The Nexus Between Systemic Risk and Sovereign Crises

Tomas Klinger and Petr Teply

(accepted to the Czech Journal of Finance on 19 May 2015)

---------- Původní zpráva ----------
Od: FaU-CJEF <redakce@fsv.cuni.cz>
Komu: tomas.klinger@seznam.cz
Datum: 19. 5. 2015 19:37:04
Předmět: k Vasemu clanku pro FaU-CJEF

Vazeni spoluautori,
jsem rada, ze Vam mohu oznamit, ze druha upravena verze Vaseho prispevku "The Nexus Between Systemic Risk and Sovereign Crises" byla prijata k publikaci v nasem casopise. Bohuzel Vam zatim nemohu napsat presny termin zarazeni, nejpravdepodobnejsi je vsak c. 6/15.

Dekujeme za spolupraci a tesime se ev. Vase dalsi prace.
S pozdravem
Renata Novakova
vykonna redaktorka

Abstract
This paper focuses on the relationship between the financial system and sovereign debt crises by analysing sovereign support to banks and banks' resulting exposure to the bonds issued by weak sovereigns. We construct an agent-based network model of an artificial financial system allowing us to analyse the effects of state support on systemic stability and the feedback loops of risk transfer back into the financial system. The model is tested with various parameter settings in Monte Carlo simulations. Our analyses yield the following key results: firstly, in the short term, all the support measures improve the systemic stability. Secondly, in the longer run, there are settings which mitigate the systemic crisis and settings which contribute to systemic break-down. Finally, there are differences among the effects of the different types of support measures. While bailouts and recapitalization are the most efficient support type and guarantees execution is still a viable solution, the results of liquidity measures such as asset relief or funding liquidity provision are significantly worse.

JEL Classification: C63, D85, G01, G21, G28

Keywords: agent-based models, bailout, contagion, financial stability, network models, state support, systemic risk

1 Introduction

The recent global financial crisis emphasized the importance of the link between the financial and the sovereign sector. The pre-crisis financial order is characteristic with risk build-up connected to banking deregulation after the collapse of the Bretton Woods system when the banks started racing for leverage. When the unsustainability of this setting surfaced and the current Eurozone crisis broke out, the sovereigns started playing an active role through several types of measures for financial system support including bailouts and recapitalization, state guarantees, asset relief or provision of funding liquidity. European Commission (2012) estimates that the volume of national support to the EU banking sector between October 2008 and 31 December 2011 amounted approx. EUR 1.6 trillion (13 % of EU GDP). It soon became obvious that the risks did not vanish but were transferred to the sovereigns. As a result, sovereign bond yields and CDS spreads rose, access to new funding became increasingly more expensive and the sovereigns found themselves in crisis with their balance sheets deteriorating (Caruana, 2012). Since a large portion of sovereign debt is held by the banking system, the crisis fed back to where it began in a vicious circle of transferring the toxic debt back and forth between the sovereign and the financial sector.

From the onset of the financial upheaval, the topic of sovereign crises became the focus of many researchers and numerous publications were written on this topic including Manasse and Roubini (2009) who provide an empirical study of the conditions leading to a sovereign crisis, Reinhart and Rogoff (2009) who explore the history of sovereign countries in individual case studies. In terms of sovereign assistance, Enderlein, et al. (2012) analyse behaviour of governments which find themselves on the verge of default. Borensztein and Panizza (2009) examine possible costs to the defaulting sovereign arising from its failure, while Dias (2012) investigates the asynchronization between periphery countries and resilient countries in the Eurozone. Laeven and Valencia (2008) and recently updated by Laeven and Valencia (2012), provide a detailed catalogue of systemic banking crises along with description of the links they had to the sovereign sector. Hansen (2013) highlights the challenge of quantifying systemic risk and discusses pros and cons of modelling and measuring systemic risk. In terms of liquidity funding problems of banks during financial distress periods, Craig and Dinger (2013) propose a new empirical approach that is concentrated on the relationship between deposit market competition and bank risk. More recently, Bucher et al. (2014) analyse the importance of bank´s liquidity management in a global low interest rate environment. Last but not least, Fidrmuc et al (2014) or Dewally and Yingying (2014) discuss effects of bank funding problems on bank lending and corporate loans.

On a related note, Estrella and Schich (2011) develop a valuation method of bank debt insurance by troubled sovereigns, Pisani-Ferry (2012) describes problems that arise from this linkage to the Euro area and Campolongo, et al. (2011) build a model estimating the probability and magnitude of economic losses and liquidity shortfalls occurring in the banking sector.

The overall aim of this paper is to contribute to the discussion on sovereign debt crises and bank crises, which have occurred both in the EU and on the international level. It examines the role of the sovereigns as providers of bank aid and members of the financial network as such.[1] The main research question is how the stability of the financial system is affected by its individual parameters associated with the link between the banks and the sovereigns, how and when its stress can translate into sovereign crises and on the other hand, how and when a sovereign crisis can feed back into the system through sovereign debt exposures. Allen and Gale (2000) firstly presented the main idea that the banks may be represented by their balance sheets, they form nodes in a network connected with mutual claims, and that an adverse shock may spread through the financial system as a contagious event. Another early analysis was carried out by Freixas, et al. (2000), who studied contagion in systems where some banks were systemically important. The simple framework of pure credit shock contagion is extended in Cifuentes, et al. (2005) and Shin (2008), who add a market liquidity contagion channel decreasing the price of illiquid assets. Finally, there are studies that analyse systemic stability by simulation experiments such as Nier, et al. (2007), Gai and Kapadia (2010) or Battiston et al. (2012), who use simulation models to examine how different banking system parameters affect its resilience. In general terms, the effects of the network structure on financial contagion has discussed, among others, by Acemoglu et al. (2013), Cochrane (2013), Georg (2013), Gofman (2014) and van Wincoop (2013). Recently, Blasques et al. (2015) presents a dynamic network model of the unsecured interbank lending market.

This paper is extension to Klinger and Teply (2014), where the authors used agent-based network simulations to assess the impact of various settings of banking regulation on systemic stability. Although using a similar modelling framework, this paper brings completely new insight into effectiveness and mechanism of state aid as it implements the existence of sovereigns and their assistance to troubled banks.

The rest of the paper is structured as follows: in the second section, we construct an original model of a financial system which will be used for testing the impact of sovereign assistance to banks and researching the feedback loops that may arise when such assistance weakens the sovereigns. In the third section, we test the model in Monte Carlo simulations to get better understanding of its inner processes and its results. Finally, we conclude the paper with a summary of our research and key findings.

