Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Modelling Financial Contagion to Examine Systemic Risks

project report

for the lecture

Modelling and Simulating Social Systems with MATLAB

ETH Zürich

December 2015

Timo Schäfer
Elsastraße 17
8004 Zürich
✉: schatimo@student.ethz.ch
Matr. no.: 14-740-211

Marion Deichmann
Murhaldenweg 8
8057 Zürich
✉: mariond@student.ethz.ch
Matr. no.: 11-299-583

Laurenz Kaiser
Badenerstrasse 280
8004 Zürich
✉: laukaise@student.ethz.ch
Matr. no.: 14-731-046

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Abstract

We model a random graph with a core periphery structure to approximate the linkages in an interbank network of 244 European banks using real balance sheet data. We aim to answer the question how equity requirements affect the spread of contagion based on an initial shock and which equity adjusting strategies are most effective to reduce systemic risks. Moreover, in case of financial distress, we want to analyse which possible bail-out strategies are most effective w.r.t. associated costs to save banks.

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1 Individual contributions

Timo developped the model for capital buffers, implemented the FDA, capital buffer simulation and the network generating function; Laurenz did data collection, implemented the network generating function, worked on the bail-out simulation; Marion worked on the bail-out simulation and implemented the eigenvector selection function.

2 Introduction and Motivations

Especially after the collapse of Lehman in 2008 researchers and policy makers have shifted their focus towards the interconnectedness of financial intermediaries regarding interbank lending. It has been shown that the default of a bank can trigger other banks' failure via the network structure (Nier, Yang, Yorulmazer, and Alentorn, 2007). Since then global discussions regarding capital requirements and banking regulations have emerged, i.e. Basel III, Volcker Rule, Liikanen report, UK Whitebook. All these measures aim to decrease the probability of default of banks due to an initial exogenous shock and hence, to reduce contagion w.r.t. financial distress.

The main objective of this seminar paper is to examine how contagion effects (and fundamental defaults) within an interbank network change w.r.t. banks' minimum equity ratios that regulators require them to hold. For this purpose, we introduce a new model in section 3.4 that presents different strategies for core and periphery banks to adjust their equity ratio to the one postulated by regulators. We aim to answer the question which banks are better able to use their strategy to decrease their probability of being exposed to a contagious default. Moreover, we aim to analyse if and through which channels contagious can be reduced assuming a financial market with frictions, namely capital rationing.

Moreover, we aim to derive policy implications w.r.t. which banks to bail out, so-called bail-out strategies. In particular, we analyse the tradeoff between bail-out costs and the spread of defaults in the interbank network. The theoretical foundation for this cost-benefit analysis is presented in section 3.5.

For both questions, the same interbank network is considered (section 3.1 and 3.3) that is based on randomly assigned links but on banks' balance sheet data from 2014. Moreover, section 3.2 introduces a pure default algorithm that determines the clearing vector of interbank liabilities for each round. Section 4 presents the data and simulation framework, section 5 exhibits the simulations' results, and section 6 concludes and gives policy implications.

3 Model

3.1 Structure of Financial Network

Let us consider a financial network with adjacency matrix A with n banks (nodes) that are randomly linked to each other by claims and obligations. We will mainly refer to a combination of the framework presented in Gai and Kapadia (2010) and Eisenberg and Noe (2001). Links represent exposure of bank i to other banks, and so are directed and weighted such that exposure is equally distributed over all counterparties. The ij-th entry of A, A_{ij}), reflects the weight of interbank exposure of bank i w.r.t. bank j. Similarly, let A_{ji}) be the weight of interbank liabilities of bank i towards bank j.

Let us assume that total assets of each bank i consist of interbank assets, A_i^{IB}, and relatively illiquid external assets (i.e. mortgages), A_i^E. Bank i's total liabilities consist of interbank liabilities, L_i^{IB}, that are endogenously determined via A, external liabilities, L_i^E, and equity, E_i. Using these notations, one can define the normalised liability matrix L where the ij-th entry is defined as L_{ji}^{IB}/L_i and L_{ji}^{IB} is the amount i owes to j and $L_i = L_i^{IB} + L_i^E$ total liabilities. For each round, one can calculate the clearing payment vector p^* as follows

$$p^* = \min[L^{IB}, \max(L'p^* + A^E - L^E, 0)] \tag{1}$$

assuming that external liabilities are paid first.[1] The default of bank i is called fundamental, due to a too large loss in external assets because of an initial shock assuming all other j banks can pay their obligations to i, if

$$\sum_{j=1}^{N} L_{ij} L_j^{IB} + A_i^E - L_i^{IB} - L_i^E < 0. \tag{2}$$

A contagious default of bank i due to other banks not being able to pay back their liabilities, appears if

$$\sum_{j=1}^{n} L_{ij} L_j^{IB} + A_i^E - L_i^{IB} - L_i^E \geq 0, \text{ but } \sum_{j=1}^{n} L_{ij} p_j^* + A_i^E - L_i^{IB} - L_i^E < 0. \tag{3}$$

[1] For a more detailed description, see Eisenberg and Noe (2001).

