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Multi-agent Network Models of Financial Stability

Dissertation Thesis

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed and properly cited resources and literature.

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0 Foreword

The recent global meltdown started as a failure of the credit system, continued as a liquidity crunch and with negative sentiment and overall market slowdown, finally transformed into an economic crisis. Subprime mortgages, weak regulatory structures and high leverage in the banking sector worsened it further (Allen, 2009).

The Bretton Woods system, first unified monetary policy code of conduct, broke down in 1971. With its end, the banking environment transformed from a heavily regulated one to a highly competitive one. Less regulation led to competitive pressures which squeezed the interest rate spreads. To maintain and increase their profits, banks shifted from high profit margins to large-scale operations. This led to three major developments in the financial markets: globalization, innovation of financial instruments and practices and speculation. Financial markets across the G-10 countries were deregulated around the same time. Banks increasingly engaged in international operations on both the asset and liability side of the balance sheet. As net savers in one country became the net borrowers in another, the line between domestic and international finance blurred. This sowed the seeds for the need of international banking regulation. (Kapstein, 1991). As banks went to race for leverage, the credit market completely changed its character and started bringing cheap funds to households who began taking mortgages on a massive scale. This steady growth in investment drove the asset prices upwards and soon it resulted in a *Ponzi scheme* where credit was granted even to people with no income. Meanwhile, to free up funds and be able to leverage further, banks and mortgage companies started repackaging loans, slicing and selling them across the financial system to other banks and investors in the form of an opportunity of a low-risk, high-return investment. This also led to an increase in off-balance sheet items. With foreign exchange trading, banks started speculating on currency values which was a high risk, high gain game.

This continued till Herstatt Bank failed in 1974 and regulators saw the need to oversee the changes in the financial markets. Central banks realized that with globalization, a national banking crisis could have rapid international repercussions (Dean and Giddy, 1981). As a result, the Basel Committee on Banking Supervision was set up in 1975. This was the first and the biggest step towards international banking supervision.

The committee was focused on defining a credit risk exposure threshold for banks to avoid such failures in future. With Basel I in 1988, minimum capital regulation standard was introduced for banks. It required banks with international presence to hold capital equal to 8% of their Risk Weighted Assets. Though, adopted and implemented by almost 100 countries it was criticized for its shortcomings like broad risk weighting categories, simplistic model and ignorance of other risks associated with banks and their functioning. The model was improved and Basel II norms were introduced in 2004. They captured credit, market and operational risk. Though the capital requirements were the same, the definition of risk weighted assets was changed. Standard and internal rating based; IRB approach was introduced; whereby banks could depend on external rating agencies for asset classification or develop internal models to do so. The introduction of IRB gave large banks a route to escape regulation.

With large banks undertaking securitization extensively, the incentive to invest in accurately rating borrowers was absent. Also external rating agencies saw large proportion of their income coming from rating securitized products and hence had lower incentives to discourage this market with poor ratings. Thus, the whole system of assessing the quality of borrowers and mortgages broke down. In fact, Basel II norms have been blamed as one of the causes for the 2008 crisis. As banks started leveraging their balance sheets, there was a flow of cheap funds to households, who started taking mortgages on a massive scale. While earlier, banks held the junior tranches with low ratings, with aggressive trading of loans, even this tranch was sold off (Allen, 2009).

The first signs of problems appeared in 2007 when the banks started writing off their subprime mortgage securities. In connection to the need of short-term financing on which the banks laid out the foundations of their business models for the last three decades, this provided a deadly mix which prepared ground for a much more severe and far-reaching systemic crisis of the financial system.

When issues started to surface, sovereigns undertook an active role, supporting the system through various kinds of aid packages. However, large state support for the financial system as well as for the economy represented a huge burden on government finances and in some cases, mainly in Europe, resulted in a sovereign debt crisis. Moreover, losing their status of risk-free borrowers and facing increasing prices for credit, sovereigns too were now significantly weakened.

Since a portion of sovereign debt is held by the banking system, the crisis feeds back to where it began in a vicious circle transferring toxic debt back and forth between the sovereign and the financial sector. Meanwhile, in the new market environment, the survivor banks struggle to restore profits. Despite pressures for recapitalization and increased systemic safety in the form of new regulatory standards, large financial institutions started a regulatory race again and inflated their balance sheets without worrying about the consequences. Also, recent history taught them that the larger, more leveraged and thus more systemically important a bank is, larger the probability of a bailout. Again, the world economy found itself on the crossroads but this time the sovereign states cannot afford to play the guardian role anymore.

The biggest challenge to any regulation has been the resistance of banks to capital regulation. They have constantly lobbied against tighter norms on the basis that equity is expensive and that extensive regulation restricts growth in banking and hence the economy.

After the crisis with several banks going bankrupt, Basel III norms were introduced in 2010 with additional focus on liquidity and leverage. These were again opposed by large banks as a hindrance to the normal functioning of banks and to growth.

Admati & Helwig (2013) mock such arguments given by banks and call them flawed and misguided. The financial system is still vulnerable with the key factors that caused the crisis still in place. Banks have been lobbying policy makers and threatening that proposed regulations would harm credit and economic growth. Though banks have admitted that it was reckless borrowing that caused the crisis they have constantly refrained from regulations on borrowing defending that it would slow down growth presenting invalid trade-offs before the public eye like Financial Stability vs Growth. Banks create a fear around regulations and defend that they would interfere with the normal functioning of banks leading to unintended consequences on growth but do not highlight the existing and potential threats of financial instability to economy and tax payers and the possibility of sovereign crisis. A bank may be too big to fail, but it is often also too big to save and mostly if issues arise for more banks in one country, it can lead to sovereign debt crisis as in the case of Greece.

Bankers have long presented the financial system as a very complex subject with them being it experts. People trust banks views and believe that they are the best informed to assist in policy making decisions. Therefore, lobbying has affected the rule making process. Policymakers have been taken in by the lobbying as they face less public opposition and haven't taken stringent measures that they should have, given the state of the crisis.

Today, banks borrow more and more as they know that this will increase their chances of getting bailed out. Rating agencies also consider this and rate the banks higher knowing that it will get bailed out, when actually they are supposed to rate it basis the probability of default. This further lowers banks cost of funds. When bank lobbyists claim that having more equity would raise their costs, they never mention the costs to taxpayers of making their borrowings cheap. Such warnings of unintended consequences are meant to scare policymakers out of doing something, without focusing properly on the issues or proposing how the actual problems should be solved. There is a fundamental conflict between what is good for bankers privately and what is good for the broader economy.

The sovereign debt crisis of the Eurozone in 2010 highlighted the link between sovereigns and banks all the more. While large state support to the financial system can lead to sovereign crisis, such crisis can have a sizeable impact on bank lending. As government debt is usually ranked lowest on risk, banks hold large amount of government debt securities. Weak and now riskier sovereigns may cause feedback loops into the banking system thereby reducing funds for lending (Popov & Horen, 2013). These relationships have also been shown by econometric studies. After testing indicators of bank and sovereign risk for Granger-causality, it was found that bidirectional linkages exist between bank and sovereign risk. The problem of weak banks and high sovereign debt reinforces each other and both get worsened in the presence of economic slowdown (Puig, Rivero & Singh, 2015).

However, banks and sovereigns are not the only players that may have systemic impact in the financial markets. Pension funds and Insurance companies can be potential economy stabilizers. They are heterogeneous long term institutional investors and can have long term macro-economic effects by two different mechanisms: by channeling important amounts of long term savings to investment and by creating and developing markets for long term bonds and stocks (Zahler, 2003).

Contractual savings under them promote more efficient risk diversification by the financial sector. Insurance companies directly help in managing risk and also contribute to risk management through reinsurance and credit protection products. Though the recent crisis generated large losses for both insurance and pension industries, regulations have been more successful in their case. Regulatory limits on eligible assets prevented excessive exposure to Asset Backed Securities; ABS, thereby limiting losses to long term savings (Impavido & Tower, 2009).

The importance of increasing resilience of the insurance and pension sector has been recognized and pension stress tests have been conducted across EU in 2015 with regular biennial stress tests for insurance companies (EIOPA, Financial Stability Report, 2015).

Our research describes the above-mentioned chain of events more rigorously and uses a set of computational models to capture their dynamics and interdependence. The overall aim of this project is to add new insights to the recent studies on banking regulations, sovereign debt crisis and bank crisis, discussed broadly at both the EU and at the international level and to contribute to policy discussions.

We address important research questions like; how the behavior of the financial system is affected by its regulation, how the system behaves in a major crisis, how and when its stress can translate into sovereign crisis on the one hand and how and when a sovereign crisis can feed back into the financial system on the other. We examine the role of sovereigns, as regulatory bodies, providers of banking aid and as members of the financial network as such.

Our models are based on two main techniques, network theory and agent-based modelling. Their main mechanism is the loss transferred from one institution to another in case of a financial system crisis. This approach captures the financial system as a network of banks and sovereigns represented by their balance sheets and linked together by mutual claims. When a subject finds itself in severe financial distress and is incapable of honoring its obligations, it sends a negative shock through the network which depending on the financial soundness of the shock-receiving creditors can result in another wave of defaults. Furthermore, to model the bi-directional linkages of the banking and the sovereign sector, we incorporate banking regulation and state aid in the form of bailouts, deposit guarantees, and liquidity modelling. Some parameters of the model have been calibrated using available data collected from BankScope, Bank for International Settlements database and databases of central banks. The effects of other parameters on the system are examined in Monte Carlo simulations. Design and conclusions based on the implementation of these models is the key added value of the research. It shows that computational modelling can be a very useful decision support tool for policy debates. This is also illustrated by the fact that these types of models are currently an important area of focus for regulatory institutions and policymakers.

Our findings and research are distributed across four comprehensive essays.

