seniority layer the bank's liability side needs to be written down to absorb losses. It is likely that the last affected layer will only be used partially to absorb losses since it is unlikely that the loss will exactly match the amount of one or several layers. The layer(s) below the last affected layer are completely written down, whereas the last affected layer is partially written down.

The algorithm operates in such a way that a complete write-down for the equity layer (CET1) means that the equity value of bank i is set to zero. A complete write-down for the debt layers implies that the obligations of bank i to its creditors are set to zero. In a partial write-down, equity and debt will be written down in proportion to the losses. If the partial write-down occurs in the equity layer, the loss will be deducted from the principal amount of bank i's equity. If the partial write-down occurs in a debt layer, then bank i's obligations will be reduced in proportion to the losses affecting that layer. The principle of proportionality applies, such that each creditor loses the same percentage of his outstanding loans in that priority class. If, after the write-down, the bank's equity ratio[45] is below 7 percent, it will be put into resolution.

Third step: Recapitalization. After the loss absorption the bank will be recapitalized at 10.5 percent CET1 capital.[46]. First the claims of shareholders (if there is remaining equity) and then

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[42] For a stylized example of a bail-in, see Figure 1.

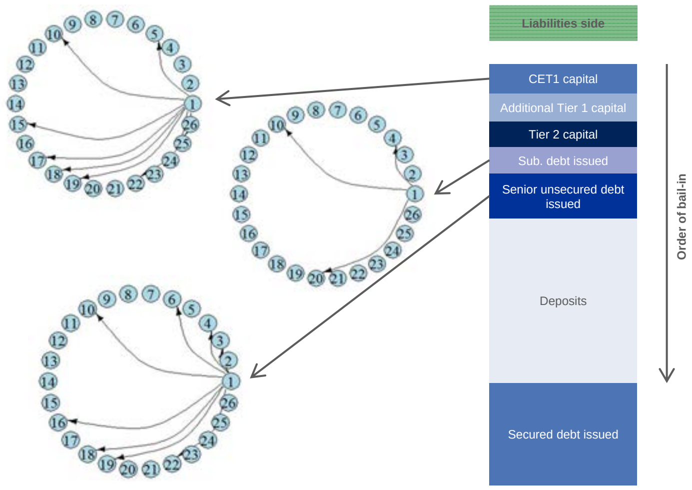
[43] The shock size for the baseline scenario is based on the maximum value of peak accumulated losses for G-SIBs from the recent crisis, as documented by a report of the Financial Stability Board (2015). The highest percentage of losses out of total assets is 4.7 percent (see Table 1 in the report), which we round to 5 percent. To put this shock size into perspective, when Bear Sterns and Lehman Brothers are included in the sample, the maximum value of peak accumulated losses rises to 9.7%.

[44] See Table 3 for the banks' balance sheet structure.

[45] The equity ratio is computed as the ratio of CET1 capital over risk-weighted assets.

[46] The 10.5 percent are based on the average of the CET 1 requirements of Significant Institutions published in the Supervisory Review and Evaluation Process (SREP) which is around 10 percent, see the Single Supervisory Mechanisms' SREP methodology under `https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm_srep_`

Figure 3: Potential contagion channels from the liability side of a bank to its creditors in different network layers



Note: Block sizes are not to scale.

creditors' claims are converted into CET1 capital in order to reach the required level of capital. We compute how much each shareholder and creditor (both inside and outside the network) contribute towards the bail-in. If no shareholders are left, then creditors get a share of the institution in proportion to the amount they contributed to the recapitalization. If there are still shareholders left, their shares get diluted as the creditors whose loans were converted into equity also get a share of bank i.

Fourth step: Direct contagion. Both the write-down and the recapitalization imply asset losses for shareholders and creditors of bank i. If one or several other banks in the network violate the equity ratio after the bail-in of bank i, we compute their asset loss and write down their liability side accordingly. This might trigger asset losses at other counterparties. The cascade stops if there are no new banks violating the equity ratio in a round.

5.2 Baseline scenario: Results

All 26 banks violate the 7 percent CET1 threshold after a five percent shock and require a recapitalization. Direct contagion effects within the 26-bank network are overall contained. This mainly

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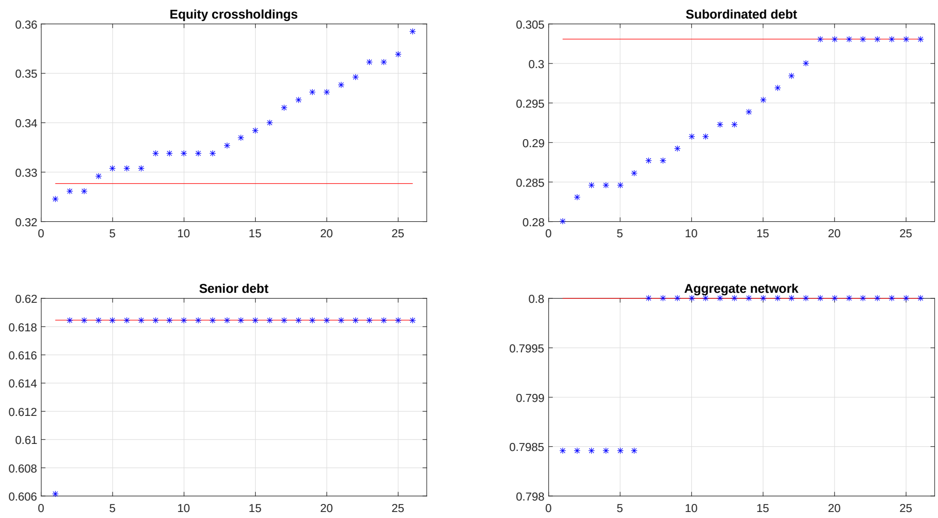
`methodology_booklet.en.pdf` We add 50 basis points since banks typically like to operate with a margin above their prudential requirements.