To model contagion, we assume that at $t = 0$ all banks are solvent and at $t = 1$ an exogenous shock to some banks (see section 4.2) decreases their value of external assets A_i^E.[2] In the following subsection, we will explain the default-based fictitious default algorithm in brief that accounts for the reverberations within the interbank network.

3.2 Fictitious Default Algorithm (Eisenberg and Noe, 2001)

We need a clearing procedure for each t such that we can determine if payments can be fully made after an initial shock on banks' external assets. For this purpose, we will use the fictitious default algorithm (FDA hereafter) introducted by Eisenberg and Noe (2001). Let total assets of bank i be $A_i = \sum_{j=1}^{n} L_{ij} p_j^* + A_i^E$ and total liabilities of bank i be $L_i = \sum_{i=1}^{n} L_{ji} p_i^* + L_i^E$. Therefore,

$$p_i = \begin{cases} L_i^{IB} & \text{if } A_i \geq L_i \\ \frac{L_i^{IB}}{L_i} A_i & \text{otherwise.} \end{cases} \tag{4}$$

Within this framework, we assume the existence of limited liability, full recovery and proportionality of paying back obligations in case of default w.r.t. interbank and external liabilities. In the following, we will describe the structure of the FDA:

1. Assume that some banks default based on a shock on external assets in $t = 1$ when in $t = 0$ all banks are initially solvent.

2. Round computing starts. Solve linear equations for all n banks by using Equation (4) for each bank i setting up a system of equations.

3. Iterate until no new default occurs and then stop.

3.3 Network Estimation

Gabrieli and Georg (2014) find that the European interbank market is well described by core-periphery networks on a national level and on a joint level these national networks are connected. First, we will utilise a Erdős and Rényi (1959) random graph model to model interbank networks on a national level. We will use real balance sheet data (interbank assets, total assets and equity positions) of the European banking market (see section 4.1).

[2] In this subsection we leave out the time index for reasons of simplicity that we will introduce in the following parts.

The relative total asset position within each country is used as proxy for the core and periphery assignment where we define arbitrary numbers of links within (m_c and m_p) and between (m_{cp}) core and periphery ss data on specific interbank lending and borrowing is not publicly available. The average degree in the core is much larger than in the periphery. The number of links is assigned in a fixed proportion of the number of nodes in the core and periphery, i.e. n_c and n_p, respectively. Nodes between countries are connected with a probability of 5%. The selection into core and periphery is somehow arbitrarily done on the basis of the relative amount of banks' total assets within its country. However, although we consider the joint European interbank network with a prespecified probability that countries within this network are connected, we disregard the possibility that the European interbank market is also lending to and borrowing from non-European markets. For sure, the assumptions made are somehow arbitrary but account for stylized facts of interbank networks and include real balance sheet data.

3.4 Capital Buffers

From a regulator's perspective, adequate capital buffers are a very important tool to accelerate financial stability. For this purpose, we introduce a new model that accounts for banks adjusting their balance sheet w.r.t. current regulatory policies using the default-based FDA from section 3.2. Let us define equity of bank i as $E_i(t) = (A_i^{IB}(t) + A_i^E(t) - L_i^{IB}(t) - L_i^E(t))^+$ where $A_i^{IB}(t) = \sum_{j=1}^{N} L_{ij} p_j^*(t)$. In the following we introduce a (not risk-weighted) equity ratio $ER_i(t)$ at time t of bank i that is defined as follows