2 The Model

As mentioned above, we follow a similar modelling framework for the bank network as Klinger and Teply (2014). However, in this paper we expand our model by the nexus between banks and sovereigns, which makes our methodology unique. While focusing in our previous paper primarily on an impact of shocks on capital adequacy of the investigated banks, were we added three other support measures to the banks ion trouble (see also Section 3.5). For each individual simulation, the model is defined in several iterations. First, the network of banks and sovereigns is initialized together with the balance sheet data of individual agents. Second, the system is stressed by several types of balance sheet shocks, which may originate from individual banks,

[1] For general discussion on the formation of financial networks we refer to Gale and Kariv (2007), Farboodi (2014) or Vuillemey and Breton (2014).

individual sovereigns or from downward pressure on asset prices. Following the initial shock, the stress propagates through the network and triggers actions of particular agents such as bank or sovereign defaults, asset fire-sales or state assistance to troubled banks. The simulation continues in a number of laps until the initial shocks completely dissolved and are not further transmitted onto other agents.

Table 1:
Input Parameters of the Model

Parameter	Interpretation	
N	Number of banks in the system*	25
p	Probability of connecting two banks with a directed exposure*	0.2
E	Total sum of external assets in the system*	100,000
θ	Interbank asset ratio (interbank/total assets)*	0.2
γ	Capital ratio (net worth/internal + external assets)*	0.05
CAD 1	Capital ratio limit that triggers bank's removal by the regulator	0
$\boldsymbol{shock_{random}}$	Shock on a random bank (in percentage of external assets)*	1
$\boldsymbol{shock_{others}}$	Shock on all other banks (in percentage of external assets)	0.1
iterations	Number of iterationsunder one set of parameters	500

Note: Parameters highlighted by asterisks are used by Nier, *et al.* (2007) and for the sake of comparability, we set them to the same values in the basic setting. The rest of the parameters are original to our model.

Source: Authors

2.1 Creating the Network

The infrastructure of the model is formed by a network of banks and sovereigns. First, the model creates an interbank network which is a random graph defined by two parameters set exogenously at the beginning of each simulation. These are the following:

1. Number of nodes N^b, determining the number of agents in the interbank network,
2. Probability p_{ij}, determining the existence of a directed edge from bank i to bank j, i.e. the probability that bank i is exposed to bank j by holding a claim against it. We assume this parameter fixed among all edges[2] between all nodes $i, j \in (1, \dots, N^b)$ and denote it as p^b. As a result, not all banks are connected to all banks and the network structure changes for every simulation. Moreover, as the exposures are not netted, two links in opposite directions may exist between each pair of banks.

The interbank network is created in two steps. First, there are N^b banks added in the system, and second, for each oriented pair of banks, an edge is created with probability p^b.

Second, we add the sovereign agents and link them with their domestic banks by exposures held by each bank to its home sovereign. We abstract from other types of connections such as exposures of states-to-banks, states-to-states or banks-to-foreign-sovereigns. For introduction

[2] This assumption may be relaxed when the model is calibrated to relevant data. However, we leave this possibility to the further research.

of sovereigns, the system takes one more exogenous parameter, initial sovereign node count $N^{s,INIT}$, determining the number of sovereigns. Subsequently, for each bank $i \in (1, \ldots, N^b)$, one sovereign $k \in (1, \ldots, N^{s,INIT})$ is sampled randomly and an oriented edge is created between these two. The bank-sovereign edges represent claims of banks on the domestic sovereign, i.e. the exposure that bank i holds to sovereign k. At the end of the edge initialization, the sovereigns having no links with any of the banks are removed from the system and the number of sovereigns left is denoted as N^s.

2.2 Initializing the Balance Sheets[3]

Table 1: Balance sheet variables of a modelled bank

a_i...TOTAL ASSETS	l_i... TOTAL LIABILITIES
s_i...sovereign debt	b_i...interbank liabilities
q_i...interbank assets	d_i...external liabilities (deposits)
e_i...external assets	c_i...equity (capital buffer)

Source: Authors

Next, the model builds balance sheets of individual banks for the given network realization. First, we calculate the aggregate variables of the system. The total value of all assets upon initialization is a sum of:

a. *interbank assets,* constituted by all the loans represented by the edges of the interbank network,
b. *sovereign debt,* constituted by individual banks' exposures towards their domestic sovereigns,
c. *external assets,* constituted by individual banks' exposures outside the network, e.g. loans to other entities such as households, foreign sovereigns and non-financial institutions or derivatives.

The banks' balance sheets are populated according to the following algorithm:

1. The sum of external assets in the system E, sum of sovereign debt towards all banks S and the share of interbank assets in total assets θ are given exogenously. The total value of all assets in the system A is determined by these as follows:

$$A = \frac{E + S}{(1 - \theta)}.$$

2. The sum of interbank assets is calculated from the total assets and the share of interbank assets in total assets:

$$Q = \theta A.$$

[3] Please note that the relationships in this section are defined so that the virtual financial system may be described by as few parameters as possible while keeping the possibility to compare simulation results of different settings of a few variables given the others remain fixed (ceteris paribus). Hence, it does not mean that relationships in this section are describing behaviour of individual balance sheet variables, it is merely an algorithm for the system initialization *before* the simulation is launched by an initial shock.

Finally, it holds that:

$$A = S + Q + E.$$

3. In line with Nier, et al. (2007) and Gai and Kapadia (2010), for Monte Carlo simulation purposes the interbank exposures are assumed homogenous. Denoting the sum of all interbank edges in the system as Z^b, the value of each individual edge is calculated as:

$$w_{ij}^b = w^b = \frac{Q}{Z^b}.$$

4. The value of each sovereign's debt is given as $\frac{S}{N^s}$ and it is assumed homogenous across sovereigns. Denoting the sum of outgoing edges from banks to k-th sovereign as z_k^{IN} (as these are incoming to the sovereign), the value of each individual edge is thus calculated as:

$$w_k^s = \frac{S}{N^s z_k^{IN}}.$$

When the aggregate variables are determined, the model initializes the balance sheets of individual banks:

5. The value of interbank assets (q_i) and liabilities (b_i) of each bank are determined by the interbank edge value (weight) and number of edges in the system as:

$$q_i = w^b \, z_i^{IN},$$
$$b_i = w^b \, z_i^{OUT},$$

   where z_i^{IN} is the number of i-th bank's incoming edges and z_i^{OUT} is the number of its outgoing edges.[4]

6. The value of sovereign debt held on each bank's balance sheet (s_i) is equal to the value of domestic government debt held by the bank.

$$s_i = w_k^s,$$

7. External assets' value of each bank is determined by a two-step algorithm described in Nier, et al. (2007):

   a. First, the difference between the interbank liabilities and internal assets is balanced by a certain amount of external assets $\tilde{e}_i$:

$$\tilde{e}_i = \begin{cases} b_i - q_i & \text{if } \; b_i - q_i > 0 \\ 0 & \text{if } \; b_i - q_i \leq 0 \end{cases}$$

   b. The rest of the total sum of external assets is distributed uniformly among all banks so that the following holds for each bank's external assets value:

[4] On the aggregate level, it holds that $\sum_{i=1}^{N^b} z_i^{IN} = \sum_{i=1}^{N^b} z_i^{OUT} = Z^b$.

$$e_i = \tilde{e}_i + \left[\frac{E - \sum_{i=1}^{N^b} \tilde{e}_i}{N^b}\right].$$

8. Each bank's capital buffer (c_i) is determined as a share of its total assets (a_i) according to the capital ratio γ_i. In line with Nier, et al. (2007) or Chan-Lau (2010), the capital ratios are assumed the same across all banks and are denoted as γ:

$$c_i = \gamma a_i.$$

9. The value of each bank's external liabilities (d_i) is calculated so that the balance sheet identity holds:

$$d_i = a_i - c_i - b_i.$$

When the balance sheets are populated, the system is initialized. The final setting of banks' balance sheets is depicted in Table 1.