The first essay, takes a detailed look at international banking regulation, particularly capital adequacy requirements known as the Basel Accords. The aim of this chapter is to thoroughly examine banking regulations, to connect the dots that led to the recent financial crisis, to provide better understanding of how the mechanism behind the regulatory measures works and to draw attention towards the importance of capital regulation. We discuss the changes that the banking business had gone through in the period since the collapse of Bretton Woods system and state the main reasons for banking regulation, such as depositor protection and systemic externalities. We study the rationale for regulating banks with a more detailed analysis of the latest norms under Basel III. We provide the description of the evolution from Basel I through Basel II to the newly proposed Basel III along with the assessment of these documents and finally, we carry out an institutional analysis of the forces shaping the form of the banking regulation. We conclude that regulation is heavily shaped by banks themselves and therefore, does not always serve the best for protecting the financial system. An early version of this essay has been published in the book Klinger, T. (2011): *Banking Regulation*, LAP Lambert Academic Publishing AG & Co. KG, ISBN 9783846516362. Also, a modified version of the same appears in the book Klinger, T., Teply, P. (2012): *Bank capital regulation: from Bretton Woods to Basel* in P. Teply (Ed.), Economic capital and risk management., Karolinum Press, ISBN 9788024621470.

In the second essay, we construct an agent-based network model of systemic risk of the banking system and use it for stress-testing some of the regulatory measures mentioned in the first chapter. We concentrate on modelling of systemic risk and impact of regulation on the resilience of the banking system. First, we briefly introduce the methodological approaches used, namely the network modelling and agent-based modelling, along with examples of their utilization in modelling of banking systems. Second, we construct a model of the banking system and provide comparative-statics analysis under several stress scenarios. Finally, we summarize the results and provide policy implications along with a short description of areas for further improvement. We draw three conclusions from this research - First, our simulations confirm that sufficient capital buffers in individual banks are crucial for protecting the stability of the whole system. Second, we show that the regulatory measures installed as preventive measures to ensure that banks possess sufficient capital buffers have almost no positive effects on stability when the system is collapsing. Finally, we highlight various data deficiencies which prevent the researchers and regulators from fully understanding the complete range of systemic risk and make it difficult to devise effective and targeted regulatory measures at this time. The essay was published in an impact-factor journal Prague Economic Papers as Klinger, T., Teply, P. (2014): *Systemic risk of the global banking system - an agent-based network model approach*, Prague Economic Papers, Vol. 23, No. 1, pp. 24–41. With this essay, the author earned an honorable mention as the Young Economist of the Year under 25 years of age at the Czech Economic Society. Moreover, this paper has been cited by leading experts in agent-based modelling of financial stability and the IMF, as in Chan-Lau, J. A. (2014), Chan-Lau, J. A. (2015) and Demekas, M. D. G. (2015).

The third essay focuses on the later stages of the financial crisis, when the instability has already spilt from the banking system onto the sovereigns, and focuses on the relationship between the two 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 analysis yields 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 means of support and execution of guarantees is still a viable solution, the results of liquidity measures such as asset relief or funding liquidity provision are significantly worse. The essay was published in an impact-factor journal Czech Journal of Finance as Klinger, T., Teply, P. (2016): *The Nexus Between Systemic Risk and Sovereign Crisis,* Czech Journal of Finance, Vol. 66, No. 1, pp. 50–69.

Whereas the third essay provides a theoretical insight into the problematic dilemma of state aid, the fourth essay takes our research further by calibrating the model to real-world data using a unique dataset put together from various sources. In order to gain more insight into the current situation and outline some practical implications for setting new policies in case of a systemic banking crisis happening later in the future we test the calibrated model in further simulations. Our analyses yield the following key results: Firstly, in the short term, all support measures improve systemic stability. Secondly, in the longer run, the effects of state support depend on several parameters but still there are settings in which it significantly mitigates the systemic crisis. The essay was published in a peer-reviewed journal ACTA VSFS as Klinger, T., Teply, P. (2014): *Modelling interconnections in the global financial system in the light of systemic risk,* ACTA VŠFS - University of Finance and Administration, No. 1, pp. 64–88. Modified version of this essay was also published as conference proceedings of Second International Conference on Electrical, Electronics, Computer Engineering and Their Applications, Manila (Philippines) as Teplý, P., Klinger, T. (2015): *Monte Carlo Simulations: A Case Study of Systemic Risk Modelling*, ISBN 978-1-5108-0887-4.

1 Bank capital regulation[1]

Abstract

In this essay, we look at international banking regulation, particularly the capital adequacy requirements known as the Basel Accords. We study the rationale for regulating the banks and describe the evolution of the Basel Accords, including the newly presented measures known as Basel III. The main conclusion is that regulation is heavily shaped by the banks themselves and does not always serve the best for protecting the financial system.

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[1] An early version of this essay has been published in the book Klinger, T. (2011): *Banking Regulation*, LAP Lambert Academic Publishing AG & Co. KG, ISBN 9783846516362. Also, a modified version of the same appears in the book Klinger, T., Teply, P. (2012): *Bank capital regulation: from Bretton Woods to Basel* in P. Teply (Ed.), Economic capital and risk management., Karolinum Press, ISBN 9788024621470.

1.1 Introduction

The 2008-2009 financial crisis pointed at the vulnerabilities and close inter-linkages of the financial system. It left the world economy paralyzed and questioned the beliefs it had held for at least three decades. The main concept put to question was banking regulation. Since the current regulatory setting failed to prevent the financial crisis or mitigate the subsequent downturn, there came an increased demand for its adjustment, and the regulation of banks became one of the most frequent topics in the financial as well as in the political world. Hence, it is a very important subject and since the new regulatory standards known as Basel III came out only very recently, it is also highly up-to-date.

The overall aim of this chapter is to thoroughly examine banking regulation, to connect the dots that led to the recent financial crisis, to provide understanding of how the mechanisms behind the regulatory measures work and to draw attention to the importance of capital regulation. The chapter is structured as follows: in the first part, after a short introduction of the basic concepts of banking, we will describe the changes that the banking business had gone through in the period since the collapse of the Bretton Woods system and state the main reasons for banking regulation, such as depositor protection and systemic externalities. Subsequently, the second part focuses on the Basel Committee for Banking Supervision and the Basel Accords, which are the main regulatory documents. We will provide the description of the evolution from Basel I through Basel II to the newly proposed Basel III along with the assessment of these documents. Finally, we will carry out an institutional analysis of the forces shaping the form of the banking regulation.

1.2 Rationale for banking regulation

Dewatripont, et al. (1994) explains different views on bank regulation. We agree that the answer does not lie solely in the individual functions such as asset transformation or payment system provision. Although these activities are vital to the economy, they are not more important than, for instance, food supply, cars or pharmaceuticals, sectors where the prudential regulation does not exist. Neither the sole existence of the deposit insurance programs or state aid explains the case,[2] since the *a priori* banking regulation is caused by the same reasons as the *ex-post* bail-outs. The truth is that the anticipation of government support for banks in distress further amplifies the need for the regulation, since it results in moral hazard and excessive risk-taking, and the same holds for the deposit insurance.[3] However, the core reasons lie in the key two types of market failure - asymmetric information and the existence of externalities.

1.2.1 Information asymmetries and representation hypothesis

Several authors' stress that regulation should be targeted to protect individual depositors, since there are differences in the information available to them and to the bank. Information asymmetry arises when one party to a contract possesses a significant informational advantage over the other party. Such situation is often linked with complex products where the costs of monitoring and understanding the situation are substantially high and especially for the financial products, their nature and intensity makes it a significant issue (Schooner & Taylor, 2009), (Mishkin, 2004). The bank deposit is a financial contract when the bank promises to return the depositor's funds at any time she demands them or at some fixed future date. However, the bank has much more information for effective judgement on the probability of honoring such promise and it may happen that either the bank will take deposits without any intention to repay them[4] or that it will not be able to repay them because of financial problems. The depositors and creditors, on the other hand, have little knowledge of the bank's financial condition, mostly because they do not know the structure of the bank's assets and off-balance sheet items and cannot verify their value. Furthermore, even if the information is available, very few depositors possess the expertise to evaluate it and draw conclusions for their behavior.

The existence of asymmetric information then leads to two issues: moral hazard and adverse selection. Moral hazard is a situation that arises when the counterparty has an incentive to behave in such a way that it increases the risk of not honoring the contract. For example, a bank may invest in excessively risky assets, because its management will

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[2] According to Dewatripont, et al. (1994; p. 30), it *"puts the cart before the horse"*.

[3] An empirical study by Detragiache, et al. (2002) concludes that especially where the institutional environment is weak, explicit deposit insurance leads to bank instability.

[4] Major scandal of this type was connected with the fraudulent Bank of Credit and Commerce International in 1980s.

be better off when the investment is successful but most of the risk is borne by the depositor when the investment becomes a failure. Adverse selection arises when the most undesirable counterparty is selected, because it has the largest incentive to put effort in entering into a contract, for example a bank in financial distress will be more eager to collect deposits or take loans. Since this phenomenon makes bad loans more likely to occur, it can happen that the lenders or depositors decide not to provide any loans to any banks, even to the financially sound ones.[5] More on the asymmetric information and subsequent behavior of banks and depositors as a rationale for the regulation of the banking system can be also found in Dewatripont, et al. (1994) where this phenomenon is presented as the *representation hypothesis.*

1.2.2 Externalities and systemic risk

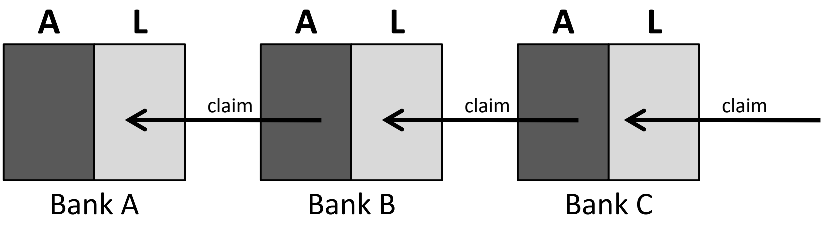
The regulation should be targeted to protect the entire system since there is a danger of severe external costs resulting from failures of individual banks. Externalities are economic benefits or costs that are not compensated or charged for and thus they are transferred to the rest of system. The unique functions of the banking business, together with its importance and network character, make it vulnerable to such costs and it can happen that a failure of one bank triggers a process that results in huge losses either to other financial institutions or to the whole economy. Although there are a diverse variety of channels that can spread and amplify the losses, we will describe only the main ones.