$$ER_i(t) = \frac{E_i(t)}{A_i^{IB}(t) + A_i^E(t)} \tag{5}$$

as long as at the same time Equation (2) and (3) are fulfilled. If the latter does not hold, bank i defaults and the remaining assets are proportionally paid to all creditors. Let us assume that in $t = 1$, some banks' external assets A_i^E are exposed to an external shock and banks try to get back to the minimum level ER required by regulators. In $t = 2$, banks that are directly connected to bank j have to depreciate this loss and equity is reduced simultaneously since issuing equity shares is not assumed at this point. To keep the by regulators required minimum ER, these banks sell external assets (here only one asset class is considered). Here, we assume the absence of fire sales. If $ER_i(t) \geq ER$, then bank i will take no action. But if $ER_i(t) < ER$, bank i will sell external assets that can be described as am aggregated portfolio of different asset classes to keep its equity ratio above the minimum requirement. We can describe the process of selling external assets as follows. Let $A_i^E(0) = Q_i(0)p$ and $A_i^E(t) = Q_i(t-1)p + \triangle Q_i(t)p$, where p is the price of the external asset (constant over time), $Q_i(t)$ the amount at time t and $\triangle Q_i(t) = Q_i(t) - Q_i(t-1)$ as long as $A_i^E(t) \geq 0$.[3] Therefore, Equation (5) can be written as

$$ER_i(t) = \frac{E_i(t)}{Q_i(t-1)p - \triangle Q_i(t)p + A_i^{IB}(t)}. \tag{6}$$

The proceeds from selling external assets are supposed to be used to pay outstanding external debt such that $ER_i(t)$ increases. Therefore, the minimum amount bank i has to sell of its external asset to restore the minimum ER is

$$\triangle Q_i(t)p \geq Q(t)p + A_i^{IB}(t) - \frac{E_i(t)}{ER}. \tag{7}$$

The amount of external assets divested at time t is restricted as follows since hedging is excluded

$$\triangle Q_i(t)p = \max\left(\min(\triangle Q_i(t)p, A_i^E(t), L_i^E(t)), 0\right). \tag{8}$$

Alternatively, we introduce a framework in which banks can improve their equity ratio by issuing equity that is supposed to be possible independent of the bank's financial situtation and is only limited to the time dimension t (market friction). We stipulate that $ER_i(t) < ER$ leads to bank i issuing an equity amount $\triangle E_i'(t)$ at time t that is defined as

$$\triangle E_i'(t) = \frac{ER(A_i^{IB}(t) + A_i^E(t)) - E_i(t)}{1 - ER}. \tag{9}$$

Furthermore, the maximum equity amount $\triangle E_i(t)$ is assumed to be limited w.r.t. each bank i's initial equity amount $E_i(0)$. This means, for initially very solvent banks it is easier to issue equity and vice versa for less solvent banks. Under this assumption, we arrive at following definition

$$\triangle E_i(t) = \min\left(\triangle E_i'(t), (E_i(0))^{1/t}\right), \ \forall t \neq 0. \tag{10}$$

The exponent $1/t$ accounts for that raising equity is restricted w.r.t. time t. Moreover, $\triangle E_i(t)$ is added on top of $A_i^E(t)$ such that bank i's balance sheet is balanced.

Finally, we combine both strategies, divesture of external assets and equity issuance

[3] If $A_i^E(t)$=0, then we assume that bank i does not start selling interbank assets and does not have to pay any fees (penalties) since it is stipulated it cannot take any more actions to increase their equity ratio.

respectively, and suppose that banks in the core can pursue the second strategy since they are well-capitalised and are more liquid than banks in the periphery. Whereas smaller banks in the periphery are assumed to follow the first strategy since costs of equity are supposed to be prohibitively high for them. Though the definitions above in Equation (8) and (10) do not necessarily suffice to maintain ER, it is assumed that there exist no penalties that impose costs on the banks since they try their best to maintain ER. Additionally, we approximate the situation before (without equity ratio before shock) and after (with equity ratio before shock) the financial crisis starting in 2007. More specifically, in the pre-crisis scenario minimum capital requirements ER are introduced in $t = 2$ after an exogenous shock took place in $t = 1$. Whereas in the post-crisis scenario, the minimum requirement already exists before the shock in $t = 1$.

Additionally, let us introduce a concept that allows banks to restore the minimum capital requirement ER and to reduce their probability of contagious default by reducing their interbank assets and paying interbank liabilities back. This is an even more realistic assumption since banks can liquidate interbank assets faster and easier than external assets since interbank assets are usually short-term assets and so more liquid. The amount of interbank assets $\triangle A_i^{IB}(t)$ bank i has to divest at time t to restore ER is analogous to Equation (9):[4]

$$\triangle A_i^{IB}(t) = \max\left(\min(A_i^E(t) + A_i^{IB}(t) - \frac{E_i(t)}{ER}, L_i^{IB}(t), A_i^{IB}), 0\right). \tag{11}$$

This problem is put into a recursive definition by setting $\gamma_i(t)$ as the amount bank i has to divest at time t since one has to account for other banks also adjusting their interbank exposure simultaneously:

$$\triangle A_i^{IB}(t) = \gamma_i(t) + \sum_j L_{ij}\gamma_j(t). \tag{12}$$

This problem can be stated in matrix notation as follows:

$$\gamma(t) = (\mathbf{1}_n + L)^{-1}\triangle A^{IB}(t). \tag{13}$$

We will not implement this strategy but we will include this approach in our discussion in section 5.