For sovereigns, the model does not require balance sheet identities for sovereigns as there the mechanics is driven by the relationship of CDS spread movements with budget deficits in individual periods. Hence, the sources for funding budget deficits are not explicitly stated (and bank credit is present explicitly mainly for modelling the shock transmission from sovereigns back to the banks). However, bank credit is not the only source of funding budget deficits other debt external to the model is allowed for. Upon the system initialization, we assume this variable to be of zero value for all sovereigns.

2.3 Introducing Negative Shocks

When the network is prepared, the system is inactive until we impose an adverse shock event, initiating the first simulation lap. There are several types of such events:

- *"Local shock"*: A share of external assets is deducted from a random bank's balance sheet.
- *"Global shock"*: The external assets price drops. In this case, a certain percentage loss on these assets is applied to balance sheets of all banks.
- *"Sovereign shock"*: A sovereign defaults on a portion of its debt. In this case, the shock is transmitted to all banks that hold exposure towards this sovereign, i.e. the banks "domestic" to the defaulting state.

Similarly, at the beginning of each next lap, each bank may receive a total asset-side shock of $\Delta = \delta + PriceShock + GovernmentShock$, whose individual components are described in detail in the rest of this section.

If the banks affected by the primary shock do not possess sufficient capital buffers, a process of cascade contagion effects unfolds, where in each lap of the simulation, the banks that default transmit the shock further onto other banks in the system. Let us consider a bank that receives a shock. Whatever the shock type, it is reflected in the balance sheet and the bank loses a certain part of its assets. Since the sum of assets must equal the sum of liabilities, the bank writes off an equal value of liabilities. Firstly, the shocks are absorbed by own equity but if the capital buffers are not large enough, the banks default on claims of other creditors. If in lap t the i-th bank suffers a shock of size $\Delta_{i,t} = l_{i,t} - a_{i,t}$, its external behaviour depends on the shock size relative to its balance sheet structure:

a) At first, the shock hits the bank's capital buffer. If $c_{i,t} > \Delta_{i,t}$, meaning that the bank is able to cover the losses by its own equity, then the capital buffer absorbs the shock completely and the bank does not send it further to other agents in the system.

b) If $c_{i,t} < \Delta_{i,t}$, the residual shock overflows to the interbank liabilities b_i, in which case its value up to the value of the interbank liabilities is uniformly divided into losses of all creditor banks. Formally, in case of m creditor banks, in the next round each creditor bank j receives from bank i a shock of

$$\delta_{ij,t+1} = min\left(\frac{\Delta_{i,t} - c_{i,t}}{m_{i,t}}, \frac{b_{i,t}}{m_{i,t}}\right). \quad (1)$$

As the propagating bank defaults, in the next lap it is removed from the system. Also, in the next lap of the simulation, the creditor banks evaluate the received shock. The simulation finishes when there is a lap when no bank propagates the shock further.

c) Additionally, it holds that:

   i. If $b_{i,t} > \Delta_{i,t} - c_{i,t}$, the shock is absorbed completely by the bank's capital and interbank liabilities.

   ii. If $b_{i,t} < \Delta_{i,t} - c_{i,t,}$, the shock overflows to external liabilities, meaning that the residual loss is covered by the depositors.

2.4 Liquidity Risk Modelling

Generally, there are two types of liquidity issues that can affect a stressed financial system: market illiquidity and funding illiquidity.[5] The former, described firstly by Kyle (1985), represents a situation in which the assets that are sold have a negative impact on the asset prices. The latter refers to inability to meet obligations when they are due. In the recent financial crisis, we witnessed both: a sudden gap in short-term bank financing caused funding illiquidity on the liability side and the subsequent fire-selling of assets as the only means for cash replenishment resulted in further rapid decline in asset prices. Therefore, both these types are accounted for in the model.

2.4.1 Market Liquidity

Along with Gai and Kapadia (2010), we assume that in case a bank is in default, it has to liquidate all of its assets before it is removed from the system. While the sovereign debt is

[5] For more details on liquidity risk and its modelling in Central and Eastern Europe we refer to Gersl and Komarkova (2009) or more recently to Cernohorska et al (2012), Vodova (2013) or Mandel and Tomsik (2014).

assumed to be more liquid and hence is liquidated in full value, the low market depth may limit the capacity to absorb the external and interbank assets. As a result, these cannot be sold for the price for which they are kept in the bank's books. Following Cifuentes, et al. (2005), we assume an inverse demand function for external assets, which takes the form of

$$P(\boldsymbol{x})_t = \exp\left(-\frac{\alpha}{E}\sum_{i=1}^{N^b} x_{i,t}\right), \tag{2}$$

where $x_{i,t}$ is the total value of external and interbank assets sold by the i-th bank in the current lap, α represents the market's illiquidity (i.e. the speed at which the asset price declines) and $P(x)_t$ is the new discounted price of external assets calculated in each lap.[6] The additional loss caused by the asset sales is then added to the initial shock on i-th bank in the current lap and transmitted accordingly. Furthermore, assuming marking to market accounting procedure, at the end of each lap the external assets of each bank are revalued such that

$$e_{i+1} = e_{i,t}P(\boldsymbol{x})_t.$$

Hence, the losses stemming from such price adjustment result to a price shock of $PriceShock_{i,t+1} = e_{i,t}(P(\boldsymbol{x})_{t-1} - P(\boldsymbol{x})_t)$ to all banks.

2.4.2 Funding Liquidity

As the failing bank liquidates all of its assets, it may withdraw a certain portion of its claims on other banks classified as short-term credit. As a result, the debtors of the failing bank may receive a funding liquidity shock which decreases their liabilities and may require them to sell a portion of their assets to balance out the gap in funding (Chan-Lau, 2010).

If i-th bank defaults, the portion λ of interbank liabilities $b_{ji} = q_{ij}$ of its debtor j gets erased from the debtor j's total liabilities such that

$$l_{j,t} = l_{j,t-1} - \lambda b_{ji,t}.$$

Subsequently, the j-th bank is forced to fire-sale external assets in the value of the funding shock. This amount of external assets is added to the total amount offered by the banks in the current lap and the j-th bank receives for them $\lambda P(\boldsymbol{x})_t b_{ji,t}$. The value of the loss $(1 - P(\boldsymbol{x})_t)\lambda b_{ji,t}$ is added to the j-th bank's credit shock δ.

2.5 Sovereign Assistance to Banks and Sovereign Distress

As a means of sovereign to support its domestic banks, we introduce four possibilities of sovereign assistance: *asset relief*, *execution of state guarantees*, *bailouts and recapitalization* and finally *provision of funding liquidity*.

