

# The Nexus Between Systemic Risk and Sovereign Crises\*

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## Abstract

*This paper focuses on the relationship between the financial system and sovereign debt crises by analyzing 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 analyze 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: first, in the short term, all the support measures improve systemic stability. Second, in the longer run, there are settings which mitigate the systemic crisis and settings which contribute to systemic breakdown. Finally, there are differences among the effects of the different types of support measures. While bailouts and recapitalization are the most efficient types of support type and execution of guarantees is still a viable solution, the results of liquidity measures such as asset relief or provision of funding liquidity are significantly worse.*

## 1. Introduction

The recent global financial crisis emphasized the importance of the link between the financial and the sovereign sectors. The pre-crisis financial order is characterized by risk build-up connected to banking deregulation after the collapse of the Bretton Woods system, when 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 aimed at supporting the financial system, including bailouts and recapitalization, state guarantees, asset relief and provision of funding liquidity. The European Commission (2012) estimated that the volume of state aid Provided to the EU banking sector between October 2008 and 31 December 2011 amounted to 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 sectors.

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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, and Reinhart and Rogoff (2009), who explore the history of sovereign countries in individual case studies. In terms of sovereign assistance, Enderlein *et al.* (2012) analyze the behavior of governments which find themselves on the verge of default. Borensztein and Panizza (2009) examine possible costs to a 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 a description of the links they had to the sovereign sector. Hansen (2013) highlights the challenge of quantifying systemic risk and discusses the pros and cons of modeling and measuring systemic risk. With respect to the liquidity-funding problems of banks during periods of financial distress, Craig and Dinger (2013) propose a new empirical approach focused on the relationship between deposit market competition and bank risk. More recently, Bucher *et al.* (2014) analyze the importance of banks' liquidity management in a global low-interest-rate environment. Fidrmuc *et al.* (2014) and Dewally and Yingying (2014) discuss the effects of banks' 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 global level. It examines the role of the sovereigns as providers of bank aid and members of the financial network as such.<sup>1</sup> 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) were the first to present 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 analyze systemic stability by means of simulation experiments, such as Nier *et al.* (2007), Gai and Kapadia (2010) and Battiston *et al.* (2012), who use simulation models to examine how different parameters of the banking system affect its resilience. In general terms, the effects of the network structure on financial contagion has been discussed by, among others, Acemoglu

<sup>1</sup> For a general discussion on the formation of financial networks, we refer the reader to Gale and Kariv (2007), Farboodi (2014) and Vuillemin and Breton (2014).

*et al.* (2013), Cochrane (2013), Georg (2013), Gofman (2014), and van Wincoop (2013). Recently, Blasques *et al.* (2015) presented a dynamic network model of the unsecured interbank lending market.

This paper is extension of Klinger and Teplý (2014), where the authors used agent-based network simulations to assess the impact of various settings of banking regulation on systemic stability. Although it uses a similar modeling framework, this paper brings completely new insight into the 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 Section 2, 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 Section 3, we test the model in Monte Carlo simulations in order to get a better understanding of its inner processes and its results. Finally, in Section 4 we conclude the paper with a summary of our research and key findings.

## 2. The Model

As mentioned above, we follow a similar modeling framework for the bank network as that used in Klinger and Teplý (2014). However, in this paper we expand our model by including the nexus between banks and sovereigns, which makes our methodology unique. While focusing in our previous paper primarily on the impact of shocks on the capital adequacy of the investigated banks, here we add four state-aid measures to the troubled banks, construct a feedback loop between the failing states and the banking system and discuss the efficiency of state aid (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, 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 rounds until the initial shocks completely dissolve and are not further transmitted to other agents.

### 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 to be fixed among all edges<sup>2</sup> between

<sup>2</sup> This assumption may be relaxed when the model is calibrated to relevant data. However, we leave this possibility to further research.

all nodes  $i, j \in (1, \dots, N^b)$  and denote it as  $p^b$ . As a result, not all banks are connected to each other 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, an edge is created with probability  $p^b$  for each oriented pair of banks.

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 and banks-to-foreign-sovereigns. For introduction 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  $i \in (1, \dots, N^b)$ , one sovereign  $k \in (1, \dots, N^{s,INIT})$  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 to any of the banks are removed from the system and the number of remaining sovereigns is denoted as  $N^s$ .