[4]We do not present mixed strategies here, i.e. mixing equity issuance and balance sheet contraction or reducing both external and interbank liabilities with the latter strategy.

3.5 Bail-outs

Another interesting aspect from a regulator's point of view is to choose between various bail-out strategies. For this purpose, we assume that a lender of last resort exists, who bails out defaulting banks. The lender of last resort (hereafter LLR) comes into play at a threshold of 5% of the n banks that have defaulted in total, as defined in (Gai and Kapadia, 2010).[5] For the analysis we will define this threshold as the level of aggressiveness of the LLR. In our simulation, the LLR gives preference to those banks which are most systemically important, if the number of defaults exceeds a certain limit per time unit t. This limit will vary during the simulation, as described in 5.2. If the number of defaults is smaller than the limit, all banks are bailed out. As a proxy for systemic importance, we draw on eigenvector centrality. Let us define eigenvector centrality of bank i as follows

$$x_i = \frac{1}{\lambda} \sum_j L_{ij} x_j \tag{14}$$

that can be written in its more compact form

$$\lambda x = Lx \tag{15}$$

where λ is its largest eigenvalue (see Newman (2004)).) For the simulation, we also use the FDA from section 3.2 to generate the initial defaults. We assume that the financial injection in t by the LLR has a sufficient volume s.t. the banks are able to meet the Basel III policy directive on tier 1 capital, i.e. an equity ratio of 4.5%. Furthermore, we assume that the financial injection is stocked onto external assets, $A_i^E(t)$. If bank i defaults at time t, it is stipulated that bank i is recovered in t as well. Hence, the volume of the injection in t is defined as

$$\text{injection}_i(t) = \frac{L_i^{IB}(t) + L_i^E(t) - (1 - ER)\left(A_i^{IB}(t) + A_i^E(t)\right)}{(1 - ER)} \tag{16}$$

where ER denotes the required equity ratio. Hence, the new external asset position, $\tilde{A}_i^E(t)$ is

$$\tilde{A}^E(t)_i = A_i^E(t) + \text{injection}_i(t). \tag{17}$$

[5] For the sake of simplicity, let us assume that banks' risk behaviour is not a function of the probability of being bailed-out (no moral hazard issues) and the absence of deposit insurance.

Thereby the LLR prevents the bank from collapsing and restores financial agility. However, we exclude banks from the bail-out procedure that already collapsed in the past.[6]

We aim to compare the different strategies by means of the costs saving contagious banks and the number of defaulted banks, i.e. how contagion spreads in the scenarios. Therefore, we define the total cost of bailing out per draw and $\forall t \leq T$ as

$$\text{totcost} = \sum_{t}^{T} \sum_{i=1}^{\zeta} \text{injection}_i(t) \tag{18}$$

where ζ is defined as $\zeta \equiv \min(\text{limit}, \text{default(t)})$. limit denotes the maximum number of banks which the LLR plans to bailout per time step t and each draw of the MC. default(t) represents the number of banks, which are in default at time step $t \leq T$. T is dependant on the spread of contagion generated by the FDA. Moreover, the selection takes place according to eigenvector centrality, as described above. From these observations, he hope to derive policy implications to impede the spread of contagion.

4 Implementation and Simulation

4.1 Data

We estimate the interbank network structure on the basis of data derived from Bankscope (URL: `bankscope.bvdinfo.com`). Our data set consists of a subset of banks from the EU15 countries and Switzerland. In order to limit the size of the data set, we only encounter banks having more than \$20bn total assets in their balance sheet. This gives us a data set of 244 banks. Besides total assets, the data set contains interbank loans, interbank assets and equity all derived from 2014.

4.2 Implementation

For the Monte Carlo simulation for both the capital buffer and bail-out simulation, we will assume that the risk factor ψ w.r.t. banks' external assets is Beta distributed: $\psi \sim \text{Beta}(a, b)$. When we say we stress x banks, then we refer to the x banks having the highest number of incoming links (interbank liabilities). We want to stress the most central banks

[6] Suppose bank i goes bankrupt at t and is also saved in t. Suppose further the same bank i collapses at a later point in time $t + \epsilon$, then this bank i will not be bailed-out again. This could refer to a moral hazard clause, if it also had and impact on the banks behaviour. Although, we exclude that in our set up.

w.r.t. degree centrality to see the most pronounced effects of contagion. Of course, one should also define the set of stressed banks differently, i.e. countryspecific stress.