Figure 4: Distribution of the density of network layers before shock (red line) and after bail-in (blue) for the 26 simulations



reflects our previous results that the securities issued by the other 25 banks currently held by these banks only amount to a small fraction of the total bail-inable securities (see Section 4.3).

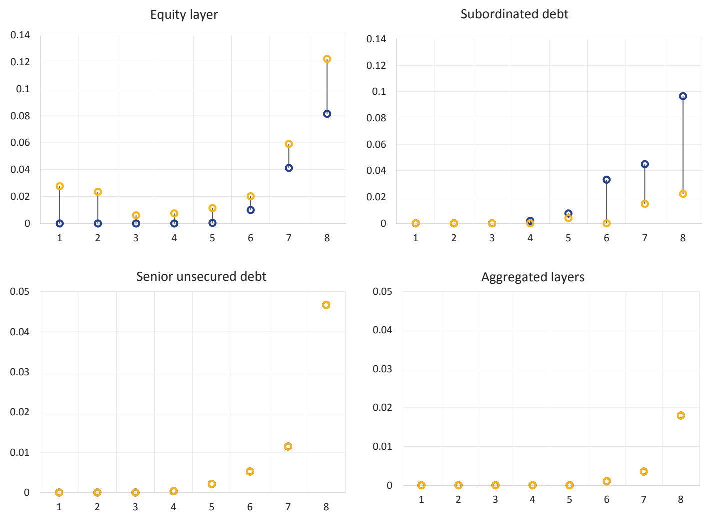
5.2.1 Results on interconnectedness

Figure 4 shows that in 90% of the simulations the equity cross-holdings layer becomes more dense after the bail-in, with increases in density up to 9%. This is intuitive, since in a bail-in the unsecured debt is converted into CET1 capital and then shares are distributed in proportion to the contribution of each creditor, who then becomes a shareholder. Therefore, the number of shareholders typically increases, since creditors become shareholders. The increase in density does not necessarily mean that any form of contagion risk increases, but it is important to note that the topology of the interbank network is affected by the bail-in. In contrast, the subordinated debt layer becomes less dense in most cases, since subordinated debt is converted to equity and therefore links in that network layer may disappear. The density of the senior debt layer decreases only in one case, which does not mean that the layer is not affected by a bail-in. Since the density is unweighted, it does not give information on whether the size of the links diminished. The density of the aggregate network is barely affected by a bail-in, in some cases it decreases very slightly.

Figure 5 displays the change in the betweenness centrality[47] of the bank under resolution. The

[47] Betweenness centrality is an indicator of a node's centrality in a network. It is equal to the number of shortest

Figure 5: Betweenness centrality before shock (blue) and after bail-in (yellow) in different network layers



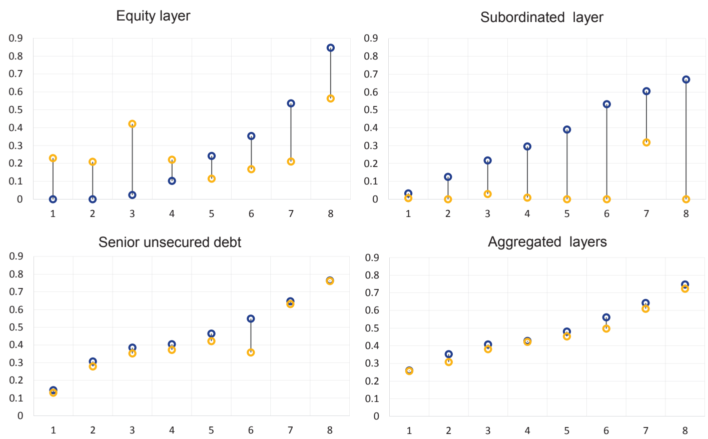
x-axis represents 8 bank clusters, which are averages of the results for at least 3 banks. Betweenness centrality increases in the equity cross-holdings layer because more links are created through the debt to equity conversion, whereas the opposite happens in the subordinated debt layer. There is no impact on the senior debt layer or on the aggregate network. If we rank banks in ascending order according to their betweenness centrality in each network layer, then, for the equity layer, the bank under resolution moves up 4.7 ranks after having been bailed in (averaging across the 26 simulations). In the subordinated layer, the bank under resolution moves down 4.8 ranks on average. The relative centrality is therefore substantially affected by the resolution procedure.

Figure 6 shows that, in the equity layer, the bank under resolution has a higher weighted clustering coefficient[48] in roughly half the cases and a smaller one in the other half. One explanation may be that the recapitalization is done in relative terms, so if a bank has less risk-weighted assets after a shock, then it needs less capital in absolute terms than before the shock. Therefore the weights used to compute the clustering coefficient decrease. For the subordinated debt the picture is very clear again, the clustering decreases significantly after a bail-in.

paths from all vertices to all others that pass through that node. A bank with high betweenness centrality has a large influence on the transfer of funds through the network, under the assumption that intermediation follows the shortest paths.