[6] Upon the system's initialization, the price is set to $P(\boldsymbol{x})_0 = 1$.

a. *Asset relief* (AR) – the sovereigns may buy what assets their domestic banks need to sell in fire sales. In this case, in each round every bank sells $x_{i,t}$ assets as described in the basic model definition, but only $(1-k^{AR})x_{i,t}$ is sold on the market since $k^{AR}x_{i,t}$ is bought-out by the bank's domestic government. Assuming $1-k^{AR}$ fixed across all banks and all sovereigns, the Equation 2 is replaced by:

$$P(\boldsymbol{x})_t = \exp\left(-\alpha(1-k^{AR})\sum_{i=1}^{N^b} x_{i,t}\right),$$

The amount of $deficit^{AR} = k^{AR}x_{i,t}$ is then added to the external debt of the i-th banks' domestic sovereign as the domestic government needs to find external financing for this rescue measure.

b. *State guarantees execution* (SG) – the sovereigns may reimburse the creditors of their domestic banks to a certain degree to lower the negative shocks. In case this measure is executed, the Equation 1 is replaced as each creditor j of bank i receives a credit shock of:

$$\delta_{j,t+1} = (1-k^{SG})min\left(\frac{\Delta_{i,t}-c_{i,t}}{m_{i,t}}, \frac{b_{i,t}}{m_{i,t}}\right).$$

The amount of $deficit^{SG} = \min\left(\frac{\Delta_{i,t}-c_{i,t}}{m_{i,t}}, \frac{b_{i,t}}{m_{i,t}}\right) k^{SG}$ is then added to the external debt of the i-th banks' domestic sovereign as the domestic government needs to find external financing for this rescue measure.

c. *Bailouts and recapitalization* (BR) – the sovereigns may pay for losses incurred by the banks to replenish their capital buffers and keep them in business. In this case when a bank i receives a shock of $\Delta_{i,t}$, the sovereign covers $k^{BR}\Delta_{i,t}$, adding this value to the bank's external assets. Again, the amount of $deficit^{BR} = k^{BR}\Delta_{i,t}$ is then added to the external debt of the i-th banks' domestic sovereign as the domestic government needs to find external financing for this rescue measure.

d. *Funding liquidity provision* (FLP) – the sovereigns may provide funding liquidity to balance out the funding shocks received by their domestic banks. In this case, the sovereign provides funding of $k^{FLP}\lambda b_{ji,t}$ to its domestic bank j in case of a shock coming from a failing bank i. As with all the previous measures, the sovereign needs to finance such measure by raising additional debt of the amount $deficit^{FLP} = k^{FLP}\lambda b_{ji,t}$.

However, resulting credit risk of sovereigns may feed back into the banking system, mainly via direct holdings of government debt by the financial sector (Caruana 2012). Moreover, Arslanalp and Tsuda (2012) confirm that domestic banks hold a significant portion of sovereign debt. Additionally, Merler and Pisani-Ferry (2012), Pisani-Ferry (2012) or Darvas et al (2014) point out that the bank holdings of sovereign debt show substantial "home bias". In the 2010 EBA Stress test sample, the average home bias in the banks' holdings of government bonds was near

60% and was the strongest in case of banks of the most distressed sovereigns of periphery countries (EBA, 2011). As a result, holdings of the home sovereign debt are perhaps the most important part of the negative feedback loop and so they form the cornerstone of our model.

First, sovereign assistance may work very well for short-term banking system stabilization, but it puts significant pressure on the intervening sovereigns. State assistance to banks requires that the sovereigns immediately issue new debt to finance such measures, which results in immediate increase in the sovereigns' credit risk through the liability side of their balance sheets (Acharya, et al. 2012). As mentioned previously, in the model, any type of sovereign assistance to the banks results in an increase of the debt of the domestic sovereign. The extra budget deficit resulting from the aid measures is the main driver of a credit risk increase in the model and is given as

$$deficit_{k,t} = deficit_{k,t}^{AR} + deficit_{k,t}^{SG} + deficit_{k,t}^{BR} + deficit_{k,t}^{FLP}.$$

Second, the sovereign credit risk in the model is represented by probability of default, which under a certain assumed recovery rate may be approximated from CDS spreads. Although strictly speaking, the extraction of this probability from the available 5-year CDS spreads would require diligent modelling of both the default state and the no-default state cash flows, we can simplify the calculation by assuming a flat CDS spread curve and implement a widely used approximation according to J.P. Morgan and Company and RiskMetrics Group (1999):

$$p_{k,t}^{default} = \zeta \left(1 - \frac{1}{\left(1 + \frac{CDS_{k,t}}{1 - RR}\right)^{\tau}} \right), \tag{3}$$

where $p_{k,t}^{default}$ is the probability that a given sovereign defaults in one year, $CDS_{k,t}$ is the annual CDS spread expressed as a decimal (e.g. if the spread is 500 basis points, $CDS_{k,t}$ is equal to 0.05), RR is the recovery rate and t is the number of years for the cumulative default probability calculation (in our case, $\tau = 1$).[7]

Third, the link between sovereign deficits and credit risk is documented by econometric studies such as Attinasi, et al. (2009) or Cottarelli and Jaramillo (2012). We use the following equation to update the sovereign CDS spreads at the end of each simulation lap:

$$CDS_{k,t+1} = CDS_{k,t} + \beta \frac{deficit_{k,t}}{GDP_k}. \tag{4}$$

[7] Moreover, as we agree with the criticism of using CDS implied probability of default pointing out that the additional premiums such as the market price of risk or liquidity premium included in the spread may result in biased estimations (e.g. Amato (2005) or Remolona, et al.(2007)), this relationship may be parameterized by a factor $\zeta \in (0,1)$ to account for the overestimation of the default probabilities.

Thus the CDS spread in period $t+n$ takes into account the previous n periods and their respective deficits. In other words, the CDS spread in period $t+n$ takes into account the accumulated debt.

Putting the previous three points together, at the end of each lap the model collects the total amount of each sovereign's deficit and feeds it into Equation 4 which is then itself plugged into Equation 3. The resulting probability of default of a sovereign k in lap $t+1$ is then

$$p_{k,t+1}^{default} = \zeta\left(1 - \frac{1}{\left(1 + \frac{CDS_{k,t} + \frac{c_1\left(deficit_{k,t}^{AR} + deficit_{k,t}^{SG} + deficit_{k,t}^{BR} + deficit_{k,t}^{FLP}\right)}{GDP_k}}{1 - RR}\right)}\right).$$

At the beginning of each simulation lap, a sovereign k may default with probability $p_{k,t}^{default}$. In that case, each creditor bank incurs a loss of $GovernmentShock = \boldsymbol{s_i}(1 - RR)$ and revalues the sovereign debt on its balance sheet accordingly.