5 Simulation Results and Discussion

5.1 Capital Buffers

For the simulation of capital buffers, we set $a = 1, b = 10$ for the low stress scenario and $a = b = 1$ for the high stress scenario. Additionally, we set x=50 banks that are stressed and select a range for the minimum requirement *ER* from 0 to 0.4 by 0.01 where each step is simulated 250 times by drawing the risk factor ψ from the specified Beta distributions.

Figure 1 depicts the results for the low stress scenario for both the pre and post crisis scenario. It is clear that under the post-crisis framework the probability of a fundamental default can be reduced significantly. For instance, for *ER*=0.1 the probability halves in comparison to the situation when *ER*=0. Evidently, for the pre-crisis framework, the probability of a fundamental default is constant for all *ER* since banks are not forced to create a capital buffer before the shock occurs. Interestingly, it is not possible to reduce the probability to a level very close to zero which is due to the assumed restrictions w.r.t. the amount of equity a core bank can issue. For instance, if issuing equity is not restricted, then fundamental defaults of systemically important fundamental institutions can be siginificantly reduced to levels close to zero.

Comparing the two strategies of core and periphery banks in Figure 1, one clearly sees that core banks can much better reduce their default probability due to contagion though they are mostly more central (w.r.t. in and outdegree) than periphery banks. Centrality in financial terms also means that core banks have access to more liquid markets and hence, are characterised (market= by more depth in comparison to periphery banks. The strategy for periphery banks presented in section 3.4 does not show a reduction in periphery banks' probability of being exposed to contagious default as exhibited in Figure 1. Their probability is constant for all *ER* and does not show any tendency to change. In this respect, it might be more appropriate for periphery banks to pursue the strategy presented at the end of section 3.4 to reduce the amount of interbank assets and thus, the interconnectedness with other banks. This means for regulators that specific regulation on how banks have to maintain minimum capital requirements is needed. A general rule to require a specific *ER* does not imply that *all* banks are less likely to default due to an initial shock and after its reverberations. For ER larger than 0.15 the probability of a contagious default does not lower for core banks as well because of the imposed restriction on the amount of equity they can issue. Hence, a massive reduction of contagion or systemic risk is not possible as long as we assume a finanical market with frictions w.r.t. capital rationing. From Equation (10), one sees that core banks can at maximum issue their initial amount of equity at time t=1 and from Equation (9) that the required 'add-on' to fulfill ER is increasing in ER. This means that there exists a value ER from above that many core banks issue their initial equity amount (maximum) at t=1 and therefore, cannot further decrease the spread of contagion. As we lower the restriction, a further reduction in default probabilities due to contagion is possible for core banks. Due to the low performance of the strategy of periphery banks, the overall reduction in the default probability due to contagion only decreases by about 5ppt based on an ER level of 0.1.

In our framework, the real effects might be underestimated due to the reasons mentioned in section 3.3. Additionally, a low fraction of banks defaulting initially does not harm banks that much since we assume that their assets are equally distributed w.r.t. their counterparties which reduces the risk of contagion significantly. In reality, of course, this assumption might not hold such that a bank is heavily exposed to very few banks.

Figure 2 presents the results for the high stress scenario. We have similar effects as with the low risk scenario. In particular, the effects of the core and periphery banks are qualitatively the same as before. In contrast to the low risk scenario, fundamental defaults cannot be reduced as significantly as with the low risk scenario. For instance, for some stressed banks it is not possible to issue a sufficient amount of equity to prevent their default because the shock is too devastating for them. Moreover, the reduction of overall contagion is reduced in a similar extent as with the low risk scenario such that this channel is not harmed by an increased initial stress level banks are facing. Comparing the default probability due to contagion in Figure 1 and 2, one sees that there is no significant difference between the low and high risk scenario for higher ER values.

Finally, one has to remark that the simulation runs under the assumption that some banks are not able to maintain the required ER but those banks are not penalised. This assumptions does not reflect the reality since normally a too low equity ratio is associated with (prohibitively) high costs, i.e. credit downgrading. Including penalities can be part of future research, i.e. when one has more granular balance sheet data to evaluate penalties more precisely than with our very aggregated balance sheet data.