[48] We compute the weighted clustering coefficient as defined in Barrat et al. (2004).

Figure 6: Weighted clustering coefficient before shock (blue) and after bail-in (yellow) in different network layers



The results presented in Figures 4 to 6 show the additional insights gathered from a multi-layer network model rather than just analyzing the aggregate network. The topological changes in the different layers can hardly be noticed from the aggregate network. Individual layers also represent different markets (here debt and equity markets), which is an additional reason why studying individual layers may be relevant.

5.2.2 Results on prudential measures for banks in the networks

Figure 7 illustrates the impact of a bail-in at bank i on the equity ratios at its counterparties. Since a bail-in entails a write-down of liabilities at the bank under resolution, this might lead to asset losses at its counterparties, whose equity then needs to be written down. One way to measure systemic effects of a bail-in is therefore to check how the creditors' equity ratios are affected. While under this scenario the direct effects of the bail-in on the other banks' CET1 capital are overall very limited, in a few cases we observe contained but still non-negligible effects.

In order to assess whether the network is resilient to direct contagion following a bail-in, the CET1 ratios of the other banks need to exceed a pre-defined threshold. If one or more banks in the system violate this threshold, they will be bailed in which will trigger losses at banks holding bail-inable securities of these banks. In the example considered here, a CET1 ratio threshold of

7 percent is employed. Figure 8 thus illustrates the distance to the CET1 ratio of 7 percent after their securities issued by the bank being resolved have been bailed in.[49] It is observed that in no cases the threshold is violated.

Figure 7: Decrease of equity ratios at counterparties in the baseline scenario

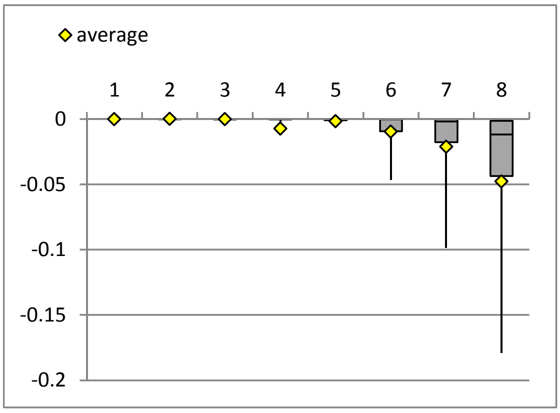
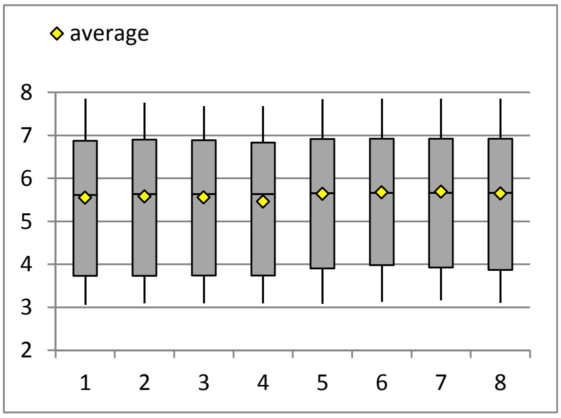


Figure 8: Distance to 7 percent CET1 at counterparties in the baseline scenario



Note: Boxplots display 10th and 90th percentiles, interquartile distribution and median.

5.2.3 Results on prudential measures for euro area banking sectors

The fact that contagion effects within the 26-bank network are overall contained mainly reflects that the securities issued by the other 25 banks currently held by these banks only amount to a small fraction of the total bail-inable securities. However, if one of the 26 banking groups within our sample were to be bailed in, it would most likely entail losses in other, smaller creditor institutions outside our network of 26 banks. While we do not have institution-specific holding information outside the 26-bank network, the ECB Securities Holdings Statistics by Sectors (SHSS) does contain sector level information about the size of the total banking sector holdings of securities issued by the 26 banks, by euro area country. Using this information one can provide an approximate view of the contagion risk to the wider banking system if one of the 26 institutions were to be bailed in. Figure 9 thus shows the banking sectors' total CET1 capital losses. For most cases, the losses are marginal in percentage terms, but can reach up to 1.3 percent of sector-level CET1 capital - averaged across at least three banks - in rare cases. Figure 10 plots decreases in CET1 ratios in euro area banking sectors using initial risk-weighted assets as denominator. Decreases in CET1 ratios are small overall.

[49] See Table 6 for the minimum, maximum and average initial CET1 ratios for the 26 banks in our sample.