The first type of externalities stems from the ever-rising interconnectedness of the financial system. This issue is linked to payment systems, over-the-counter derivatives contracts and extensive global interbank contracts, which result in very complex financial networks. Even though the growing interconnectedness leads to better risk diversification and smoother credit allocation, it also increases the potential of situations when a failure of one institution results in an adverse shock to its creditors, who may potentially spread it further in the next rounds when they fail themselves. Such situation is described in Brunnermeier, et al. (2009b) with a basic, naive scheme of shock propagation which he calls a *"Domino"* effect. Here $Bank\ A$ has borrowed from $Bank\ B$ who has borrowed from $Bank\ C$. When $Bank\ A$ defaults, then $Bank\ B$ suffers a loss. If the loss is too large

[5] Classic case where the asymmetric information results in no trade is illustrated on the used car market in Akerlof (1970).

to be covered by $Bank\ B$'s capital, the shock spreads further to $Bank\ C$. Moreover, because of the financial innovation, the banks are able to hide significant portion of their contracts on the off-balance sheet and thus these risks are usually not known of until they materialize in a form of a systemic crisis.

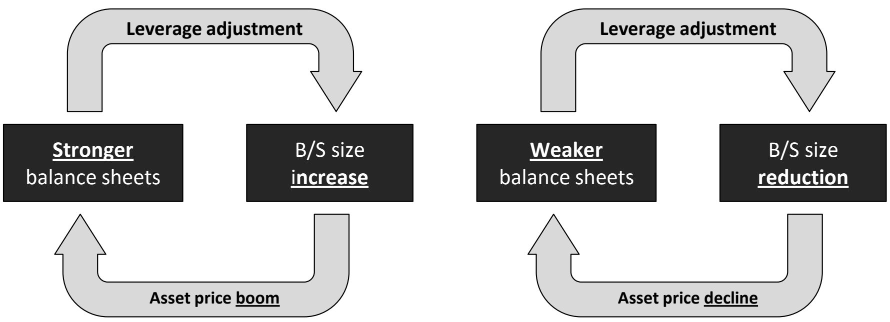
Figure 1.1: The "Domino" effect of financial contagion



Source: Authors based on Brunnermeier, et al. (2009b)

Asset prices are another channel for the external costs to arise. Simulation studies show that externalities stemming from interconnectedness materialize only assuming very large shocks (Brunnermeier, et al., 2009b). However, if the asset prices are not fixed and banks are not passive in their distress behavior, the situation further aggravates. Facing funding difficulties, in order to keep certain level of equity-to-loan ratio or because of sheer panic, banks begin to get rid of a portion of their assets. Moreover, if the balance sheet values are not fixed by the book prices of the assets and are marked to market, there is a danger of asset price spirals (Klinger, 2011).

Figure 1.2: The "asset price spiral" effect during the boom and bust periods



Source: Authors based on Brunnermeier, et al. (2009b)

Figure 1.2 demonstrates that, due to marking to market, in times of economic boom, banks' balance sheets expand as prices increase. Keeping the loan-to-equity ratio constant, the banks can purchase more assets, pushing their prices even higher. In an economic downturn, this mechanism gets reversed and the shrinking balance sheets with eroded equity force the banks to sell parts of their assets and use the funds to repay their obligations. The marked to market leverage in financial intermediaries is strongly pro-cyclical, due to which banks reaction to asset price changes is very strong. Since financial markets are not perfectly liquid, in case of an upturn, leverage ratio falls and banks accumulate surplus capital and aggressively look for borrowers to increase the size of their balance sheet. This leads to predatory pricing which in the long run can cause a downturn like that of 2008. In the downturn, banks would then sell securities and deleverage. The greater supply of assets pushes further downward pressure on the asset prices weakening balance sheets further. (Adrian & Shin, 2010). As the price is declining, mainly with the whole financial sector acting in a synchronous manner, this leads to huge spill-over losses. The systemic risk, represented mainly by the interconnectedness and spill-over externalities, does not pose danger only to banks and other financial institutions. Due to the vital importance of the financial system to the real economy, the costs are likely to spread to other businesses and individuals, and result in losses of economic output. This danger is also taken as a reason for state bail-outs which ultimately transfer the costs from the banks to the taxpayer Therefore, given the risk of moral hazard and systemic risk associated with banks they are required to maintain capital over and above the market level requirements. For example, deposit insurance in the case of US banks, makes FDIC (Federal Deposit Insurance Corporation) the largest uninsured creditor in most US banks. Regulatory capital is required to limit this exposure of the government and taxpayers. (Berger &Herring, 1995)

1.3 Banking system evolution

From the end of World War II until the end of 1970s, the financial system was heavily regulated. This was caused partly by the regulatory responses to the Great Depression, and partly by the Bretton Woods system. There were such as the Glass-Steagall Act in the US and several similar concepts in the rest of the world, which separated commercial banking and investment banking. Also, the cross-border capital flows were restricted by exchange controls, and banks were required to hold certain minimum reserves. In addition, in order to ensure the stability of the banking system, the governments prescribed fixed interest rates for which the banks collected the deposits and provided loans and usually the spreads between these two rates were rather wide. For these reasons, the business model of the banks was said to be the 3-6-3 rule: The bankers collected deposits at 3% interest rate, lent them at 6% and were on the golf course by 3 in the afternoon (Schooner & Taylor, 2009). In other words, the banking business was relatively simple and safe.

However, with the collapse of the Bretton Woods system and the process of European integration, deregulation began, restrictions were removed and the character of the banking business was on its way to change. Because of the deregulation of currency transfers, capital was allowed to flow freely across borders and the banks'cross-border operations increased more than twenty fold over the next two decades. The system experienced a wave of banking consolidations. Securitization, i.e. production of loans repackaging them and selling them on the secondary markets, helped to heavily leverage the banks and derivatives took risky positions off the balance sheets. Such development has led to increased systemic risk (Klinger, 2011). With the international capital flows and global financial products, the system became much more interconnected and complex. Banks' balance sheets grew with the new funding possibilities pushing their leverage to unsustainable values. Though small and risky banks partly disappeared because of the competitive pressures, the remaining ones posed much greater threat to the system should they fail. Finally, because of the opaque bilateral contracts, it became very hard for an outsider, including a regulator, to map the inter-linkages in the financial sector. Even though many of these dangers came to surface during the 2008 financial crisis, the banking system so far has remained very similar.

1.3.1 International regulation

Although until 1970s, banks were subject to stringent regulation, it was exercised almost solely at the national level with each government setting its own rules. While this concept was possible during the Bretton Woods system, increasing international operations of banks and the emergence of multinational banks with multiple subsidiaries across the world implied the need for worldwide coordination of the regulatory policies. Dale (1994) presents three main reasons for the post-1970s banking system to be regulated internationally:

1. Because of the new international structures that banks can form, it is necessary to understand which authority should be responsible for regulation of which banks.

Otherwise, a bank may manage to evade regulatory attempts of all countries of its operation.

2. Since the national banking sub-systems are closely linked together in the international interbank market, there is a risk that one country would be adversely affected by problems originating elsewhere.
3. The incentives to support domestic banks may lead to decreasing the regulatory burden in individual countries. This may put the other jurisdictions in danger and their banks in a competitive disadvantage, and it can even lead to a race to the bottom, when the competition of regulatory authorities would result in global under-regulation.

1.4 Basel Accords

In this part, we will focus on the Basel Committee on Banking Supervision and its main prescriptions for the banking regulation before the 2008 crisis, namely the Basel I and Basel II accords. After a short description, we will examine the aspects of the first two Basel accords and their problems which surfaced in the recent financial crisis.

Figure 1.3: Timeline of the Basel accords

Source: Authors inspired by Teplý (2010c)

1.4.1 Banking regulation before the global crisis

After the Bretton Woods collapse, it did not take long time for the new types of international risks to manifest. On June 26, 1974, due to large losses on foreign exchange operations, German Bankhaus Herstatt was deprived of its banking license. Due to the time-zone difference between Germany and New York, when the Herstatt bank was closed by the German regulators, it was middle of the trading day in New York. Since most of the Bankhaus Herstatt's counterparties were located in New York and these banks still had not settled their accounts with the German bank, they were exposed to losses accounting for a half-day trading. This regulatory failure caused panic and the prices for interbank credit and foreign exchange soared in the days to follow (BCBS, 2004a). Disintermediation of short term corporate loans, growth in off balance sheet items, twenty-four-hour trading and global communications changed the business mix and risk profile of banks to a more complex and global one (Bardos, J, 1987).

As recognition of the new situation that arose in the banking business in response to Bankhaus Herstatt failure, the central-bank governors of the Group of Ten countries established the Committee on Banking Regulations and Supervisory Practices, now known as the Basel Committee for Banking Supervision (BCBS). Initially designed to "*close gaps in the supervisory net",* it serves as a common forum for cooperation and coordination of its member countries on banking supervision, and was engaged in three main areas of action (BCBS, 2009, p.1):

1. Information exchange on national supervisory arrangements,
2. Improvement of techniques for the international supervision,
3. Setting minimum regulatory standards in areas when they are considered desirable.

According to the BIS Factsheet, there were 27 members of the Committee,[6] each represented by its central bank and also by the institution responsible for prudential banking regulation, if this is not the central bank. The first meeting was scheduled in 1975 and since then the committee holds three or four meetings a year (BCBS, 2009). The committee is not a formal international institution: it does not have permanent staff and the results of its activities do not automatically come into force as international laws. Nevertheless, it releases documents on recommendations, guidelines, and best practices for supervision of internationally active banks (Tarullo, 2008). These documents are then often transferred into the national laws and have become the regulatory standard for worldwide international banking.

The first document prepared by the committee was the 1975 Basel Concordat which established joint responsibility of home and host authorities for regulation of international banks. The committee also developed the Core Principles for Effective

[6] The list includes Argentina, Australia, Belgium, Brazil, Canada, China, France, Germany, Hong Kong SAR, India, Indonesia, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, Russia, Saudi Arabia, Singapore, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. (BCBS, 2011b)

Banking Supervision, which is a set of best practices providing a comprehensive description of standards that can be used for implementation or assessment of banking regulation in individual countries (BCBS, 2006a). Nonetheless, the most important documents published by the Committee are the Basel Capital Accords, which will be discussed further in this text.