## 2.2 Initializing the Balance Sheets<sup>3</sup>

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

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

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  $\theta$  are given exogenously. The total value of all assets in the system  $A$  is determined by these as follows:

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

<sup>3</sup> 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 that the others remain fixed (*ceteris paribus*). Hence, this does not mean that relationships in this section describe the behavior of individual balance sheet variables; it is merely an algorithm for the system initialization *before* the simulation is launched by an initial shock.

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

$$Q = \theta A$$

Finally, it holds that:

$$A = S + Q + E$$

3. In line with Nier *et al.* (2007) and Gai and Kapadia (2010), for the purposes of the Monte Carlo simulation the interbank exposures are assumed to be 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 to be homogenous across sovereigns. Denoting the sum of outgoing edges from banks to the  $k$ -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 the interbank assets ( $q_i$ ) and liabilities ( $b_i$ ) of each bank are determined by the interbank edge value (weight) and the 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 the  $i$ -th bank's incoming edges and  $z_i^{OUT}$  is the number of its outgoing edges.<sup>4</sup>

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. The value of the external assets 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  $\tilde{e}_i$ :

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

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

**Table 1 Balance Sheet Variables of a Modeled 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' calculations.

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

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

8. Each bank's capital buffer ( $c_i$ ) is determined as its total assets ( $a_i$ ) times the capital ratio  $\gamma_i$ . In line with Nier *et al.* (2007) and Chan-Lau (2010), the capital ratios are assumed to be the same across all banks and are denoted as  $\gamma$ :

$$c_i = \gamma a_i$$

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 created, 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, as the mechanics are driven there 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 modeling the shock transmission from sovereigns back to the banks). However, bank credit is not the only source for funding budget deficits, as other debt external to the model is allowed for. Upon initialization of the system, 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 the 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 to 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. First, the shocks are absorbed by the bank's own equity but if the capital buffers are not large enough, the bank defaults 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 behavior 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 with 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 the 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 Modeling

Generally, there are two types of liquidity issues that can affect a stressed financial system: market illiquidity and funding illiquidity.<sup>5</sup> The former, first described 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 the inability to meet obligations when they are due. In the recent financial crisis, we witnessed both:

<sup>5</sup> For more details on liquidity risk and its modeling in Central and Eastern Europe, we refer the reader to Geršl and Komárková (2009) and, more recently, to Černožorská *et al.* (2012), Vodová (2013) and Mandel and Tomšík (2014).

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 of cash replenishment resulted in a 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 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:

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

where  $x_{i,t}$  is the total value of external and interbank assets sold by the  $i$ -th bank in the current lap,  $\alpha$  represents the market's illiquidity (i.e. the speed at which the asset price declines) and  $P(\mathbf{x})_t$  is the new discounted price of external assets calculated in each lap.<sup>6</sup> The additional loss caused by the asset sales is then added to the initial shock to the  $i$ -th bank in the current lap and transmitted accordingly. Furthermore, assuming the marking-to-market accounting procedure, at the end of each lap the external assets of each bank are revalued so that  $e_{i,t+1} = e_{i,t}P(\mathbf{x})_t$ .

Hence, the losses stemming from such price adjustment result in a price shock of  $PriceShock_{i,t+1} = e_{i,t}(P(\mathbf{x})_{t+1} - P(\mathbf{x})_t)$  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 the  $i$ -th bank defaults, the portion  $\lambda$  of interbank liabilities  $b_{ji} = q_{ij}$  of its debtor  $j$  gets erased from the debtor  $j$ 's total liabilities so that  $l_{j,t} = l_{j,t-1} - \lambda b_{ji,t}$ .

Subsequently, the  $j$ -th bank is forced to carry out a fire sale of its 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  $\lambda P(\mathbf{x})_t b_{ji,t}$ . The value of the loss  $(1 - P(\mathbf{x})_t) \lambda b_{ji,t}$  is added to the  $j$ -th bank's credit shock  $\delta$ .

<sup>6</sup> Upon the system's initialization, the price is set to  $P(\mathbf{x})_0 = 1$ .