Figure 9: Relative equity loss in euro area banking sectors after the bail-in of bank i in the baseline scenario

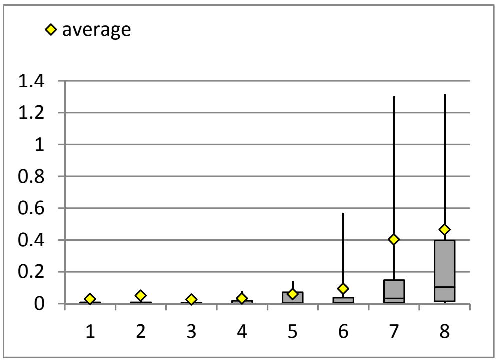
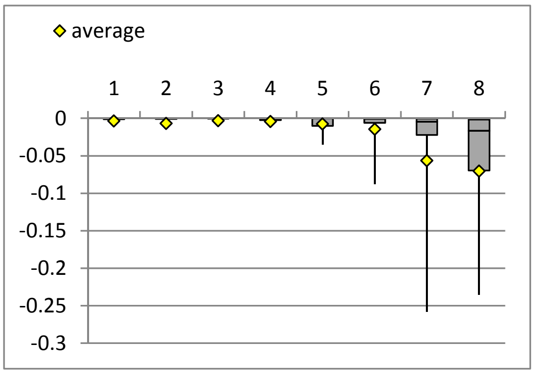


Figure 10: Decrease in CET1 ratios in euro area banking sectors after the bail-in of bank i in the baseline scenario



Note: Boxplots display 10th and 90th percentiles, interquartile distribution and median. RWAs (denominator of the equity ratio) are kept constant.

5.2.4 Results relevant for resolution

Table 9 shows the most senior layer of the balance sheet affected by the write-down of 5 percent of total assets and then the subsequent recapitalization to 10.5 percent CET1 capital. In most cases the senior unsecured layer is affected by the bail-in and in one case deposits. The percentage loss of the most senior layer affected is illustrated in Figure 11. The relative losses in the senior unsecured layer are between 0 and 40 percent, with one outlier where all of senior debt needs to be bailed in - this is the case where the deposit layer would be affected. It is important to highlight how to interpret these numbers. When creditors lose for example 40 percent of the senior unsecured debt owed to them by the bank that is bailed in, this only means that they lose 40 percent of their investment in the senior unsecured bonds of the bank that is bailed in. This does not necessarily mean that they lose the whole amount in monetary terms. Indeed, some or all of that debt may be converted into equity in order to recapitalize the bank. Therefore counterparties may incur losses in the debt instruments, but these losses do not necessarily materialize one-to-one summing across all the counterparties' assets together after the bail-in.

As discussed in Section 2, under exceptional circumstances, the Single Resolution Fund (SRF) may contribute to the recapitalization of the failing bank subject to a number of strict conditions including the requirement that losses totalling not less than 8 percent of total liabilities including own funds have already been absorbed by creditors of the failing bank through the use of the bail-in tool. Figure 12 shows the total contribution of banks' creditors to the bail-in in terms of total

Table 9: Most senior layer affected by write-down and by recapitalization, number of cases out of the 26 baseline simulations

	CET1	Tier 2	Sub. debt	Senior unsecured debt	Deposits
Write-down	7	12	4	3	0
Recapitalization	0	0	6	19	1

initial liabilities. In roughly 60 percent of the simulations the 8 percent requirement would have been fulfilled. We also run a counterfactual analysis, where we check up to which seniority layer the banks in our sample would need to bail in their liabilities to get access to the resolution fund. In most cases, to fulfill the 8 percent requirement, banks in the sample would need to bail in at least a fraction of senior unsecured creditors (see Figure 13).

Figure 11: Percentage loss in the most senior layer affected after a recapitalization to 10.5 percent CET1 capital

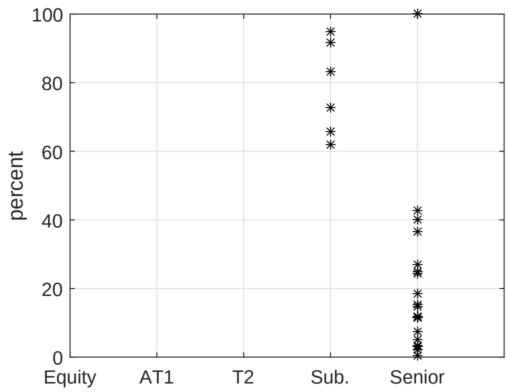
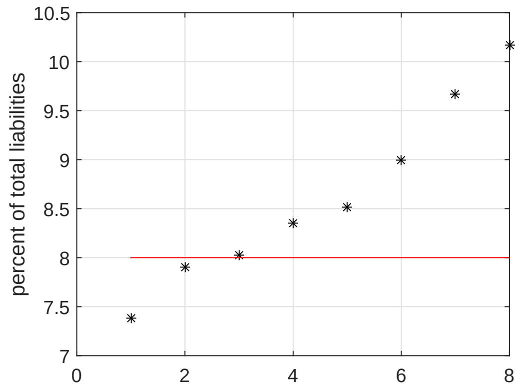


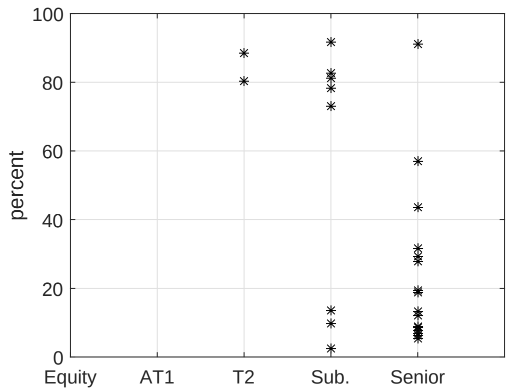
Figure 12: Write-down plus recapitalization in percent of total initial liabilities, red line marks 8 percent threshold for access to resolution fund