3 Monte Carlo Simulations

This section presents the results of the Monte Carlo simulations performed with our model. First, we describe the simulation process and how the model is controlled. Second, we analyse the model's behaviour under various settings of the network structure and global parameters. Third, we introduce sovereign assistance to the banks and examine efficiency of the individual support measures given that the states have unlimited access to funds. Fourth, we describe the system behaviour when a sovereign defaults and show what parameters have the greatest effect on systemic stability in this case. Finally, putting it all together with the risk transfer mechanism from the banks to sovereigns and a feedback loop back to the banking system, we provide a comprehensive model allowing us to test the individual support measures under various circumstances.

3.1 Model Control

Monte Carlo simulations are based on comparative statics experiments where the simulations are performed under varying combinations of input parameters.[8] In each experiment, the simulation is launched under a set of different parameter settings where some of the parameters are fixed and some vary as they are fed to the model in a form of a loop on a certain predefined interval. To obtain the results for each parameter combination, we run the model in several repetitions, each with a different realization of its random variables, and we average the resulting observed variable into a single data point. This approach is in line with Nier, et al.

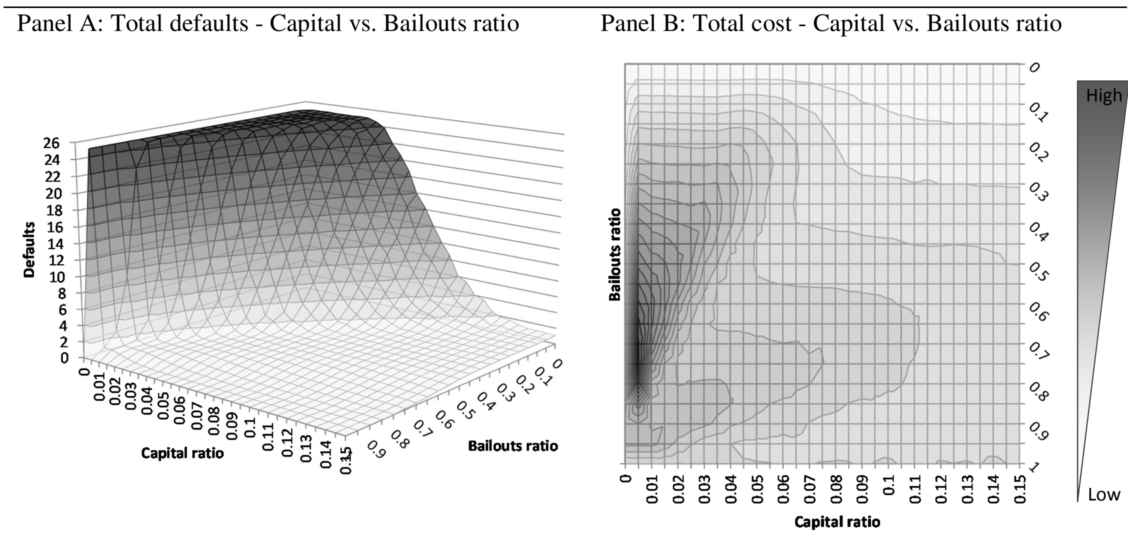
[8] The model was programmed in plain Java. The input parameters are set prior to the simulation launch. As an output, the model produces a csv file with data that may be subsequently analysed in any statistical software.

(2007). However, since our model (consisting of 25 banks) runs fast enough to achieve the results of much higher iteration count in reasonable time, we run each parameter setting 500 or even 1000 times instead of the original 100 iterations. This allows us to present readable charts without further smoothing and ensures higher robustness of our results (Klinger and Teply, 2014). Because the simulations are not based on real-world data but rather describe the general system behaviour, we are more interested in the observable patterns than in particular numerical results. Hence, we visualize the simulation outcomes by surface or heat map plots, which allow us to observe the effects of two varying parameters at once.

3.2 Sovereign Assistance

This section evaluates the positive impact of state support on systemic stability as well as the cost of the support measures. Note that the feedback loops are not introduced yet and although it shows the costs of the support measures, the following analysis does not include the propagation of sovereign weakness back into the banking system. Due to the limited scope of this paper, we will restrict the analysis on *bailouts and recapitalization* of institutions that are receiving negative shocks. As mentioned in Section 2.5, in this case the domestic sovereign pays for some fraction of the losses before the receiving institution writes down its capital and hence it is conceptually the same as providing additional capital to the receiving institution. Figure 1a shows how many of the initial 25 banks default given certain capital ratio and certain bailout ratio (i.e. how large portion of the bank's loss is covered by the public sector). It demonstrates the relatively high efficiency of this measure which manages to prevent a systemic breakdown. With low bank capital ratio levels, there is always a short interval of the amount of state support on which the support measure becomes effective (i.e. that the number of defaults is decreasing with the bailouts ratio). Moreover, it holds that the lower the capital ratio, the shorter this interval.

Figure 1: Bailouts and recapitalization effects



Source: Authors
Note to Panel A: Our modelling network consists of 25 banks. The vertical axis ticks are spaced by two defaults so the maximum tick on the axis amounts to 26.
Note to Panel B: Darker colour indicates a higher extra deficit caused by the measure.

Figure 1b shows the "costs" of the bailouts represented by the total extra deficit resulting from the measure. We see that at low capital levels, the relationship between the deficit and the intensity of the bailout measure is positive and linear up to a certain bailout ratio behind which it becomes negative, falling back to relatively low levels. TK At a given capital level, the highest bailout costs arise at the level of bailout intensity which is high enough to represent a significant cost to the domestic sovereign but still too low to prevent the shocks from spilling over the banks' capital barriers onto the next line of creditors. Moreover, in this situation the failing bank liquidates its assets, further worsening the situation through the market liquidity channel. Beyond such level of bailout intensity, the number of defaults suddenly drops as the bailout measure becomes effective.

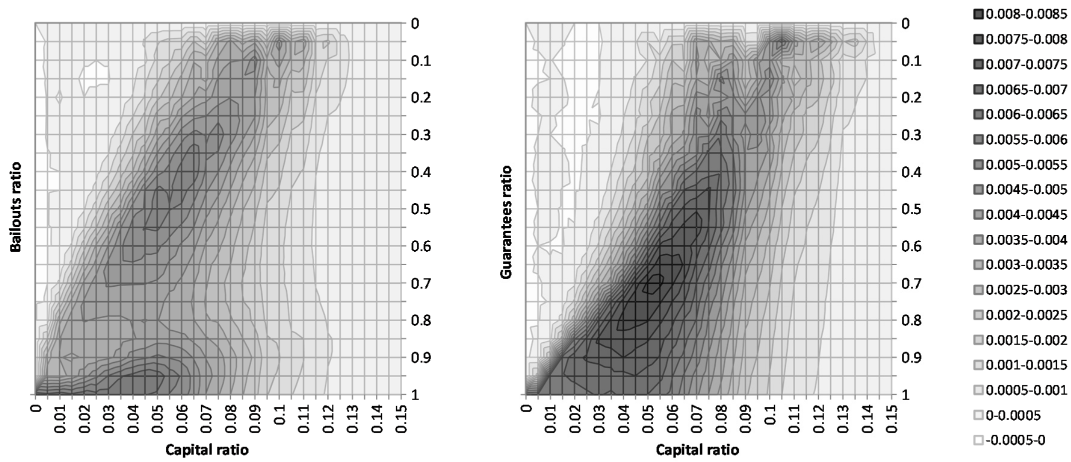
3.3 Cost Efficiency of the Support Measures

Individual support measures may be compared in terms of cost-benefit efficiency, as shown in Figure 2. To obtain the values of cost efficiency for each support intensity value (horizontal axis), we first calculated how many less banks fail compared to the situation of no state support. This measure, representing the benefit of the individual measures, is then divided by the extra deficit associated with its execution. As a result, the individual panels of Figure 2 depict how many banks are saved by one currency unit of state support.