## 2.5 Sovereign Assistance to Banks and Sovereign Distress

As ways for a 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*.

- a) *Asset relief (AR)*: The sovereigns may buy whatever 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 that  $1 - k^{AR}$  is fixed across all banks and all sovereigns, Equation 2 is replaced by:

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

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

- b) *Execution of state guarantees (SG)*: The sovereigns may reimburse the creditors of their domestic banks to a certain degree in order to reduce the negative shocks. In the case that this measure is executed, Equation 1 is replaced as each creditor  $j$  of bank  $i$  receives a credit shock of:

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

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 bank's 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 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 bank's 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 offset 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 the 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 in the amount of  $deficit^{FLP} = k^{FLP} \lambda b_{ji,t}$ .

However, the 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) and 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 the case of banks of the most distressed sovereigns of periphery countries (EBA, 2011). As a result, holdings of the domestic 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 stabilization of the banking system, 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 an 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 domestic sovereign’s debt. 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 the probability of default, which under a certain assumed recovery rate may be approximated from CDS spreads. Although, strictly speaking, extraction of this probability from the available five-year CDS spreads would require diligent modeling 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):

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

where  $p_{k,t}^{default}$  is the probability that a given sovereign will default 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,  $\tau = 1$ ).<sup>7</sup>

<sup>7</sup> 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 (see, for example, Amato, 2005, or Remolona *et al.*, 2007), this relationship may be parameterized by the factor  $\zeta \in (0,1)$  to account for the overestimation of the default probabilities.

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

$$CDS_{k,t+1} = CDS_{k,t} + \beta \frac{deficit_{k,t}}{GDP_k} \quad (4)$$

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 the sovereign  $k$  in lap  $t+1$  is then

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

At the beginning of each simulation lap, the sovereign  $k$  may default with probability  $p_{k,t}^{default}$ . In that case, each creditor bank incurs a loss of  $GovernmentShock = s_i (1 - RR)$  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 analyze the model's behavior under various settings of the network structure and global parameters. Third, we introduce sovereign assistance to the banks and examine the efficiency of the individual support measures, given that the states have unlimited access to funds. Fourth, we describe the system's behavior when a sovereign defaults and show which 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 the sovereigns and putting a feedback loop back into 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.<sup>8</sup> 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 into the model in the form of a loop at 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.* (2007). However, since our model (consisting of 25 banks) runs fast enough to achieve the results of a much higher iteration count in a reasonable time, we run each parameter setting 500 or even 1,000 times instead of the generally used 100 iterations. This allows us to present readable charts without further smoothing and ensures higher robustness of our results (Klinger and Teplý, 2014). Because the simulations are not based on real-world data but rather describe the general system behavior, 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.

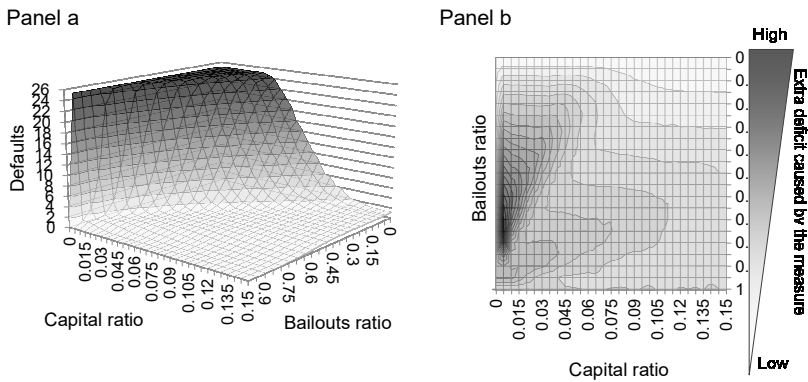
### 3.2 Sovereign Assistance

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 have not been 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 illustrate the analysis of *bailouts and recapitalization* of institutions that receive 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 this is thus conceptually the same as providing additional capital to the receiving institution. *Figure 1a* shows how many of the initial 25 banks default given a certain capital ratio and certain bailout ratio (i.e. how large a 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 at which the support measure becomes effective (i.e. at which the number of defaults decreases with the bailout ratio). Moreover, it holds that the lower the capital ratio, the shorter this interval.