5.3 Adverse scenario

Under the adverse scenario, first all banks in the network are subject to a shock at the same time, where each bank is hit by a shock of a different magnitude but generated from the same distribution. The size of the shock is drawn from a normal distribution that is truncated from minus infinity to zero, such that we get only non-positive shocks. Before truncation, the distribution has a mean of 0.24 and a standard deviation of 0.09. This was calibrated deliberately such that with the truncated distribution we are able to match the mean (-2.8 basis points) and the standard deviation (3.3 basis points) of the CET1 capital loss of SSM banks in the adverse scenario in the October

Figure 13: Percentage to be written down in the most senior layer to reach 8 percent of total liabilities



2014 Comprehensive Assessment. Then the weakened system is subjected to the baseline scenario, where one bank at a time is hit by a five percent shock and is bailed in. The procedure is repeated a 1000 times, which means that we simulate the adverse scenario a 1000 times for each of the 26 banks.

5.3.1 Results for the banks in the network

Table 10 displays the results. On average, 18 percent of the banks do not meet the prudential requirement of 7 percent CET1 after the common shock. After the idiosyncratic shock and the subsequent write-down of losses, on average 3.3 percent of the banks fail in addition to those already failing after the common shock. Of these, 98 percent fail because they were hit by the idiosyncratic shock directly. Only 2 percent of banks fail due to direct contagion after the write-down and on average only by a small margin, since the average equity ratio of these banks is 6.9 percent for a failure threshold of 7 percent. Averaging across the thousand simulations for each of the 26 bail-in scenarios we find that in 1.4 out of 26 scenarios deposits will be hit, compared to 1 out of 26 scenarios in the baseline specification.

Table 10: Average equity ratios and percentages of default

	min	**mean**	**max**	**percentage of defaults**
After common shock	0	4.53	6.99	18.31
Additional defaults after idiosyncratic shock	0	0.34	6.99	3.2
Additional defaults due to direct contagion	6.49	6.92	6.99	0.06

Figure 14 illustrates the impact of a bail-in at one bank on the equity ratios at its counterparties. Bearing in mind that the mean of the common shock distribution is -2.8 percent and that we plot average results for a thousand simulations, we see again that the impact of the bail-in on equity ratios at its counterparties is small, since the decrease barely goes beyond the average impact of the common shock. The distance to the 7 percent CET1 threshold decreases on average by three percent compared to the baseline scenario (see Figure 15).

Figure 14: Average percentage point decrease of equity ratios at counterparties in the adverse scenario

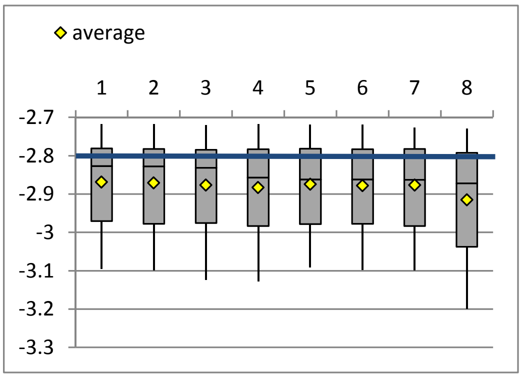
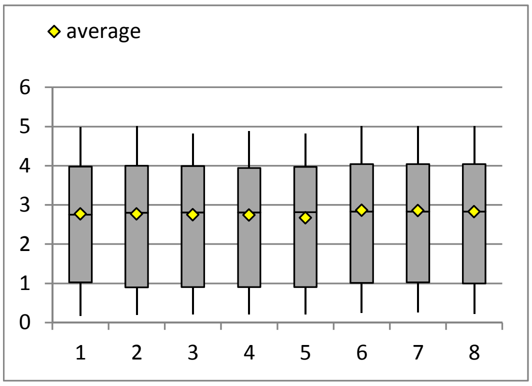


Figure 15: Distance to 7 percent CET1 at counterparties in the adverse scenario

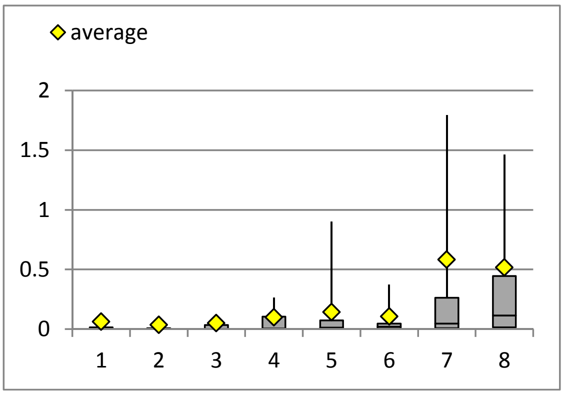


Note: Boxplots display 10th and 90th percentiles, interquartile distribution and median. Blue line represents the average impact of the common shock.