Figure 2: Cost-benefit analysis of state support measures

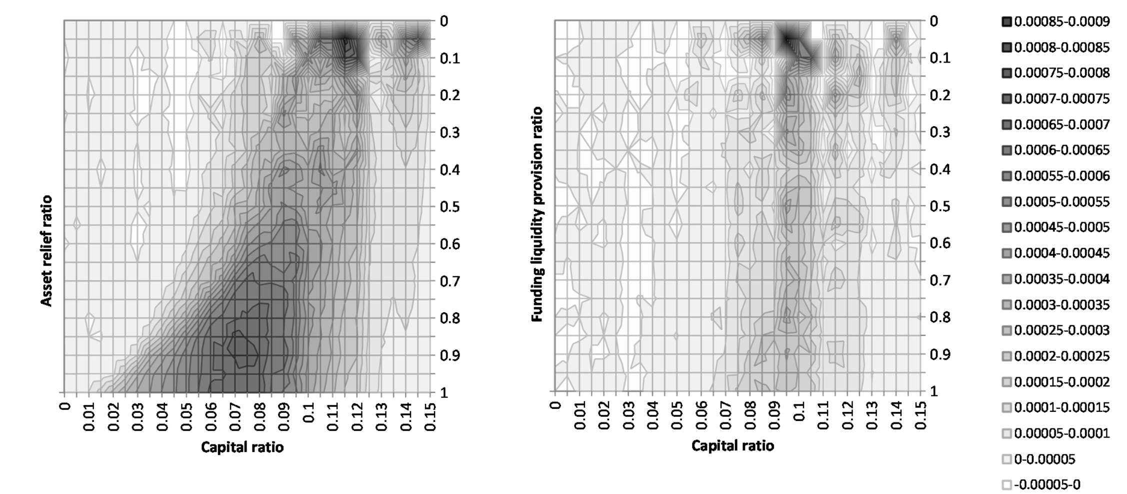
Panel A: Bailouts and recapitalization

Panel B: Guarantees execution



Panel C: Asset relief

Panel D: Funding liquidity provision



Source: Authors
Note 1: The scale of the response variable in panels A and B is ten times larger than in C and D.
Note 2: The darker colour indicates higher efficiency of state support for a particular measure.

The first finding is that direct support such as bailouts and guarantees proves much more efficient than measures which aim only on the resulting liquidity issues. Due to such disproportion in effectiveness, in Figure 2a and Figure 2b, the support efficiency is plotted on ten times higher scale than in case of Figure 2c and Figure 2d. Second, on both Figure 2a and Figure 2b, we see a diagonal pattern where the state support is most efficient. This corresponds e.g. with the diagonal area in Figure 1a when the system is changing its state from stable to failed. The interpretation of this finding is that the state aid works in the most cost-effective way when the system is *on the verge* of collapse, i.e. it is useless to pump more funds into it when it would collapse at any rate but also it is useless to help the banks when they are out of danger. TK Furthermore, Figure 2c shows that although the efficiency in case of asset relief is ten times lower, the pattern is similar, only with the area of higher efficiency shifted further to the right. Again, this is caused by the asset relief being even less direct support measure in relation to the initial shock than state guarantees. Finally, it is clear from Figure 2d that given this parameter setting, funding liquidity provision is not an effective support for systemic stability.

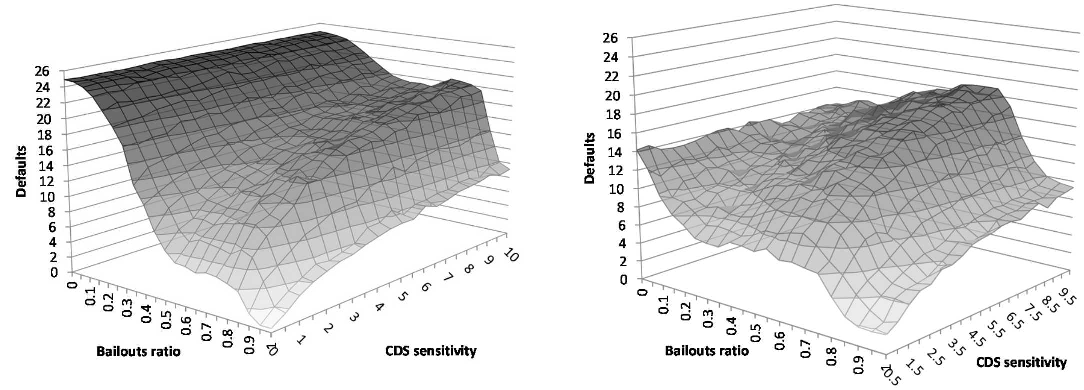
3.4 Feedback Loops

Putting together the results of banking crises, state support and the effects of state defaults, we may close the feedback loop by implementing a mechanism connecting the state support and state defaults. First, according to Equation 3 in Section 2.5, a sovereign may default with probability implied from its CDS spread. As the CDS spreads contain not only the premium for credit risk of the insured bonds but also additional premiums such as the market price of risk or liquidity premium, we adjust the CDS-implied probability by a parameter $\zeta \in (0,1)$, which we set to 0.5. Although the decision on its value is rather arbitrary, the results' dependence on this parameter is linear with moderate slope and so the choice of its value does not degrade the robustness of the model. We also implement the relationship between state support and sovereign risk. Again, due to the scope of this paper, we present detailed results only for *bailouts* *and recapitalization*. Finally, the results of *funding liquidity provision* are not presented as this support measure did not prove to have almost any significant positive effects.

Figure 3: Bailouts and recapitalization with feedback loops

Panel A: Bailouts ratio vs. CDS sensitivity, Capital ratio = 0.04

Panel B: Bailouts ratio vs. CDS sensitivity, Capital ratio = 0.08



Source: Authors

Note: Our modelling network consists of 25 banks. The vertical axis ticks are spaced by two defaults so the maximum tick on the axis amounts to 26.