*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 non-linear: it is positive up to a certain bailout ratio behind which it becomes negative, with the deficit falling back to relatively low values. At a given capital level, the highest bailout costs arise at the level of bailout intensity, which is high enough to represent

<sup>8</sup> 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 analyzed in any statistical software.

**Figure 1 Bailouts and Recapitalization Effects**



*Notes to Panel A:* Our modeling network consists of 25 banks. The vertical axis ticks are spaced at two -  
*Note to Panel B:* The darker color indicates a higher extra deficit caused by the measure.

*Source:* Authors' calculations.

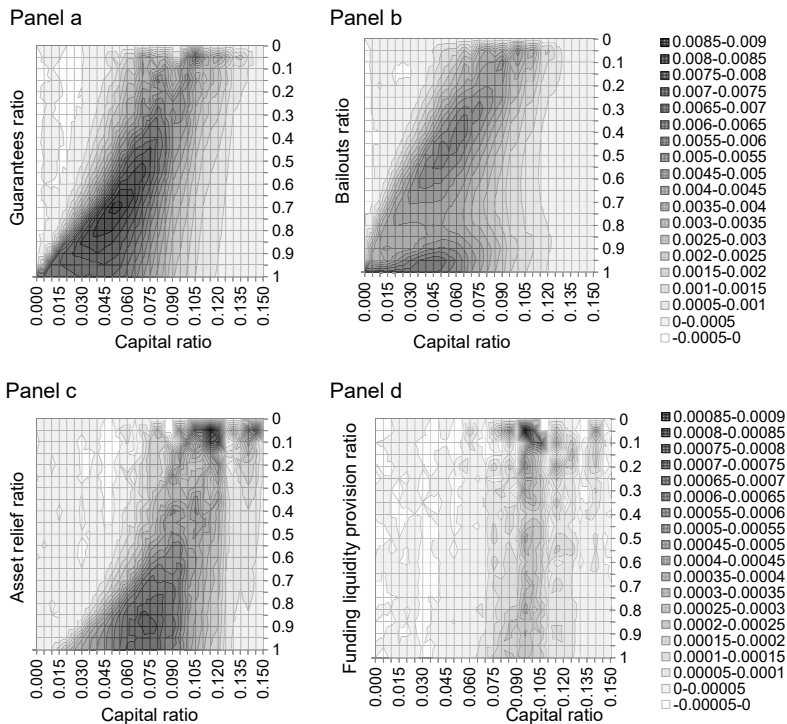
a significant cost to the domestic sovereign but still too low to prevent the shocks from spilling over the banks' capital barriers onto the next line of creditors. Moreover, in this situation the failing bank liquidates its assets, further worsening the situation through the market liquidity channel. 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 fewer banks fail compared to the situation in which no state support is provided. 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.

The first finding is that direct support such as bailouts and guarantees proves much more efficient than measures which are aimed only at the resulting liquidity issues. Due to such disproportion in effectiveness, in *Figure 2a* and *Figure 2b* the support efficiency is plotted on tenfold larger scale than in the case of *Figure 2c* and *Figure 2d*. Second, in both *Figure 2a* and *Figure 2b* we see a diagonal pattern where the state support is most efficient. This corresponds with, for example, 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 situation is serious enough but the system has not yet collapsed entirely. Furthermore, *Figure 2c* shows that although the efficiency in the 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 of a direct support measure in relation to the initial shock than state

**Figure 2 Cost-Benefit Analysis of State Support Measures**



Notes: The scale of the response variable in panels A and B is ten times larger than in C and D. The darker color indicates higher efficiency of state support for a particular measure.

Source: Authors' calculations.

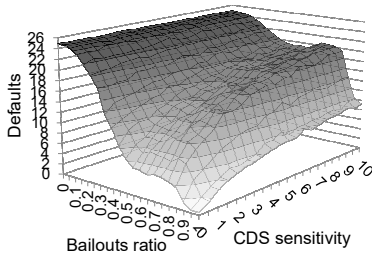
guarantees. Finally, it is clear from *Figure 2d* that, given this parameter setting, provision of funding liquidity is not an effective means of support for systemic stability.