5.3.2 Results on prudential measures for euro area banking sectors

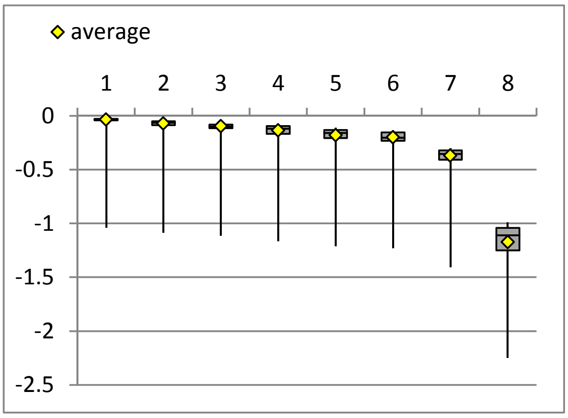
We also provide an approximate view of the direct contagion risk to the wider banking system if one of the 26 significant institutions were to be bailed in. Figure 16 illustrates the impact of a bail-in at one bank on its creditors in euro area banking sectors as a whole in terms of relative equity loss. While in most cases, the immediate impact on banking systems' solvency is rather muted, for a few resolved banks the aggregate CET1 reduction could amount up to 1.8 percentage points in the worst cases. Figure 17 displays the decrease in equity ratios in euro area banking sectors in the 5th percentile after the thousand simulations of the bail-in of bank i. In other words, these are the worst outcomes. We can see that in rare tail events a national banking sector's CET1 ratio can decrease by up to 2.3 percentage points after a bail-in, bearing in mind that these are averages across the results for at least 3 bail-in scenarios.

Figure 16: Relative equity loss in euro area banking sectors after the bail-in of bank i in the adverse scenario



Note: Boxplot displays 10th and 90th percentiles, interquartile distribution and median.

Figure 17: Decrease in equity ratios in national banking sectors in the 5th percentile after the bail-in of bank i in the adverse scenario



Note: Boxplot displays minimum, maximum, interquartile distribution and median. RWAs (denominator of the equity ratio) are kept constant.

Table 11: Average equity ratios before and after the recapitalization at the level of the peer group

Initial average equity ratios			After the recapitalization		
All banks	Non-G-SIBs	G-SIBSs	All banks	Non-G-SIBs	G-SIBs
12.6	12.9	11.9	12.4	12.7	11.9

5.4 Recapitalization at the level of the peer group

In the baseline scenario, bank i is recapitalized to 10.5 percent CET1 capital. In the following simulation, we modify the baseline scenario such that bank i is recapitalized at the same level as the average of its peer group. We divide our sample of 26 banks into two subgroups. The first subgroup consists of banks that belong to the global systemically important banks (GSIBs) as defined by the Basel Committee, eight out of the 26 banks belong to this group. Their average equity ratio is 11.9 percent. The second subgroup are simply the 18 remaining banks and their average equity ratio is 12.9 percent. The initial average equity ratio (before the shock) across all banks is 12.6 percent. The average equity ratio of the bank under resolution after the recapitalization at the peer group level is 12.4 percent and is thus very close to the average initial equity ratio, compared to the average equity ratio of 10.4 percent in the baseline scenario.

As in the baseline scenario, one bank does not have enough eligible liabilities for bail-in and therefore its equity ratio is the same under both types of recapitalization. In the recapitalization at the level of the peer group, the senior layer is always affected by the recapitalization, compared to the baseline senario where subordinated debt is sometimes the highest layer to take the hit. This is due to the fact that the recapitalization to the level of the peer group requires a higher bail-in than in the baseline scenario, since the average equity ratio for both peer groups is higher than 10.5 percent CET1 capital.

5.5 Different sizes of the idiosyncratic shock

In the baseline scenario, bank i was hit by a shock of 5 percent of total assets. In the following simulation, we will use the baseline scenario, but vary the shock size from 1 to 12 percent of total assets in increments of 1 percentage point. To put these shock sizes into perspective, Conlon and Cotter (2014) found that European banks that were fully nationalized by the state during the recent financial crisis had to write down losses of 7.1 % out of total assets on average. European banks that were recapitalized had to write down losses of 4% out of total assets on average. Figure 18 shows the average of the highest layer hit by the write-down and the recapitalization. Starting with a shock size of 7 percent, the average of the highest layer affected goes beyond the senior unsecured layer. Figure 19 displays the number of banks - out of the 26 banks in sample - that would need to bail in at least a fraction of deposits to be recapitalized at 10.5 percent CET1. For shocks up to 4 percent there are enough eligible liabilities. Starting with a shock size of 5 percent, for an increasing number of banks the bail-in would hit the deposit layer.

Figure 18: Average of the highest layers hit by write-down (red) and recapitalization (blue), by shock size