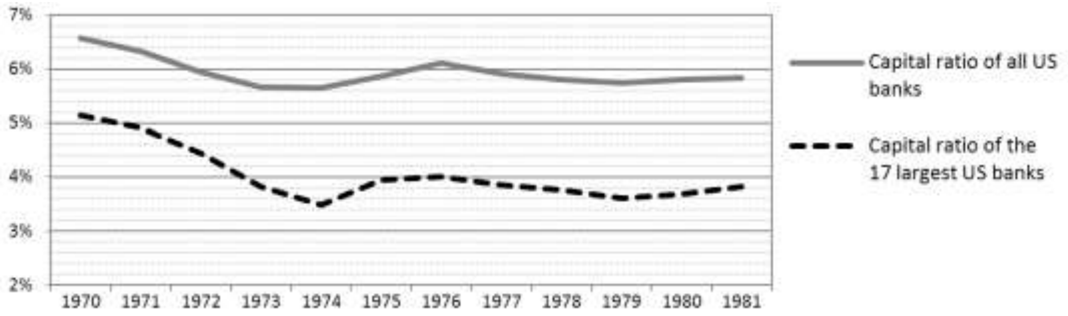
As mentioned earlier, bank capital serves as a cushion that absorbs the expected and unexpected losses and prevents them from being transferred to the rest of the system. Although under the assumption of perfect markets, it does not matter whether the banks are funded by equity or debt (Modigliani & Miller, 1958); in reality it is profitable for them to hold much lower capital levels than would be socially desirable. The reasons are twofold:

1. Debt has significant tax advantages because the interest paid to the creditors is tax-deductible, while the dividends paid for the stakeholders are not (Sinkey, 2002). Even though higher levels of debt are linked with higher bankruptcy costs, which may balance the advantages of debt financing to some point, the banks' shareholders have limited liability and its managers even more so (John, et al., 1991). The capital structure optimization thus usually results in severe undercapitalization.
2. In most countries, there exists a certain form of deposit insurance, an institute of lender of last resort and high probability of bail-outs for banks that are too big to fail. Because of such safety nets, the risk perceived by the depositors and creditors is lower than would be in the case of no intervention. Since the confidence in a bank is positively affected by its net worth as well as by the government guarantees (Mejstřík, et al., 2009), the higher the guarantees, the less capital the banks need to hold for not losing the trust of their counterparties and the public.

When looking into the past, we see that on an average, capital ratios had been declining until the end of World War II and then, under heavy regulation and the Bretton Woods system, they started to rise again. Nevertheless, with mounting competitive pressures resulting from the 1970s and 1980s deregulation, the banks' margins started to decrease. Subsequently, the banks were trying to raise revenues by lending more while the level of capital on their balance sheets remained fixed or even declined (Tarullo, 2008).

Therefore, the capital ratios of the main international banks were deteriorating and as we can see in Figure 1.4, the largest, internationally active banks were leading the way.

Figure 1.4: Declining capital ratios: example for the US banks



Source: Authors based on Tarullo (2008)

1.4.1.1. Basel I

In response, in around 1980s, individual BCBS member countries introduced a certain level of capital ratios for their domestic banks. These were not simple leverage ratios, but their computation involved assigning weights to assets according to the risks they featured. In 1988, these efforts were put together in a form of a common framework for capital regulation, which was introduced by the Committee as the Basel I Accord which was to be implemented until the end of 1992.

BCBS (1988) set the capital adequacy ratio as the central concept of bank regulation, which all internationally active banks should have been required to maintain, and which can be summarized into a simple formula:

$$\left(CAD_{Total} = \frac{Tier\ 1\ Capital + Tier\ 2\ Capital}{RWA} \geq 8\%\right)$$
$$\wedge \left(CAD_{Tier1} = \frac{Tier\ 1\ Capital}{RWA} \geq 4\%\right),$$

There, CAD_{Total} and CAD_{Tier1} stand for the capital adequacy ratios prescribed by the regulation, $Tier$ 1 and $Tier$ 2 are two different types of capital and RWA stands for the sum of risk-weighted assets. It also holds that

$$RWA = \sum_{i=1}^{n} w_i A_i,$$

,where w_i stands for the weight of i-th asset A_i in the total portfolio of n assets. The weights are assigned according to the credit risk of the borrower by fixed rules. For example, government bonds or cash have zero weight. On the other hand, claims on the private sector are weighted by 100%.

As to the capital classification, Tier 1 consists mostly of equity and disclosed reserves and it is used as the main measure by the regulators, while Tier 2 describes less reliable items such as undisclosed reserves, loan-loss provisions or subordinated term debt. A closer definition of the two categories of capital and also a list of types of assets and their respective risk weights can be found in the original document (BCBS, 1988).

From the outset, this relatively simple rule was criticized for several deficiencies that include:

1. The capital ratio is too simplistic and it is not an outcome of too much scientific analysis but rather of a political discourse. Also, the risk weights are set by intuition in the best case; or even according to the pressure of politically powerful groups in the worst case (Benston, 1998 in Schooner, et al., 2009).
2. The risk weighting categories are too broad, which incentivizes the banks to perform regulatory arbitrage, i.e. replacing the assets that have relatively overvalued risk weights with the ones that are in the same category but are relatively riskier (Schooner & Taylor, 2009). Because of this risk-shift, the level of capital in the banking system was again beginning to decline. Though the full extent has been difficult to measure, banks especially larger ones, extensively used securitization, credit derivatives and other financial innovations to reduce risk- weighted assets by shifting credit risk from their banking books to trading accounts. This process of regulatory capital arbitrage; RCA, effectively reduced the capital requirement of banks against the real per dollar of economic risk held by them (Jones, D, 2000).
3. Basel I also did not address other types of risk. Although historically, credit risk is the main type of risk in banking, mostly with the fluctuating interest rates and the banks' involvement in market activities, it was necessary to regulate the area of market risk as well. This was partly addressed in 1996, when the Basel I was amended with measures for market risk measurement and regulation. For market

risk calculation, the banks should have used models using value-at-risk (VaR), which is the maximum expected loss on a portfolio at a specified confidence level over a given holding period (Mejstřík, et al., 2009).

Moreover, in the late 1990s, the banks themselves commenced their lobby for change. The bankers were complaining about the differences between the assigned risk weights and the actual risks and arguing that the risk management techniques had improved significantly since the introduction of Basel I.

1.4.1.2 Basel II

The revision process of the Basel Accord started in 1999 and lasted five years. Finally, in 2004 it resulted in the new Basel II which was to be implemented by 2007 (BCBS, 2004b). In contrast to Basel I which is about 25 pages long, the new document accounts for full 239 pages and thus its detailed description is out of scope of this chapter. We will illustrate only the basic facts, full description can be found either in the Accord itself (BCBS, 2004b) or in Schooner, et al. (2009) or Tarullo (2008). The regulation is divided into three sections called pillars.

The first pillar, Minimum Capital Requirements, which contains the capital requirements, is the most similar one to Basel I. The Tier 1 and Tier 2 capital definitions remain the same, as well as the minimum ratios of 4% and 8%. What changes significantly is the definition of risk weighted assets, i.e. the denominator of the ratio, which now involves credit risk, market risk and newly also operational risk measures.

$$CAD_{Total} = \frac{Tier\ 1\ Capital + Tier\ 2\ Capital}{Credit\ risk + Market\ risk + Operational\ risk} \geq 8\%\ ,$$

As has been mentioned, the market risk measures have been amended to Basel I in 1996 and do not change in Basel II. The credit risk measures, on the other hand, were modified significantly to allow for better risk sensitivity and the operational risk measure is a completely new concept. As to the credit risk regulation, instead of five broad categories of assets which were assigned fixed risk weights under Basel I, the new accord allows for two basic options (BCBS, 2001).

1. A standardized approach assigns the risk weights according to the external ratings provided by rating agencies

2. An internal rating based (IRB) approach allows for usage of internal credit assessment models, subject to strict supervision of methodological and disclosure standards. This approach further allows for two options according to the extent of the banks' participation on determining the value of risk-weighted assets:
   a. the "foundation" IRB approach, where the banks determine the probabilities of default and the other inputs are provided by the regulator,
   b. the "advanced" IRB approach, where the risk calculation is solely the banks' responsibility and the regulator only validates the calculation process.

Regarding the measures for operational risk, the banks can again choose among more options, varying from the most standardized Basic Indicator Approach where the capital requirement is calculated as a 15% fixed percentage of gross income, to Advanced Measurement Approach, where the capital charge is calculated by the bank itself. However, as with the credit risk measures, the methods used for calculation need to meet certain standards and are reviewed by the regulator (Mejstřík, et al., 2009).

The extended involvement of banks' internal processes demanded the regulators to change the approach to banks supervision. Instead of simply prescribing the rules and checking the capital levels, it is necessary to examine how well the banks assess risks. The second pillar, Supervisory review defines the process of dialogue between the banks and the regulators and comprises of four main principles (BCBS, 2004b):

1. Banks should have a process for assessing their capital adequacy in relation to their risk profile.
2. Supervisors should review and evaluate banks' internal capital adequacy assessments and strategies, as well as their ability to monitor and ensure their compliance.
3. Supervisors should be able to intervene if they are not satisfied with the result of this process, they should expect banks to operate above the minimum regulatory capital ratios and they should have the ability to require banks to hold capital in excess of the minimum.
4. Supervisors should seek to intervene at an early stage to prevent capital from falling below the minimum levels.

Providing enough information is necessary to ensure that the market participants can better understand the risk profiles of individual banks and adequacy of their capital positions. Therefore, the third pillar, Market discipline and transparency, aims to strengthen the market discipline through enhanced disclosure by banks which is required in several areas, mostly comprising the banks' methods for risk assessment and capital adequacy calculation (BCBS, 2001). Although the core set of requirements in the second and third pillars apply to all banks, it is clear that the rules ought to be more demanding for the banks using the internal approaches for risk assessment.