5.2 Bail-outs

For the analysis of the bail-out, we use the same high and low stress scenarios as defined in section 3.4. Furthermore, we consider a comparison of the selection scheme of the LLR to bail out banks in distress. First, the LLR draws on eigenvector centrality and hence it will bail out the most systemically important banks. Second, we choose a random selection scheme as benchmark. For both cases we look at a range of maximum numbers of banks to bail out per time t from none to a maximum of roughly 15% of the interbank network, by increments of two. As for the simulation of the capital buffers, the number of stressed banks is set at x=50. But for our setup we stress the most central banks according to their respective outdegree (i.e. assets). For each step of the 250 simulations in the Monte Carlo framework, we draw the risk factor ψ from the Beta distributions as specified for the low and high case in section 3.4 as well.

Unlike our expectation, we do not see a significant effect w.r.t. decrease of total defaults from changing the selection scheme from a random approach to choosing to save banks according to their eigenvector centrality representing their systemic importance. The figures for the simulation from random selection are not presented. The cost of bailing out is consistent with the high and low stress scenario. With size of the shock, the cost of bailing out also increases. Therefore, this implies that according to our framework introduced in section 3.5, for policy makers, it does not matter which banks to save if they want to enhance financial stability.

Figure 3, representing the high stress scenario using eigenvector centrality as selection scheme, shows that relative defaults decrease with the maximum number of banks saved per time step t. The number of fundamental defaults evidently remains constant which means that the number contagious defaults is decreasing. Surprisingly, the decrease in contagious defaults decreases linearly with the number of maximum banks bailed-out per time step t.

Figure 4, also exhibitng the high stress scenario using eigenvector centrality as selection scheme, shows that bail-out costs increase with the maximum number of banks saved per time step t as expected. The qualitative results for the low stress scenario will not be presented here, since the implications are analogous to the high stress scenario and do not give further insight.

The FDA algorithm seems to be inappropriate to simulate bail-outs. It would be interesting to see the mechanism using a DebtRank algorithm, see i.e. Battiston, Puliga, Kaushik, Tasca, and Caldarelli (2012). Using the DebtRank algorithm, one can compute the value of equity lost within the financial network and compare this number to the bail-out costs.

6 Summary and Outlook

We have shown in our capital requirement simulation that core banks can pursue a strategy that can lower their risk of contagious default though there exist restrictions w.r.t. issuing equity. Those restrictions result in no further reduction in the probability of contagious defaults at some point when capital requirements increase. The same channel can be used to decrease the number of fundamental defaults. But the strategy for periphery banks presented in section 3.4 does not show a reduction in their probability of being exposed to contagious defaults. Therefore, in our setting, core banks are better able to use their strategy to decrease their default probability due to contagion than periphery banks are. In general, the probability of contagious defaults is only marginally reduced by introducing capital requirements whereas the probabiliy of fundamental defaults can be lowered much more significantly - assuming the strategy profiles depicted in section 3.4. To conclude regading bail-out strategies, using our FDA framework and the assumptions stated above, there are no significant differences w.r.t. bail-out costs in terms of the selection scheme and only, obviously, in the maximum number of banks that is chosen by regulators to save per time step t.

For future research, it would be interesting to conduct this sort of a simulation within a non pure-default model that might give more precise results than the FDA that we used. For instance, the DebtRank algorithm explicitly accounts for banks that not only default but also are in financial distress and thus, gives an approximation of the value of equity lost due to an initial shock to a group of banks (Battiston, Puliga, Kaushik, Tasca, and Caldarelli, 2012). Furthermore, one should implement the alternative strategy of periphery banks to maintain the minimum equity ratio by selling interbank assets and so to reduce their interconnectedness within the interbank market. It is of great interest to see whether this strategy results in a significant overall reduction in contagious defaults. Particulary, one can check then if this is a more appropriate strategy for periphery banks to pursue to reduce their probability of defaulting due to contagion.

7 References

Battiston, S., M. Puliga, R. Kaushik, P. Tasca, and G. Caldarelli (2012): "DebtRank: Too Central to Fail? Financial Networks, the FED and System Risk," *Scientific Reports*.

Eisenberg, L., and T. H. Noe (2001): "Systemic Risk in Financial Systems," *Management Science*, 47(2), 236–249.

Erdős, P., and A. Rényi (1959): "On random graphs I," *Publ. Math. Debrecen*, 6, 290–297.

Gabrieli, S., and C.-P. Georg (2014): "A network view on interbank market freezes," *Deutsche Bundesbank Discussion Papper*, 44.