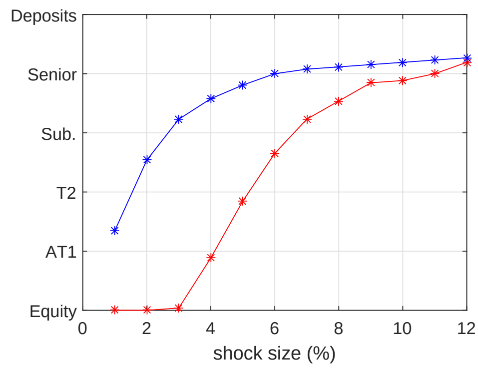
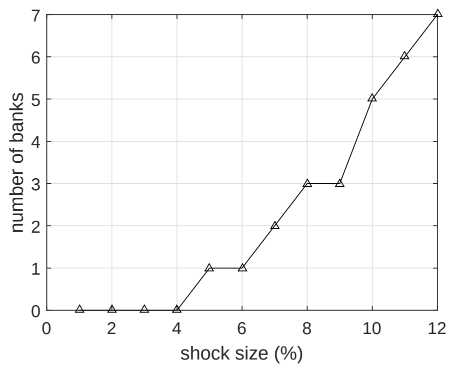
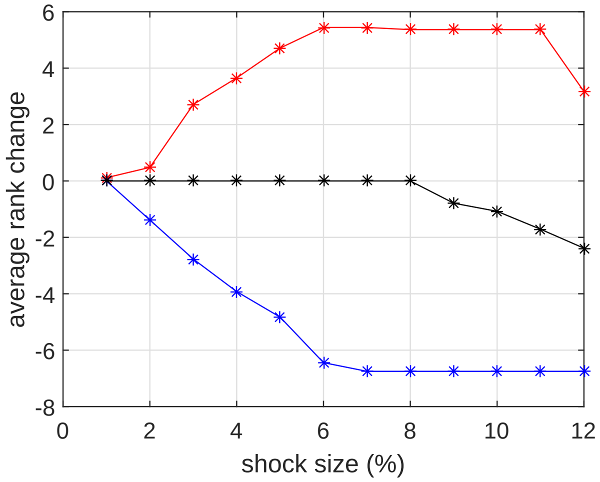


Figure 19: Number of banks where the bail-in would exceed all the liabilities up to and including senior unsecured debt, by shock size



Simulating the baseline scenario for different shock sizes also allows to illustrate the change in network topology conditional on the shock size. Figure 20 shows the average change in betweenness centrality ranking for the bank under resolution by shock size. Leaving aside that the levels differ slightly, the average change in the centrality ranking of the bailed-in bank in the equity layer is

Figure 20: Average change in betweenness centrality ranking for the bank under resolution in the equity (red), subordinated (blue) and senior unsecured (black) layers by shock size



the mirror image of the rank change in the subordinated layer. For a shock size of 12 percent, the average rank change in the equity layer decreases. This is due to the fact that for a shock size of 12 percent, some banks already lose their total bail-inable debt in the write-down, so there is no debt left to convert to equity. These banks have a betweenness centrality of 0 in the equity, subordinated and senior layers after the resolution, since they have no more links in these layers. Figure 18 showed that the senior layer is increasingly affected when the shock size is increased. Figure 20 provides an additional perspective on this. Since the betweenness centrality we compute in unweighted, when the centrality ranking of a bank decreases, this means that links are actually severed and not just depleted. Starting with a shock size of 9 percent, the bank under resolution also loses links in the senior layer.[50]

6 Discussion

6.1 Policy implications

Four main policy implications are evident from the simulations and analysis performed.

First, for most of the shock sizes considered, the direct contagion effect on banks within the network considered is subdued due to the low cross-holdings of bank bail-inable debt within the

[50] Asset losses of that magnitude occured during the recent financial crisis, see Table A1 in Financial Stability Board (2015).

network. This shows the effectiveness of low interbank cross-holdings of bail-inable debt and the advantage of dis-incentivizing interbank G-SIB TLAC holdings as envisaged by the Financial Stability Board (FSB) and the Basel Committee on Banking Supervision (BCBS).[51]

Second, for the scenarios considered, the largest impact is mostly outside of the banks considered in our network. As our network consists of the 26 largest euro area banking groups, the implication is that mostly smaller euro area banks and other holders of bail-inable bank securities are affected by a bail-in of one of the 26 largest euro area banking groups. In such cases a bail-in might have systemic implications. Noteworthy in this context is that the FSB and the BCBS[52] are also considering to dis-incentivize the holdings of smaller internationally active banks to G-SIB TLAC holdings. Applying this policy to the euro area banking sector as a whole could help in mitigating contagion following the bail-in of a bank to national banking sectors. This policy option could thus be welcomed to ensure that losses are spread evenly across banking and non-banking sectors and the burden of a bail-in is not concentrated in one banking system or particular bank. Furthermore, depending on the case at hand, institution-specific measures to further limit holdings of bail-inable debt between two banks may be warranted.

Third, the results presented in Section 5.2.1 on the change in network measures after a bail-in have shown that banks exiting the resolution become more central and the equity cross-holdings across the largest 26 euro area banking groups have become more dense after a bail-in. Regulators will thus need to carefully assess if the bank under resolution has become more systemic after the bail-in and whether the banking sector has become more prone to contagion because it has become more dense after the resolution. These issues can be - again - mitigated by low interbank cross-holdings of bail-inable debt, since in a debt-to-equity conversion creditors acquire shares in proportion to the amount they contributed to the recapitalization. If the cross-holdings of bail-inable debt are low, then the equity cross-holdings resulting from the conversion will also be low.

Fourth, the analysis shows that in a significant amount of cases the bail-in following a shock of more than 5 percent of total assets hits the senior unsecured debt layer (and in certain configurations even the deposit layer). In one case, a counterparty fails after the write-down at the bank under resolution, as a result of the increased exposure of that counterparty via the interbank market channel. This shows that resolution authorities will need to carefully consider the level and composition of TLAC/MREL - to avoid direct contagion and that certain creditors such as deposits or perhaps even senior unsecured debt are hit. In some cases, requirements to issue additional subordinated debt to increase loss absorbing capacity and decrease the probability that senior unsecured debt or even deposits are bailed in may be called for.

[51] See BCBS Consultative Document - TLAC Holdings - November 2015, access under: http://www.bis.org/bcbs/publ/d342.pdf

[52] Ibid.