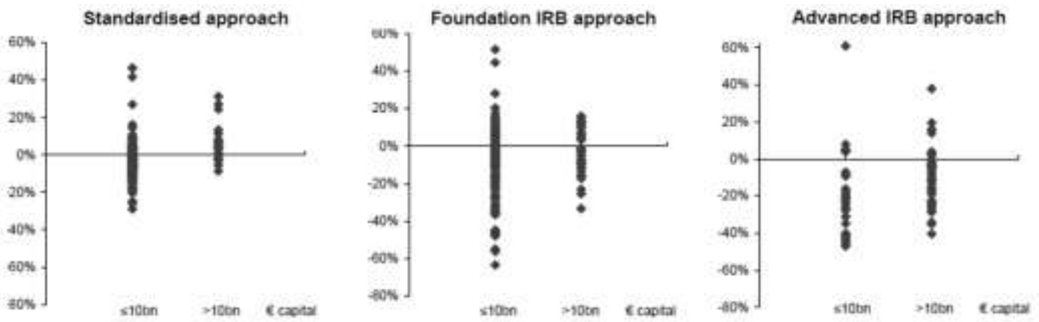
Despite its complexity, Basel II did not succeed in fulfilling its main proclaimed goal: ensuring stability of the banking system. On the contrary, in some aspects it can be even thought of as one of the reasons of the financial crisis of 2008. On the following lines, we will introduce the main aspects in which Basel II was, and still is, criticized.

Firstly, the existence of several possible approaches to calculation of capital requirements means that there is no common ground on which the capital requirements may be compared among banks. While the standardized approach does not differ too much from Basel I, the IRB approach involves processes that are more complex and more difficult to control by the regulators, and that provide more space for the large banks to shape their capital requirements according to their needs. (Klinger, 2011). The risk based bucketing proposal, tied to internal bank ratings lacks detail and comparison across bank portfolios. Grouping of bonds into three buckets is very broad. For example, putting A and BBB (investment grade corporate borrowers) together with BB and B (below investment grade borrowers) incorrectly prices risk within that bucket. (Altman and Saunders, 2001).

Nevertheless, even without choosing the models that are explicitly bad, for some institutions, Basel II meant looser regulation. According to QIS-5 (BCBS, 2006b)[7], for the large banks using the advanced IRB approach, the capital requirements would fall on average by more than 26%, while the smaller ones using the standardized approach would experience an increase of 1.7%.

[7] The abbreviation stands for "Quantitative Impact Study" These documents are prepared by the Basel Committee usually for assessment of the impact of newly proposed measures on the banks' capital adequacy.

Figure 1.5: QIS-5 results for Basel II



Source: Authors based on BCBS (2006b)

Second, the eligibility criteria for using the IRB models are designed so that only a small number of the largest banks were able to meet them. Since the IRB approach enables banks to lower their capital requirements, it puts the smaller banks into competitive disadvantage, deforms the market and further increases the market share of the large banks (Lall, 2010). Because the large banks are the ones who hold comparatively lower capital ratio levels, the circle closes and leaves the system vulnerable and severely undercapitalized.

The events of 2008 showed that the models used for the assessment of credit and market risk are flawed in their very assumptions. Firstly, the calculation of risks relies to a large extent on historical data. However, given the pace of financial innovation and introduction of new products, the data samples were often too small and the historical information on these products' performance was a poor indicator of the losses to come. Secondly, most of the models for market and credit risk calculation assume that the losses on individual assets are independent events. However, during the recent financial downturn, assets among which no correlations were anticipated became correlated, which resulted in much larger losses than expected by the models (Lall, 2010). As the Goldman Sachs´ Chief Executive Officer put it after the crisis, *"[i]n the past several months, we have heard the phrase "multiple standard deviation events" more than a few times. If events that were calculated to occur once in 20 years in fact occurred more regularly, it does not take a mathematician to figure out that risk management assumptions did not reflect the distribution of the actual outcomes. Our industry must do more to enhance and improve the scenario analysis and stress testing"* (Blankfein, 2008).

Partly, these problems might have been anticipated. Particularly the utilization of VaR models, which has been a part of the Basel accords since the introduction of market risk measures into Basel I, could have been well tested on the data from e.g. the Asian Crisis of 1997 or the Brazilian Crisis of 1994-98. Credit spreads which have empirically proven to be accurate forecasters of subsequent default rates at the start of 1990 should be used as an alternative. A revised bucket and weighing system proposed basis the examination of data on bond issues over 1981-1999 could prove to be more effective (Altman and Saunders, 2001). Basel II is also often criticized for its pro-cyclicality, i.e. reducing capital requirements during boom times and raising them during a downturn. In recession, as the perceived quality of the held assets is declining, the need for regulatory capital increases. This holds for credit risk as well as market risk.

1. Rising probabilities of default calculated by the internal models and declining ratings used by the standardized approach result in decline in the banks' credit willingness. As the banks begin to deleverage, the liquidity in the system suddenly falls and the sources of funding that were previously taken for granted drain out, which further worsens the economic conditions. Moreover, this mechanism may be amplified by liquidity spirals as modelled in Brunnermeier, et al. (2009a).
2. When the banks reach the limit of minimum capital requirements, they face two possibilities: seek additional sources of funding or sell certain part of their portfolio, usually the riskier one. In adverse financial conditions when the funding possibilities are scarce, the banks choose the latter option, which results in asset fire sales. Not only does this push the asset prices down but it also leads to destabilization of financial markets, as modelled in Hermsen (2010).

One of the priorities of Basel II was to stop the regulatory arbitrage that the banks performed via moving their assets to off-balance sheets by securitization. For this reason, the BCBS proposed to assign the capital requirements linked to individual securitization tranches according to external ratings. However, after an intense lobbying, in the final version of the accord, for banks using the IRB approach, most of the requirements were dramatically reduced (Table 1.1).

Table 1.1: Proposed and final risk weights for individual tranches of asset-backed securities

Originally Proposed in 1991		Finally appeared in Basel II in 2004	
External Rating	**Risk Weight**	**External Rating**	**Risk Weight**
AAA to AA-	20%	AAA	7%
A+ to A-	50%	A+	12%
BBB+ to BBB-	100%	BBB+	35%
BB+ to BB-	150%	BB+	250%
B+ or below	deducted from capital	below BB-	deducted from capital

Note: The risk weights were lowered for the IRB banks only. Banks using the standardized approach had to follow the risk weights as originally proposed. The ratings are according to Standard & Poor's methodology.

Source: Authors based on BCBS (1999) and BCBS (2004b)

Because of these tiny risk weights, after 2004, the banks began to use the off-balance sheet instruments in large quantities to lower the required capital. Asset-backed securities rose from 7% of US GDP in March 2004 to an 18% in June 2007, which was a larger increase in the three years after the publication of Basel II than in the entire previous twenty years. When the related risks began to materialize in 2007/2008, it became clear that this measure had created incentives for the banks to securitize the exposures and distribute them into the market rather than keeping them on their balance sheets, where the related risks would be much easier to observe and control (Lall, 2009). Similar fate met the trading book regulation. Initially, the Basel Committee planned for an additional capital charge to cover the various risks associated with credit derivatives. However, the industry pressure again resulted in severe undercapitalization of this area (Lall, 2010).

1.4.2 Regulation after the crisis and beyond

In this part, we will introduce the new capital framework known as Basel III. After the description of its contents, we will analyze the institutional background of the Basel processes, and what impact it has on Basel III. Finally, we assess the outcomes of the new measure and provide certain alternative approaches.

1.4.2.1 Basel III measures

As mentioned above, the deficiencies of Basel II surfaced during the financial turmoil which was triggered by the American sub-prime mortgage market, and which led to several bank bankruptcies and billions of dollars of world-wide state aid to the banks. The Global Financial Crisis shook the foundations of the regulatory system when it showed that the prudential requirements, which were supposed to protect the financial system against a catastrophic meltdown, spectacularly failed (Schooner & Taylor, 2009).

In response, after several adjustments of the Basel II framework concerning securitization and the trading book and after several Consultative documents[8] on the new capital accord, on December 16, 2010, the Basel Committee published the final version of Basel III. Comprising two key documents, (BCBS, 2010a), which states the capital requirements and (BCBS, 2010b), which describes the new measures regarding the banks' liquidity, the accord aims to *"improve the banking sector's ability to absorb shocks arising from financial and economic stress, whatever the source, thus reducing the risk of spillover from the financial sector to the real economy"* (BCBS, 2010a). Basel III brings new measures in several key areas, which will be examined more closely below. These are capital quality, capital quantity, restriction of leverage and liquidity requirements.

The new regulatory framework introduces changes in the structure of the required capital base in order to improve its quality, consistency and transparency (BCBS, 2010a). As an answer to the crisis which demonstrated that the most important capital reserves are the retained earnings and common shares, the banks will have to deduct goodwill, general intangibles and some investments in other financial institutions from common equity. This will increase the amount of common equity they will be required to hold. In addition, there is a requirement for deduction of deferred tax assets from the capital base, which is a convenient measure since the banks in crisis with no or extremely low incomes do not have to pay the income tax and thus they have nothing to subtract the DTAs from.

According to the recent Basel III Quantitative Impact Study, these changes in capital definition will affect all types of capital across all banks, but the impact on internationally active banks from Group 1 will be much stronger. The main drivers of the capital levels decline are deductions of goodwill and deferred tax assets (BCBS, 2010c).

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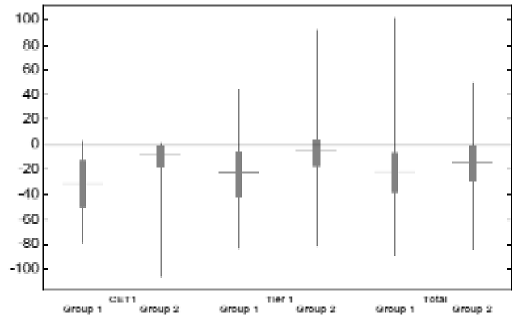
[8] The consultative documents are proposals published by the BCBS in order to receive comments from the local authorities, banks and other companies in the industry. These comments are then taken into account in preparation of the final accord.

Figure 1.6: Changes in capital levels according to QIS



Note: On y-axis, there is a percentage change in the capital levels after full introduction of Basel III. Group 1 banks are those that have Tier 1 capital in excess of €3 billion, are well diversified, and are internationally active. All other banks are considered Group 2 banks.