Gai, P., and S. Kapadia (2010): "Contagion in Financial Networks," *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, pp. 2401–2423.

Newman, M. (2004): "Analysis of weighted networks," , 70(5), 056131.

Nier, E., J. Yang, T. Yorulmazer, and A. Alentorn (2007): "Network models and financial stability," *Journal of Economic Dynamics and Control*, 31(6), 2033–2060.

A Figures

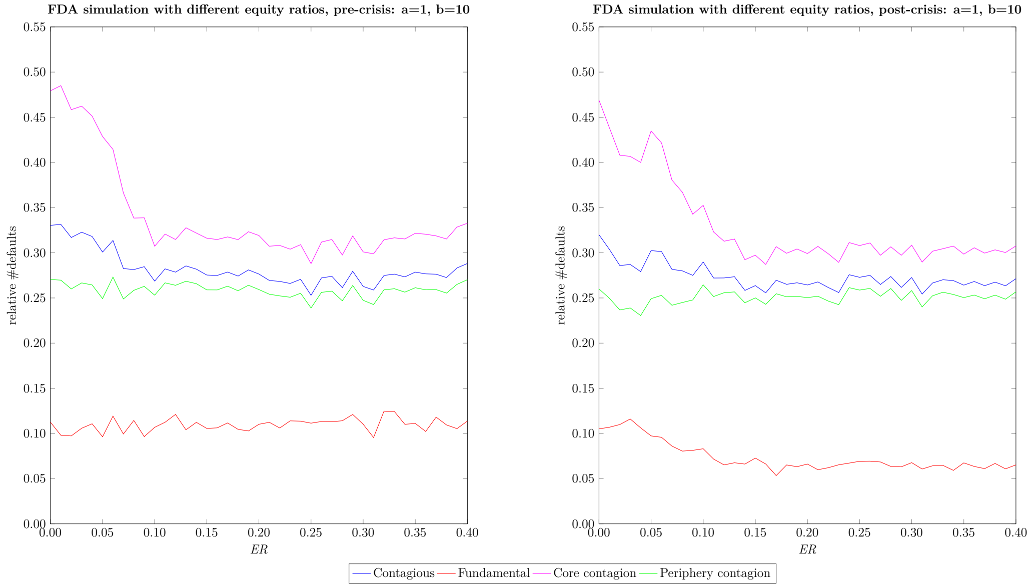

Figure 1: **Low-risk scenario.** Plot for default probabilities in dependence of minimum capital requirement *ER*. Core (periphery) contagion means the fraction of core (periphery) banks that default due to contagion. Contagious (fundamental) default means the overall probability of defaults due to contagion (an exogenous shock).

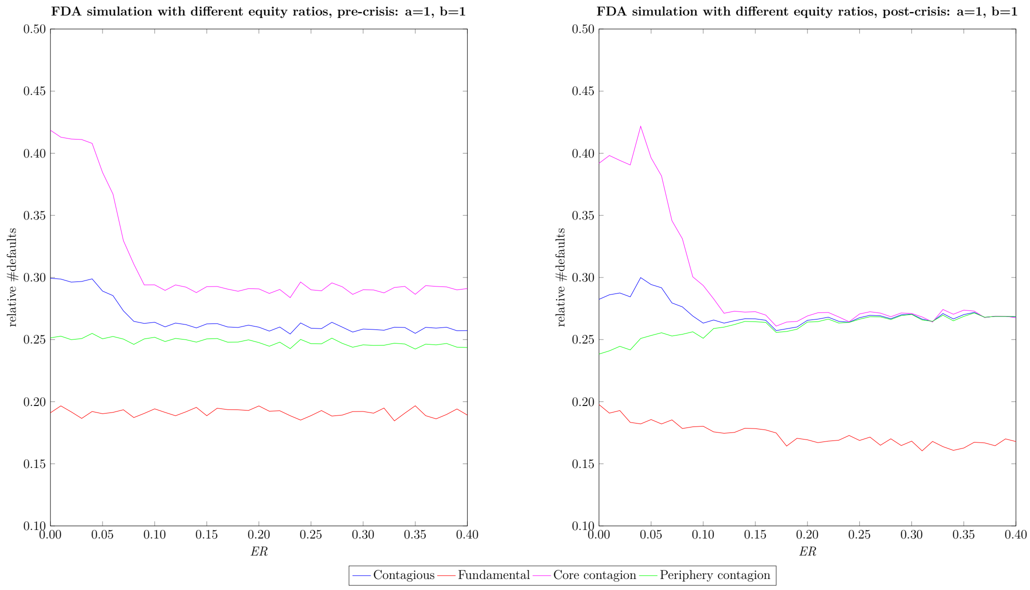

Figure 2: **High-risk scenario.** Plot for default probabilities in dependence of minimum capital requirement *ER*. Core (periphery) contagion means the fraction of core (periphery) banks that default due to contagion. Contagious (fundamental) default means the overall probability of defaults due to contagion (an exogenous shock).