6.2 Further research

The analysis performed in this paper only assesses direct contagion risks and excludes indirect forms of contagion such as pecuniary externalities or risk-shifting behaviour of banks. In the following we will outline how these additional channels might play out if added in the present framework. A second limitation to our framework is that it is a sectoral model and therefore it does not include general equilibrium effects. To conclude the paper, we will therefore briefly discuss potential effects on other sectors, volumes and prices.

Pecuniary externalities may be added to the present framework in the form of bankruptcy costs. Bankruptcy costs increase the direct costs of default via legal fees or administrative costs. They also include indirect costs such as delays in payments to creditors and disruptions to the provision of financial intermediation services necessary to the real economy. One option is to attach a fixed cost to bankruptcy, like for example Elliott et al. (2014). They find that the accumulation of failure costs can exceed the drop in asset value that precipitated the cascade and thereby amplify the propagation of shocks. A second possibility is to include default costs through a multiplier on losses when a node defaults, like Glasserman and Young (2015a). This approach allows estimating how much the probability of contagion, and the expected losses induced by contagion, increase as a function of bankruptcy costs. They find that bankruptcy costs must be rather large in order to have a significant impact on the propagation of expected losses.

In our simulation, we do not add bankruptcy costs, since we are interested in estimating a lower bound on spill-over effects. In our framework, the inclusion of default costs would affect how far in the creditor hierarchy the bail-in would go, since higher asset losses would imply a higher bail-in. Since the contagion channels are small, the addition of default costs would probably not lead to larger impacts on counterparties within the network.

Besides bankruptcy costs, fire sales are another common way in the financial networks literature to include pecuniary externalities. Fire sales depress asset prices and via marking-to-market lead all financial institutions exposed to the fire sold assets to incur (additional) losses (see for example Cifuentes et al. (2005) and Greenwood et al. (2015) for such a fire sales mechanism in an interbank network). In our simulation, we do not add fire sales, since we are interested in estimating a lower bound on spill-over effects. In our framework, the inclusion of fire sales would need to be coupled with the addition of common exposures to assets and marking-to-market. This might generate stronger spill-overs than in the current framework, because the lower asset price would lead to additional losses at counterparty banks.

Besides pecuniary externalities, risk-shifting behaviour and confidence crises are important shock transmission channels. Trust is an important aspect in interbank lending (see Iori et al. (2015), Lenzu and Tedeschi (2012) and Lux (2014) on relationship lending in interbank networks). Glasserman and Young (2015a) analyse crises of confidence in the credit quality of particular firms in an interbank network. If a firm's perceived ability to pay declines, then so does the market value of its liabilities. In a mark-to-market regime this reduction in value can spread to other firms that hold these liabilities among their assets. Their analysis suggests that this channel of contagion is likely to be considerably more important than simple spill-over effects. Another potential consequence of a confidence crisis is that counterparties stop rolling over debt, which may lead to a funding crisis (Allen et al., 2012; Anand et al., 2012).

In the present framework we do not include confidence crises, but we plan to do so in further research. In case of bad news about the performance of a bank and rumours about the possibility of a bail-in, counterparty banks may decide to withdraw funds from the ailing bank or increase interest rates for extending credit. The ailing bank would need to sell assets to cover for the higher funding costs, potentially setting in motion a fire sale spiral. These feedback loops may lead to stronger spill-over effects if incorporated in our framework.

To conclude, we will briefly discuss the limitations of ex post network analysis. Interbank networks are limited to the banking sector and do not include formal treatment of the impact on other sectors, on prices or the real economy at large. While network analysis does not formally capture these effects, it is possible to make informed conjectures based on our data or the existing literature.

To give an indication on the macroeconomic impact of a bail-in, we compute the holdings of euro area residents of bail-inable debt and equity issued by the 26 banking groups, broken down by sectors using SHSS data. Over a third of the bail-inable debt and equity issued by the 26 banking groups and held by euro area residents is held by the banking sector. The household sector, the insurance sector as well as money market funds (MMF) and non-MMF investment funds all hold between 10 and 15% of that debt and equity issued. Financial losses for households, for example, may cause reductions in consumption and thereby underutilization of productive capacity in the economy at large.

Glasserman and Young (2015b) highlight how results from financial network analysis might be viewed in a wider macroeconomic perspective. They argue that ”contractual obligations between financial firms play a critical role in managing liquidity needs, intermediating between lenders and borrowers, and diversifying risk exposures”. One could think of these obligations as ”intermediate goods” that ”have economic value to the contracting parties, and their impairment would correspond to genuine economic losses”.

In addition, financial losses may have further consequences for the real economy. Less funding may be available for new investment projects. Similarly, existing investments may have to be terminated early in order to meet short-term obligations, which may lead to inefficiencies. Furthermore, as highlighted above, bankruptcy carries significant administrative and legal costs.

Finally, bail-in may have potential effects on volumes and prices in the interbank market. As mentioned above, trust is an important element in interbank lending. The mere anticipation of a bail-in may lead to an increase in interest rates for the borrowing bank, or to a decrease in funding volumes or in extreme cases in a refusal to rollover. If a bail-in takes place, it is also important how far in the creditor hierarchy the bail-in reaches, since future funding costs of banks are likely to also depend on how creditors estimate the risk of being bailed in. These dynamic effects are left for further research.

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