Source: Authors based on BCBS (2010c).

As to the basic capital requirements as we know them from the previous accords, the Tier 1 capital ratios have also been increased. Common Equity Tier 1 capital requirement was raised from 2% to 4.5% and Tier 1 capital requirement from 4% to 6% of risk-weighted assets, while the total capital requirement stayed at 8%. In addition to the adjustment of these standard requirements, there are two buffers further increasing the banks' need to raise capital, and also there is a proposal of additional requirement for systematically important financial institutions (SIFIs).

- The banks will need to hold a Capital Conservation buffer of 2.5% of risk-weighted assets, which is a "softer" requirement that does not have to be met at all times. However, when the banks do not hold this capital reserve, their ability to spend their retained earnings by paying off bonuses to the management and dividends will be limited until the banks return to full compliance.
- The countercyclical buffer goes even further and addresses the criticism of pro-cyclicality of Basel II by building up an additional capital reserve in times when the risks of system-wide stress are growing. In periods of excess credit growth, the national authorities can introduce a capital requirement which will vary between zero and 2.5% of risk-weighted assets. This reserve may then be used in the periods of stress (BCBS, 2010a).
- The requirements for SIFIs are an attempt to internalize the externality of a possible failure of large, systematically important banks by enhancing their loss-absorbing capacity beyond Basel III requirements. Although the form of this new

regulation is yet to be introduced, it is expected that this measure will entail further capital charges (Hannoun, 2010).

Table 1.2: Individual capital requirements of Basel III

Measure	Core Tier I	Total Tier I	Total Capital	Notes
Basic capital requirements	4.5% (2%)	6% (4%)	8% (8%)	*Core Tier 1 represents the highest form of loss absorbing capital (share capital and retained earnings).*
Capital Conservation buffer	2.5% (0%)			*Must comprise common equity, bringing total common equity requirement to 7%.*
Countercyclical capital buffer	0%-2.5% (0%)			*Determined by national supervisors depending on local circumstances.*
Additional requirement for SIFIs	To be determined by the BCBS (0%)			*Still under consideration at the global level. Expected to be set in the region of an additional minimum possibly 5% for global SIFIs and 2-3% for domestic SIFIs, as a combination of common equity and contingent capital.*

Note: The ratios required under Basel II are in the brackets

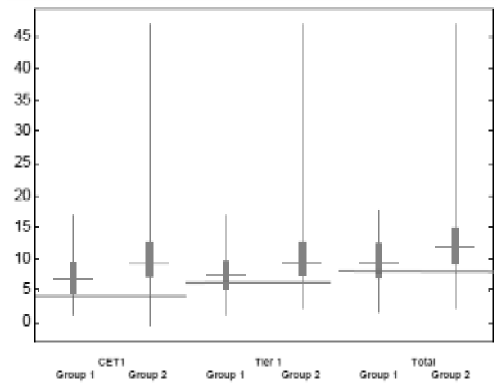
Source: Authors based on BCBS (2010c)

The new Basel III accord also addresses the issues of low risk weights, especially for securitizations and OTC derivatives including:

- The models will be required to use stressed inputs, i.e. calculate the capital requirements according to historical data of a 12-month period of stress situation. This period (i.e. 2008 would be a good example) must be approved by the regulator.
- The capital requirements for the risks connected to securitization will be increased, with certain lower-rated securitization exposures obtaining an overwhelming 1250% risk weight. Also, higher collateral haircuts will be introduced (BCBS, 2010a).
- Basel III also introduces measures for mitigating counterparty credit risk, i.a. higher charges for bilateral OTC exposures and zero charge for the derivatives traded through the central counterparty.

When adding up all those requirements, we arrive at a significant amount of capital that will be needed compared to Basel II. A question arises: What will be the cost of the new regulation? The answers differ across the industry; some stress the negative impact on economic recovery and economic growth due to higher credit costs, others are expressing concern whether the new rules are stringent enough. We will examine the differing views in the next parts of the chapter.

Figure 1.7: Capital ratios according to QIS



Note: Group 1 banks are those that have Tier 1 capital in excess of €3 billion, are well diversified, and are internationally active All other banks are considered Group 2 banks.

Source: Authors based on BCBS (2010c)

Figure 1.7 depicts banks' compliance with the Basel III basic capital requirements according to QIS. As we can see in Table 1.3, after introducing the new capital definition and asset risk-weighting, all the basic current capital ratios decline. When we add the Capital conservation buffer, a median Group 1 bank will find itself under the minimum required level of CET1.

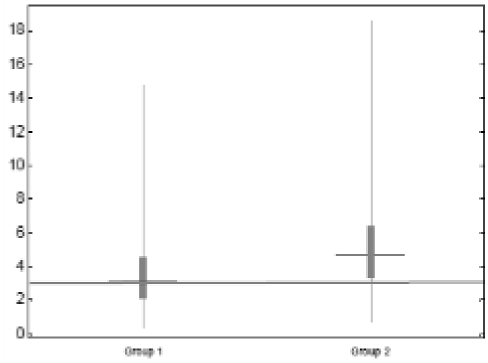
Table 1.3: Comparison of basic Basel II and Basel III capital ratios according to QIS

	CET1		Tier 1		Total	
	Basel II	***Basel III***	***Basel II***	***Basel III***	***Basel II***	***Basel III***
Group 1	11.1	5.7	10.5	6.3	14	8.4
Group 2	10.7	7.8	9.8	8.1	12.8	10.3

Source: Authors based on BCBS (2010c)

Another issue revealed by the past two years is that for some assets, in recession, the risk weights can become irrelevant. That is why there is a new requirement for a simple non-risk-based leverage ratio of 3%, calculated as Tier 1 capital over the bank's total assets, off-balance sheet exposures and derivatives (Hannoun, 2010). Such simple rule ensures that even when the risk weights on individual assets fail, the impact is not as disastrous.

Figure 1.8: Leverage ratio according to QIS



Source: Authors based on BCBS (2010c)

According to the QIS, approximately 42% of the Group 1 banks and 20% of the Group 2 banks in the sample would have been constrained by this measure as of December 31, 2009, assuming the new definition of Tier 1 capital. On average, the large banks' ratio in 2009 was 2.8% with some of them even deeper below (BCBS, 2010c).

As a response to the recent crisis, Basel III adds into its portfolio of regulatory measures also liquidity requirements. The banks will have to maintain certain amount of assets that can be quickly transformed into cash to cover sudden cash outflows when there is a need for source of financing quicker and cheaper than can be found in the inter-bank market.

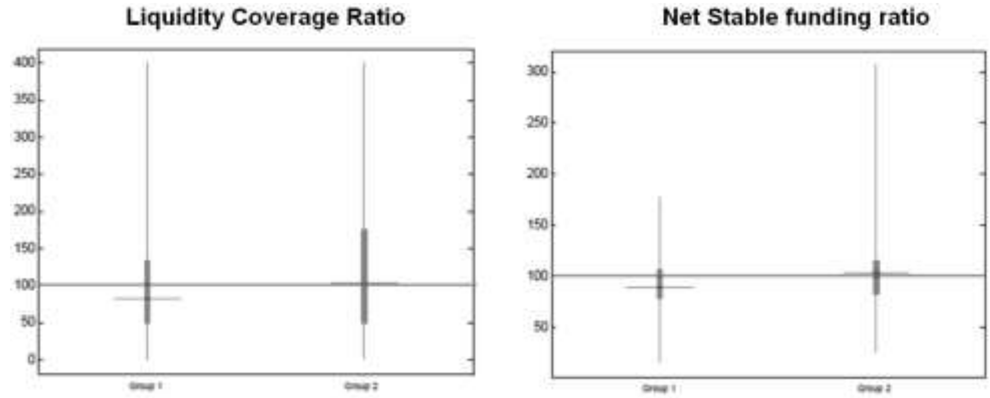
Table 1.4: Liquidity requirements under Basel III

Measure		***Formula***	***Notes***
Liquidity Coverage Ratio	*NSFR =*	$\frac{\textit{Available Stable Funding}}{\textit{Required Stable Funding}}$	*"High-quality liquid assets" are those assets that can be easily and immediately converted into cash at little or no loss of value.*
Net Stable Funding Ratio	*LCR =*	$\frac{\textit{High quality assets}}{\textit{30 day net cash outflows}}$	*"Stable funding" is defined as the portion of those types and amounts of equity and liability financing expected to be reliable over a one-year time horizon under conditions of extended stress. The amount of such funding "required" is a function of the liquidity characteristics of various types of assets held, on or off the balance sheet.*

Source: Authors based on BCBS (2010b)

Basel III regulates the liquidity risk by two measures, the Liquidity Coverage Ratio and the Net Stable funding ratio. While the first one is a requirement to keep cash reserves that could finance at least the first 30 days of a liquidity crisis, the second one requires having stable refinancing options available for the assets that cannot be turned quickly into cash.

Figure 1.9: LCR and NSF ratios according to QIS



Source: Authors based on BCBS (2010c)

When looking at the QIS, we see that in 2009, the large banks' ratios for both the liquidity measures were on average under the required 100%. Particularly the Net Stable Funding Ratio is highly controversial and has often been the target of the industry's complaints. From the regulatory point of view, this measure tackles the banks' overreliance on wholesale markets, which can turn into a serious problem in the periods of liquidity stress. The banks, on the other hand, believe that the little gain in systemic safety cannot outweigh the cost of changes to their business models (Elliott, 2010). A dynamic liquidity coverage ratio (DLCR) should be preferred over the current NSFR which creates a bias to finance assets with a maturity of less than one year. Also, in principle, the liquidity horizon should be given by the length of time needed by a bank to adjust the maturity profile of its funding structure. In this respect, a distinction could be made between countries and banks that have access to more liquid markets. A one-size-fits-all regulation is unlikely to be optimal (Dermine, J, 2013).

That is why there is a rather long period of observation (the rules are to be fully implemented in 2018) and the parameters can be subject to further calibration.