### 3.4 Feedback Loops

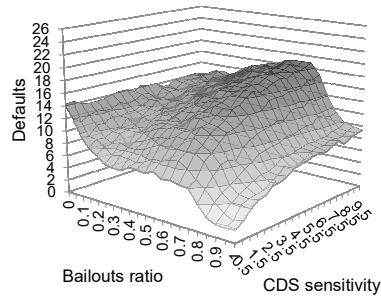
Putting together the results of banking crises, state support and the effects of state defaults, we may close the feedback loop by implementing a mechanism connecting the state support and state defaults. First, according to Equation 3 in Section 2.5, a sovereign may default with the probability implied from its CDS spread. As the CDS spreads contain not only the premium for the credit risk of the insured bonds but also additional premiums such as the market price of the risk or liquidity premium, we adjust the CDS-implied probability with the 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 a 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*.

**Figure 3 Bailouts and Recapitalization with Feedback Loops**

Panel a



Panel b



*Notes:* Our modeling network consists of 25 banks. The vertical axis ticks are spaced at two defaults so the maximum number of ticks on the axis amounts to 26.

*Source:* Authors' calculations.

*talization.* Finally, the results of *provision of funding liquidity* are not presented, as this support measure proved to have almost no significant positive effects.

*Figure 3* shows the behavior of the system when the crisis is tackled by *bailouts and recapitalization* of the troubled banks. *Figure 3a* depicts a collapsing system at a capital ratio of 4%. Here we see that at low CDS sensitivity to deficits resulting from the support measures (parameter  $\beta$ ), 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 defaulting banks significantly. However, with increasing CDS sensitivity, the measure becomes less and less effective. Also, at higher CDS intensity levels, an interesting pattern appears, in which higher bailout intensity does not necessarily mean fewer total defaults. This is because at bailout intensity of 0.8, state action weakens the sovereigns more than it supports the banks. At 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 riskier 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 the case of negative shocks, 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

**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

Notes: The number of plus “+” signs represents the degree of positive effect. Zero represents a mixed or neutral effect.

Source: Authors’ calculations.

the former two. Finally, provision of funding liquidity had very little effect on systemic stability, even though it is rather expensive for the sovereigns. Unlike Klinger and Teplý (2014), who focused on systemic stability as a result of different regulatory settings, here we expand our research to four measures of support for troubled banks, which we discuss further: bailouts and recapitalization, execution of guarantees, asset relief and provision of funding liquidity. *Table 2* provides the summary of these support measures.

Even though some are effective in the short run, in the 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, state support may be worse than in the case of no state intervention. Finally, the application of support measures was biased by the “privatization of profits and socialization of losses” approach taken by politicians in many developed countries as documented by the mentioned EUR 1.6 trillion in state aid provided to the EU banking sector between October 2008 and 31 December 2011. As a result, the related costs were borne by the taxpayer through bailouts rather than by financial institutions’ shareholders through bail-ins. Despite some pending regulatory efforts to avoid taxpayers’ involvement in banks’ bailouts, we agree with Šutorová and Teplý (2013, 2014) in stating that the recent Basel III global banking regulation is not sufficient and will neither protect financial markets from future crises nor the taxpayer from provision of further subsidies to the 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 modeled on an aggregate scale, using banking systems’ exposure matrix based on data from



BIS International Financial Statistics. In this case, foreign claims data on the 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 a 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, the IMF International Financial Statistics database, Arslanalp and Tsuda (2012) or individual central banks' databases. Moreover, it is important to stress the flexibility and extensibility of our modeling approach, which may lead to many more conclusions. In the future, this will allow us to add features of financial systems that are the subject of 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 of 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 relief 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 systemic stability. When the feedback loops are implemented, the effects of state support depend on several parameters: there are settings at which it significantly mitigates the systemic crisis and settings at which it contributes to systemic collapse. Finally, there are differences among the types of rescue measures used by governments and central banks. While bailouts and recapitalization comprise the most efficient type of support and execution of guarantees is still a viable solution, the results of liquidity measures such as asset relief and provision of funding liquidity are significantly worse. These findings are intuitive and reflect reality, as asset relief is obviously very costly for a government. On a related note, liquidity support from central banks means temporary help to the banks with 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, state support may be worse than the situation when there is no state intervention.

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