Figure 3 shows the behaviour of the system when the crisis is tackled by *bailouts and recapitalization* of the troubled banks. Figure 3a depicts a collapsing system at capital ratio of 4%. Here we see that at low CDS sensitivity to deficits resulting from the support measures (parameter β), bailouts are truly effective for crisis mitigation. Especially in the first half of the bailout intensity interval, state action manages to decrease the number of defaulted banks significantly. However, with increasing CDS sensitivity, the measure becomes less and less effective. Also, at higher CDS intensity levels, an interesting pattern appears where higher bailout intensity does not necessarily mean less total defaults. This is because at bailout intensity of 0.8, state action weakens the sovereigns more than it supports the banks. On even higher bailout intensities, however, the measure becomes effective again as it almost completely blocks the systemic crisis, restraining it to only zero to ten failed banks, depending on the CDS sensitivity.

Figure 3b depicts the situation at a higher capital ratio of 8%. We still see that, state support may slightly ease the situation at very low CDS sensitivity levels. However, when the market perceives additional deficits as more risky and hence the CDS sensitivity is high, state support weakens the sovereigns significantly and is potentially harmful to the system. Nevertheless, it holds again that with full bailout intensity, the bailout measure remains effective for crisis mitigation.

3.5 Results Summary

In case of negative shocks, the banks may be supported by four main state aid measures: bailouts, guarantees, asset relief or provision of funding liquidity which on one hand may weaken the sovereigns but on the other hand may contribute significantly to systemic stability.

In the simulation setting, bailouts and guarantees proved to be the best measures in terms of effectiveness as well as cost efficiency. Asset relief was also effective but due to its large costs did not measure up to the former two. Finally, funding liquidity provision had very little effect on systemic stability but is rather expensive for the sovereigns. Unlike Klinger and Teplý (2014), who focused on bailouts and recapitalization, here we expand our research to other three support measures to the banks in trouble: guarantees execution, asset relief and funding liquidity provision.

Table *2* provides the summary of these support measures.

Table 2: Impact of individual support measures

Measure	Effectiveness	Cost-efficiency	Description
Bailouts and recapitalization	+++++	+++++	Captures shocks before they hit the receiving bank
Guarantees execution	++++	++++	Captures shocks the receiving bank propagates onto its creditors
Asset relief	+++	+	Eases the asset price decline by absorbing a portion of external assets that would be otherwise fire-sold on the market
Funding liquidity provision	+	0	Captures funding shocks by providing liquid assets to the banks whose creditor defaults and who would not be able to renew their credit lines

Source: Authors

Note: The number of plus signs "+" represents the degree of positive effect. Zero "0" represents mixed or neutral effect.

Even though some are effective in the short run, in longer run the support measures weaken the sovereigns through extra deficits and increase the probability of a sovereign default. Failing sovereigns then return the shock to the banking system through negative feedback loops. Generally, for systems in total collapse, state aid may significantly ease the extent of the crisis despite sovereigns being weakened by the support. However, especially in situations when only some part of the system is destabilized and when the sovereigns' default probabilities are sensitive to extra deficits, the state support may be worse than the case of no state intervention. Last but not least, the application of support measures was biased by the 'privatization of profits and socialization of losses' approach by politicians in many developed countries as documented by the mentioned EUR 1.6 trillion national support to the EU banking sector between October 2008 and 31 December 2011. As a result, the related costs were borne by the taxpayer through bail-outs rather than by financial institutions´ shareholders through bail-ins. Despite some pending regulatory efforts to avoid taxpayers´ involvement in banks´ bail-outs, we agree with Sutorova and Teply (2013; 2014) stating that the recent global banking regulation Basel III is not sufficient and will neither protect financial markets from future crises nor the taxpayer from further subsidies to banking industry.

3.6 Further research opportunities

In our further research, we plan to calibrate the model to the increasingly available and more complete real world data. The interbank network may be modelled at aggregate scale, using banking systems exposure matrix based on data from BIS International Financial Statistics. In this case, foreign claims data on immediate borrower basis from the consolidated banking statistics may be used similarly as in Chan-Lau (2010). Alternatively, we may take a sample of real-world banks and construct an interbank exposure network based on a probability map similar to the recent research of the ECB's Halaj and Sorensen (2013), who constructed such network for the banks that reported during the 2010 and 2011 EBA stress tests. As sources of the rest of the data necessary for the model calibration we may use databases such as Bankscope, IMF International Financial Statistics database, Arslanalp and Tsuda (2012) or individual central banks' databases. Moreover, it is important to stress out the flexibility and extensibility of our modelling approach, which may lead to many more conclusions. In the future, it allows us to add features of financial systems that will be subject to most current discussions.

4 Conclusion

In this paper we built an agent-based network model of an artificial financial system to illustrate the interconnectedness between systemic risk and sovereign crises. Our approach is suitable for stress testing of banks, determining the boundaries for parameters of banking regulation and most importantly for testing the effects of various types of state support in both the short- and the long run. Subsequently, we used Monte Carlo simulations and testing the nexus between financial crises and sovereign crises through four types of support measures: i) bailouts and recapitalization, ii) execution of state guarantees, iii) asset buy-outs and iv) provision of funding liquidity. Our analyses showed that in the short term or when the feedback loop of risk transfer from sovereigns to the financial system is not active, all the support measures improve the systemic stability. When the feedback loops are implemented, the effects of state support depend on several parameters: there are settings in which it significantly mitigates the systemic crisis and settings in which it contributes to the systemic collapse. Finally, there are differences among rescue measure types used by governments and central banks. While bailouts and recapitalization are the most efficient support type and guarantees execution are still a viable solution, the results of liquidity measures such as asset relief or funding liquidity provision are significantly worse. These findings are intuitive and reflect the reality as asset relief is obviously very costly for a government. On a related note, liquidity support from central banks means a temporary help to the banks in liquidity problems but cannot help the banks facing solvency problems in the long-term. We also show that especially in situations when only some part of the system is destabilized and when the sovereigns' default probabilities are sensitive to extra deficits, the state support may be worse than the case of no state intervention.

References

Acemoglu D, Ozdaglar A, & Tahbaz-Salehi A (2013). Systemic Risk and Stability in Financial Networks. NBER Working Papers 18727, National Bureau of Economic Research, Inc.

Acharya V V, Drechsler I & Schnabl P (2012): A tale of two overhangs: the nexus of financial sector and sovereign credit risks. *Banque de France Financial Stability Review*, April, Issue 16.

Allen F, Gale D (2000): Financial Contagion. *Journal of Political Economy*, 108(1):1-33.

Amato J (2005): Risk Aversion and Risk Premia in the CDS Market. *BIS Quarterly Review*, December, 55-68.

Arslanalp S, Tsuda T (2012): Tracking Global Demand for Advanced Economy Sovereign Debt. *IMF Working Paper 12/284*.

Attinasi M-G, Checherita C, Nickel C (2009): What Explains the Surge in Euro Area Sovereign Spreads During the Financial Crisis of 2007-09?. *ECB Working Paper No. 1131*, December.

Battiston S, Delli Gatti D, Gallegati M, Greenwald B, Stiglitz J E (2012): Default cascades: When does risk diversification increase stability? *Journal of Financial Stability,* 8(3):138-149.