1.4.2.2 Basel III implementation

Table 1.5: Implementation dates of individual Basel III measures

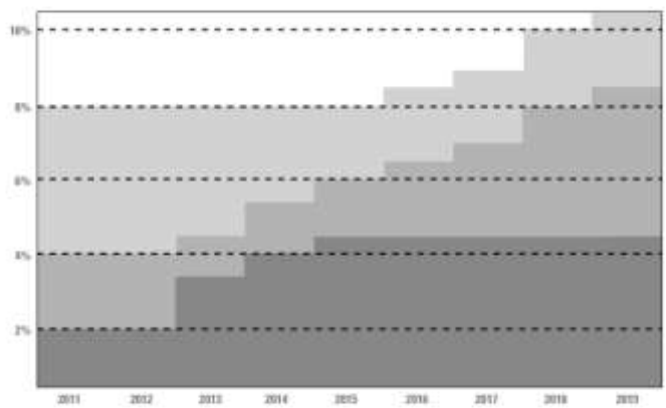
Group	*Measure*	*Implementation begins*	*Implementation ends*
Capital quality	Capital deductions	2013	2022
	Core Tier 1 ratios	2013	2015
Capital quantity	Market risk and securitization	2012	2012
	Counterparty credit risk	2013	2013
	Conservation buffer	2016	2019
Leverage	Leverage ratio*	2013	2018

Liquidity	Liquidity coverage ratio*	2013	2015
	Net stable funding ratio*	2014	2018

Note: The measures denoted with asterisk are subject to observation period and may be recalibrated.
Source: Authors based on BCBS (2010a) and McKinsey&Company (2010)

None of the aforementioned measures will come into force immediately - the Basel III requirements will be phased in over a period at least until 2019. There is an implementation plan for the individual parts of Basel III to be put into force by the national regulators and also there will be observation periods dedicated to potential recalibration of certain parameters. Table 1.5 shows the implementation schedule is rather loose. Although the risks related to securitization will be reassessed with higher risk weights already in 2012, most of the measures will be introduced no sooner than January 2013. The capital ratio timeline shows that the adjustments for CET1 ratio will be in full force in 2015, whereas the one for Tier 1 capital will not reach its target level even until 2019.

Figure 1.10: Implementation timeline of individual capital ratios



Source: Authors based on KPMG (2010a)

Moreover, since the Basel Accords are only sets of standards and principles, it is not certain whether Basel III will be transposed into national law of all the individual Basel Committee member states within the planned deadline and some countries may even choose not to implement it at all. On the other hand, the Declarations of G20 summits indicate that the proposed regulation still has its full support[9] and also the EU will implement Basel III in its new Capital Requirements Directive (Clifford Chance, 2010).

[9] See the declarations of G20 Summits in Seoul (G20, 2010a; p. 8) or Toronto (G20, 2010b; pp. 4, 15-17).

Not only may the regulation fail in its outcomes as we have seen in the case of Basel II; it may even be the underlying incentives and processes that are flawed. On the following lines, we first provide insight into the negotiations and lobby behind the creation of the first two Basel accords and we describe the process behind Basel III. With Basel Accords, banking regulation shifted from national legislative and executive bodies to international organizations. In the trilateral accord between the USA, UK and Japan on capital regulation, the US and UK initially objected to the accounting of hidden reserves held by Japanese banks including real estate and corporate equities. With Japanese holding the largest banks in the world in 1987, the trilateral accord was negotiated to allow up to 45% of unrealized gains on securities and other equities to be included as part of base capital (Kapstein, E.B., 1991).

We have indicated several times before that the international regulation is rather a political issue than a technical one. Barth, et al. (2005) states that, in a broader context, it is performed in an environment of political, legal, cultural and technological forces, and it involves a sequence of agency problems and interest group pressures. Although this scheme is rather simplified, the crucial point is that it is not possible to study banking regulation without considering the motivation of those who set and implement the policies.

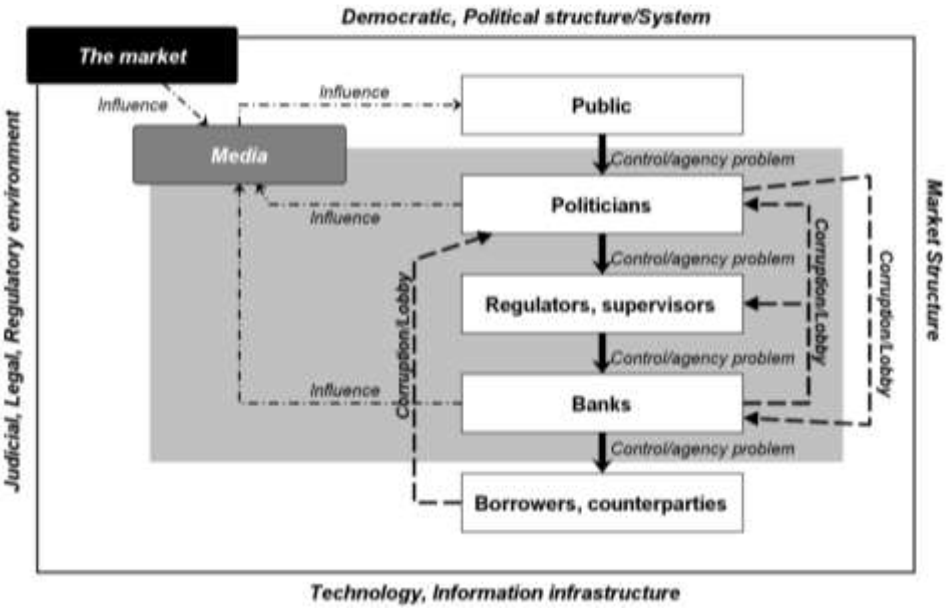
Figure 1.11 depicts several interest groups connected together in a chain of agency relationships. At the heart of the problem, there are three subjects, each with very different objectives:

- The banks seek to maximize profits while managing risks, notably the credit risk arising from the selection of borrowers, and control whether they behave responsibly. The banks are also trying to shape the regulatory environment by lobby, corruption, and also by influencing the public opinion via the channel of media.
- Regulators' main objective is to create standards, rules and enforcement measures that ensure that the banks behave in a way that does not threaten the stability of the system and lead to external costs. However, their decisions are being influenced not only by the incomplete information the banks provide but also with personal connections, offers of jobs and other benefits (Barth, et al., 2005).

Moreover, although the regulators are not politically accountable, they may try to expand their power by increasing complexity and extent of the regulation.[10]

- In order for the politicians to meet their objective of getting re-elected, they need to respond to potential public demand for regulation via controlling and influencing the work of the regulators and supervisors. Clearly, politicians not always pursue the public interest. They are also often dependent on donations and financing by the banks so they have to listen to their needs. Moreover, the politicians can be influenced by the borrowers who lobby for favorable regulatory policies. Whom the politicians listen to the most depends largely on the current stage of the political cycle.

Figure 1.11: Banking regulation framework



Source: Authors inspired by Barth, Caprio, & Levine (2005)

Because of the strong lobby by the banks, the processes behind the Basel accords creation and implementation are sometimes regarded as regulatory capture whereby the large banks with enough influence seize the procedure and turn it into their advantage. The best description of such situation can be found in Lall, (2009), Lall (2010) or Tarullo (2008) and the following analysis draws mainly on these works. The examples of the

[10] The incentive for the regulators to increase their control via increasing the extent of the regulation and disregarding the costs it brings to the economy has a parallel in the "Hubris motive" used for the explanation of corporate takeovers. According to the Hubris hypothesis, the managers of the bidding firms are acting against their shareholders' interests by paying too much for their targets. (Roll, 1986)

regulatory capture begin right with Basel I. In 1983, the US Congress imposed capital requirements on US banks in order to prevent future needs for expensive state aid. The American banks complained that it would put them into competitive disadvantage, mostly compared to Japanese banks, whose market share grew rapidly and who were not required to hold such high capital levels. In response to fierce lobby, American regulators put lots of effort into international negotiations which resulted in a common framework for capital regulation and which increased US banks' competitiveness.

Table 1.6: Shift in the proclaimed objectives of Basel II

Original consultative document[1]	Final version of Basel II[2]
"continue to promote safety and soundness in the financial system and, as such, also at least maintain the current overall level of capital in the system" "continue to enhance competitive equality"	"develop a framework that would further strengthen the soundness and stability of the international banking system while maintaining sufficient consistency that capital adequacy regulation will not be a significant source of competitive inequality among internationally active banks"
"constitute a more comprehensive approach to addressing risks"	"maintain the aggregate level of [capital] requirements, while also providing incentives to adopt the more advanced risk-sensitive approaches of the revised Framework"
"focus on internationally active banks, although its underlying principles should be suitable for application to banks of varying levels of complexity and sophistication"	"arrive at significantly more risk-sensitive capital requirements that are conceptually sound and at the same time pay due regard to particular features of the present supervisory and accounting systems in individual member countries"

Source: Authors based on BCBS (1999) and BCBS (2004b)

In addition, we have already mentioned that the negotiations on Basel II commenced mainly because of the large international banks' complaints about the relevance of the specified risk categories of assets. The changes in regulation originally seemed well-intended, with set of strong objectives, as we can see in Table 1.6. However, after the six years of preparations and pressure of the interest groups, the initial objectives could be found only partly in the final version of Basel II. Instead, the Basel Committee came out with even looser regulation of the internationally active banks, which proved deadly in 2008. In the light of the recent situation, it is almost comical to read in the final version of Basel II that *"the Committee has benefited greatly from its frequent interactions with industry participants and looks forward to enhanced opportunities for dialogue."*[11] The process that led to Basel III can again be explained on the basis of Figure 1.11. In contrast to Basel II, the recent change in regulation was not inhibited by the banks. The

[11] (BCBS, 2004b; p. 4)

major hallmark of the economic crisis was the failure of Lehman Brothers in September 2008, when the losses of the financial system finally spread into the real economy.[12] First, it was the public anger and pressure for change of the banking regulation which induced the politicians, in our analysis represented by the G-20, to call for capital adequacy reform. At the summit in Pittsburgh a year after Lehman collapse, the G-20 introduced its requirements for banking regulation including the leverage ratio, countercyclical measures, liquidity standards and systemic charge for banks which are too-connected-to-fail (G20, 2009).