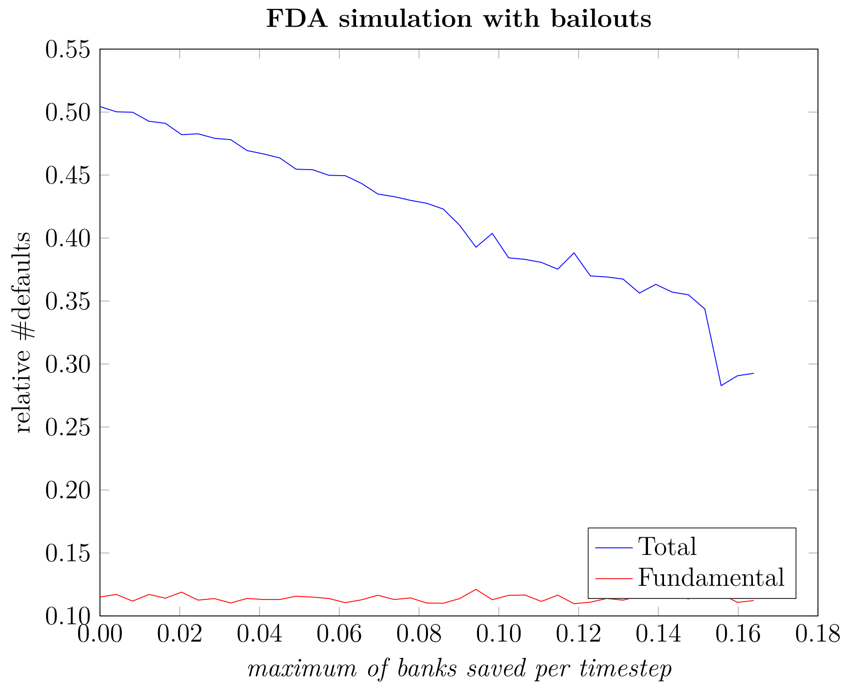

Figure 3: **High-risk scenario.** Plot for total defaults using eigenvector centrality as selection scheme in dependence of maximum number of banks bailed-out per timestep t.

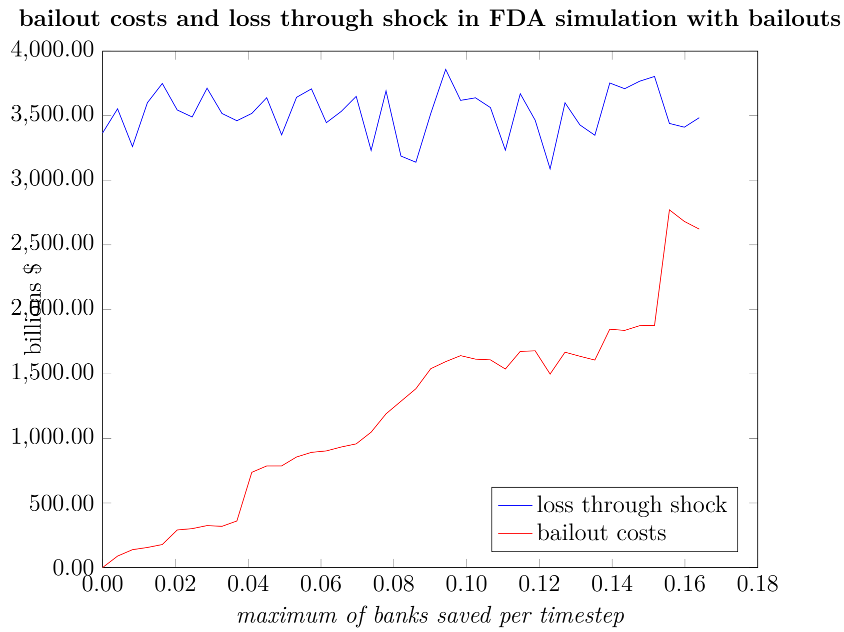

Figure 4: **High-risk scenario.** Plot for total bail-out cost and the loss from the initial shock using eigenvector centrality as selection scheme in dependence of maximum number of banks bailed-out per timestep t.