Blasques F, Bräuning F, van Lelyveld I (2015): A dynamic network model of the unsecured interbank lending market. BIS Working Papers No 491/2015.

Borensztein E, Panizza U (2009): The Costs of Sovereign Default. *IMF Staff Papers*, 56(4):683-741.

Bucher M, Hauck A, Neyer U (2014). Frictions in the Interbank Market and Uncertain Liquidity Needs: Implications for Monetary Policy Implementation (July 9, 2014). Available at SSRN: http://ssrn.com/abstract=2490908 or http://dx.doi.org/10.2139/ssrn.2490908

Campolongo F, Marchesi M, De Lisa R (2011): The Potential Impact of Banking Crises on Public Finances: An Assessment of Selected EU Countries Using SYMBOL. *OECD Journal: Financial Market Trends*, 2(23):73-84.

Caruana J (2012): Financial and Real Sector Interactions: Enter the Sovereign 'Ex Machina'. *BIS Working Papers No. 62*, 9-19.

Cernohorska L, Teply P, Vrabel M (2012): The VT Index as an Indicator of Market Liquidity Risk in Slovakia. *Journal of Economics*, 60(3):223–238.

Cifuentes R, Ferruci G, Shin H S (2005): Liquidity risk and contagion. *Journal of the European Economic Association*, 3(2):556-566.

Cochrane, J. (2013). Finance: Function Matters, Not Size. Journal of Economic Perspectives 27 (2), 29-50.Cottarelli C, Jaramillo L (2012): Walking hand in hand: Fiscal policy and growth in advanced economies. *IMF Working Paper 12/137*.

Craig V, Dinger V (2013): Deposit market competition, wholesale funding, and bank risk. *Journal of Banking & Finance*, 37, 3605-3622.Darvas Z, Hüttl P, Merler A, de Sousa C, Walsh T (2014): Analysis of developments in EU capital flows in the global context. Final Report Bruegel N° MARKT/2013/50/F

Dewally M, Yingying s (2014): Liquidity crisis, relationship lending and corporate finance. *Journal of Banking & Finance*, 39, 223-239.

Dias J (2012): Sovereign Debt Crisis in the European Union: A Minimum Spanning Tree Approach. *Physica A-Statistical Mechanics and Its Applications*, 391(5):2046-2055.

EBA (2011): European Banking Authority 2011 EU-Wide Stress Test Aggregate Report. London: European Banking Authority.

Enderlein H, Trebesch C, von Daniels L (2012): Sovereign Debt Disputes: A Database on Government Coerciveness During Debt Crises. *Journal of International Money and Finance*, 31(2):250-266.

Estrella A, Schich S (2011): Sovereign and Banking Sector Debt: Interconnections through Guarantees. *OECD Journal: Financial Markets Trends*, Issue 2.

European Commission (2012): Facts and Figures on State Aid in the EU Member States. *Commision staff working document.*

Farboodi, M. (2014). Intermediation and Voluntary Exposure to Counterparty Risk. Available at: http://bfi.uchicago.edu/research/working-paper/intermediation-and-voluntary-exposure-counterparty-risk-0Fidrmuc, J, Schreiber P, Siddiqui M (2014): The Transmission of Bank Funding to Corporate Loans: Deleveraging and Industry Specific Access to Loans in Germany. Available at: http://ies.fsv.cuni.cz/default/file/get/id/26564.

Freixas X, Parigi B, Rochet J C (2000): Systemic risk, Interbank relations and liquidity provision by the Central Bank. *Journal of Money, Credit, and Banking*, 32(3):611-638.

Gai P, Kapadia S (2010): Contagion in financial networks. *Proceedings of the Royal Society A*, 466(2120):2401-2423.

Gale D M, Kariv S (2007): Financial Networks. The American Economic Review, 97 (2): 99–103.

Georg C P (2013): The Effect of the Interbank Network Structure on Contagion and Financial Stability. *Journal of Banking and Finance*, 77(7): 2216 – 2228.

Gersl A, Komarkova Z (2009): Liquidity risk and banks' bidding behavior : evidence from the global financial crisis. Czech Journal of Economics and Finance, 59(6):577-592.

Gofman, M (2014): Effciency and Stability of a Financial Architecture with Too-Interconnected-to- Fail Institutions. Available at http://gofman.info/SMM/Gofman_Financial_Architecture.pdf

Hansen L P (2013): Challenges in Identifying and Measuring Systemic Risk, NBER Working Papers, No 18505.

Halaj G, Sorensen C K (2013): Assessing interbank contagion using simulated networks. ECB Working Paper No. 1506, January.

Chan-Lau J (2010): Balance Sheet Network Analysis of Too-Connected-to-Fail Risk in Global and Domestic Banking Systems. IMF Working Paper 10/107.

J.P. Morgan and Company, RiskMetrics Group (1999): *The J.P. Morgan Guide to Credit Derivatives: With Contributions from the RiskMetrics Group.* s.l.:Risk Publications.

Klinger T, Teply P (2014): Systemic risk of the global banking system - an agent-based network model approach. *Prague Economic Papers*, 23(1): 24–41.

Kyle A S (1985): Continuous auctions and insider trading. *Econometrica*, 53(6):1315–1335.

Laeven L, Valencia F (2008): Systemic Banking Crises: A New Database. *IMF Working Paper 8/224.*

Laeven L, Valencia F. (2012): Systemic Banking Crises: An Update. *IMF Working paper 12/163.*

Manasse P, Roubini N (2009): "Rules of Thumb" for Sovereign Debt Crises. *Journal of International Economics*, 78(2):192-205.

Mandel M, Tomsik V (2014): Monetary policy efficiency in conditions of excess liquidity withdrawal. *Prague Economic Papers*. 23(1): 3-23.

Merler S, Pisani-Ferry J (2012): Hazardous tango: Sovereign-bank interdependence and financial stability in the euro area. *Banque de France Financial Stability Review*, April, Issue 16.

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

Pisani-Ferry J (2012): The euro crisis and the new impossible trinity. *Bruegel Policy Contribution 2012/01*, January.

Reinhart C M, Rogoff K (2009): *This Time Is Different: Eight Centuries of Financial Folly.* 1st ed. s.l.:Princeton University Press

Remolona E M, Scatigna M, Wu E (2007): Interpreting Sovereign Spreads. *BIS Quarterly Review*, March, 27-39.

Shin H S (2008): Risk and Liquidity in a System Context. *Journal of Financial Intermediation*, 17(3):315-329.

Sutorova B, Teply P (2013): The impact of Basel III on lending rates of EU banks," *Czech Journal of Finance*, 63(3): 226–243.

Sutorova B, Teply P (2014): The Level of Capital and The Value of EU banks under BASEL III. *Prague Economic Papers*, 23(2): 143–161.

Vuillemey G, Breton R (2014): Endogenous Derivative Networks. Working Papers 483, Banque de France.Vodova, P (2013): Liquid assets in banking: what matters in the Visegrad countries?

E & M EKONOMIE A MANAGEMENT. 16(3): 113-129.