With due complaints of the banking industry, the Basel Committee started negotiations on the new regulatory framework known as Basel III. However, in the second phase of the process, the pressure of the disorganized public ceased as the economic situation in advanced economies improved. From this point, the process has been again gradually taken over by the well-organized international banks. As we know from Figure 1.11, these institutions have two options for shaping the regulatory environment: direct influence through personal connections, lobby and corruption, and indirect influence through the media.

- There are evident personal connections between the two opposing sides, with IIF members getting jobs at the Basel Committee and otherwise. Lall (2010) provides an overview of opinion shifts of the ex-Basel Committee members who joined the IIF. The banking industry even managed to recruit Jacques de Larosière, authors of the Larosière report, which was one of the first to point at the necessity of a regulatory reform. Because of these links, the banking industry managed to get closer to the Basel Committee and organize confidential discussions with its members.
- The banks were also directly influencing the public by predicting severe costs the new regulation would bring, and they had been doing so even before the Basel Committee came out with specific figures in its proposals. Again, Lall (2010) provides examples of the industry's estimates of the new measures' impact on loan prices or GDP growth. These forecasts which the bankers were threatening

[12] According to the IMF World Economic Outlook Database, the GDP growth in the US practically stopped in 2008 and fell to -2.6% in 2009. In the Euro area in 2008 it fell to 0.5% in 2008 and -4.1 in 2009 (IMF, 2011)

the public with *"were based on pure guesswork"*[13] and they were becoming increasingly extreme as the consultation period was approaching its closing date.

To these two tactics we must also add the constant pressure for implementation delays, which resulted in the aforementioned situation of extended timescales for the new accord's full operation. Moreover, the phase-in period is long enough for the banks to succeed in watering down the measures that are yet to be calibrated or even devised, such as the systemic surcharge, liquidity ratios and the leverage ratio.

Although the core documents of the new accord have already been published in December 2010, still lots to-dos remain: the measures need to be calibrated and implemented in the individual countries, and the regulators need to prepare themselves for monitoring the banks' compliance with the new ratios. The banks, on the other hand, ought to start planning their capital and liquidity needs and changes in their internal processes. It is clear that the new accord will incur some additional costs to the banks, be it for raising more capital or for the implementation of the new risk-management and reporting procedures, and these costs are even likely to transfer to the economy in the form of higher interest rates or transaction fees.

One such example will presumably be the trade finance, products of transaction banking such as letter of credit, which are of vital importance for promoting economic activity.[14] In contrast to other off-balance sheet products, these usually entail relatively low levels of risk - according to ICC (2010), the empirical data show that there are only 1,140 defaults in the full sample of 5,223,357 trade finance transactions provided by observed nine international banks over a period from 2005 to 2009, which accounts for only 0.02% rate of default. However, mainly because of the leverage ratio which will not take into account the risk profiles of individual assets, the banks will be required to hold capital against the whole value of their trade finance asset portfolio. According to Standard Chartered, in Beck (2010), Basel III will bring a $270 billion cut in international trade flows, which would increase the price by 40% and result in 0.5% decrease of global GDP. On the other hand, from several aspects, Basel III is a step in the right direction and the benefits are likely to outweigh the costs. The increase in capital requirements, tighter

[13] (Lall, 2010; p. 30)

[14] In contrast to e.g. investment banking, transaction banking is one of the areas where the Czech banks can feel the pressure of the new regulation as well.

capital definition and the new liquidity charges will ensure that the financial system is again at least a little bit safer. A question remains whether that is enough or not, however. Very high levels of capital requirements might lead to unintended evils. A bank's incentive to monitor risk might fall with much change in bank capital structure towards equity. Bankers are better if not best placed to assess counterparty risk as against its shareholders. Therefore, interbank debt should be put at risk to reduce moral hazard and incentives to reach a too big to fail status (Dermine, J, 2013).

1.4.3 Alternative solutions

Many experts call for even tighter regulation,[15] some for an entirely different concept. We agree with Dewatripont, et al. (2010) that the capital requirements need to be simplified. It does not matter how sophisticated the capital ratios are, they can never capture all aspects of risk the major financial institutions are facing. Moreover, the current setting of various buffers is rather opaque and difficult to monitor by the regulators and also by the investors and the public. Instead, simple and easily verifiable indicators are needed that quickly point to problematic banks and allow for a quick discretionary reaction. Only in this setting the regulation will not be designed only to *"fight the previous crisis"*.[16] We suppose that as to the capital requirements, much more attention should be given to the leverage ratio, which is the ultimate measure of how a bank is able to cover its own losses. The leverage ratio also tackles the Basel II problem with pro-cyclicality, since it automatically requires more capital if the credit pool is expanding.[17] In order to avoid a domino effect to interconnected banks, regulation must be enforced to measure counterparty exposure, transparency and strict diversification of risk. (Dermine J, 2013).

Furthermore, the current situation of low yields with severe negative implications for long term investors as insurers and pension funds have triggered debate on the impact of non-banking financial institutions on the overall financial sector stability. It has become clear that some transmission channels propagating systemic risk within the financial systems lies beyond the banking system. Regulations and regular stress testing of pension

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[15] See, for instance, the letter sent to FT on November 9, 2010, where 20 leading banking experts suggest capital ratios of at least 15% (Admati, et al., 2010).

[16] (Dewatripont, et al., 2010; p. 8)

[17] However, since this measure alone would incentivize the banks to seek more risky assets with higher yield, there ought to be also a measure that uses some simplified version of risk-weighted approach, presumably the simple capital ratio of Basel I (Pakravan, 2010).

fund and insurance companies is therefore important to protect long term savings and investments (EIOPA, Financial Stability Report, 2015). With this in place, these institutions can be potential economy stabilizers. They are heterogeneous long term institutional investors and can have long term macro-economic effects by two different mechanisms: by channeling important amounts of long term savings to investment and by creating and developing markets for long term bonds and stocks. (Zahler, 2003).

1.5 Chapter Summary

It is necessary to regulate banks' operations because of the two types of market failures: asymmetric information and existence of externalities. The overall aim of banking regulation is protecting the depositor and assuring systemic stability, i.e. ensuring that the distress of one or more banks will not bring the whole system to collapse. Since the banking business has a cross-border character, the regulation has to be performed on an international basis, chat still remains as a global chase, however.

The Basel committee was established to ensure international coordination of banking regulation. In 1988, it published the first version of regulatory standards known as Basel I which prescribed a simple capital ratio that the internationally active banks should have been required to maintain. However, this prescription was criticized for its over-simplicity and in 2004 it was followed by Basel II, a second regulatory document increasing the complexity of the regulatory measures and giving the large banks the possibility to calculate their individual capital requirements via the IRB approach. Nevertheless, the recent financial crisis pointed at the deficiencies of Basel II. It showed that banking regulation had fallen victim to regulatory capture by large international banks and that it failed to protect the financial system since it did not ensure sufficient capital buffers. Moreover, it even contributed to the economic downturn because of its pro-cyclical nature.

As a result of the 2008-2009 global market upheaval, a revision of the current regulatory framework was needed, which finally escalated into the publication of a new set of standards known as Basel III. This latest set of standards should increase the system's resilience by redefining what constitutes the regulatory capital, and by raising the current capital ratios or adding new ones. It also adds measures for increasing the banks' liquidity so that they are better able to withstand transient shocks. However, there are also doubts about its efficiency – as with the Basel II, the lobby of the international financial institutions has been again trying to shape the form of the new rules, or at least secure long transition periods for their implementation. We agree with Teplý et al. (2012) who state the Basel III regulation is not sufficient and will not prevent financial markets from future crisis due to its expected calibration, delayed implementation and strong pressure from the banks' lobbyists. Also, Sutorova and Teply (2013; 2014) state that the recent global banking regulation Basel III is not sufficient and will neither protect neither financial markets from future crisis nor the taxpayer from further subsidies to banking industry. Basel III is almost exclusively micro-prudential in its focus, concerned with the solvency of individual banks, rather than being macro-prudential, concerned with the resilience of the financial system as a whole (Shin, 2010).

Policymakers, researchers and regulators have, since the crisis, explored various regulatory options beyond Basel III. Shin (2010), proposes that a levy or tax on the non-core liabilities, which reflect the stage of the financial cycle and under –pricing of risk in the financial system; can serve to mitigate pricing distortions that lead to excessive asset growth. The Financial Stability Contribution (FSC) recommended by the IMF in its report on the bank levy to the G20 leaders is an example of such a corrective tax. Also, regulators are trying to address the linking effects between financial crisis and sovereign crisis. For instance, under the Internal Rating Based (IRB) Approach, risk weight typically applied to domestic sovereign debt by banks is often close to zero. Regulators have been trying to understand the effects of eliminating the present favorable treatment of sovereign exposures (BIS, 86th Annual Report, 2015/16). The need for additional policy measures beyond monetary policies is being highlighted for a well- grounded exit from the crisis. Legal framework around bankruptcy, complementing fiscal policy and structural reforms are needed to successfully mitigate a crisis or pull an economy already facing one (IMF, 2015).

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2 Systemic risk of the global banking system [18]

Abstract

The global banking system proved significantly vulnerable to systemic risk during the 2007-2009 financial crisis. In this paper, we construct an agent-based network model of systemic risk of a banking system, and use it for stress-testing several different regulatory measures. First, our simulations confirm that sufficient capital buffers in individual banks are crucial for protecting the stability of the whole system. Second, we show that the regulatory measures installed as preventive measures to ensure that the banks possess sufficient capital buffers have almost no positive effects to stability when the system is collapsing. Finally, we highlight various data deficiencies which prevent the researchers and regulators from fully understanding the complete range of systemic risk and make it difficult to devise effective and targeted regulatory measures at this time.

JEL Classification: E61, G01, G21, G28

Keywords: agent-based modelling, banking regulation, Basel III, capital, interbank network, systemic risk

[18] The essay was published in an impact-factor journal Prague Economic Papers as Klinger, T., Teply, P. (2014): *Systemic risk of the global banking system - an agent-based network model approach*, Prague Economic Papers, Vol. 23, No. 1, pp. 24–41. With this essay, the author earned an honorable mention as the Young Economist of the Year under 25 years of age at the Czech Economic Society. Moreover, this paper has been cited by leading experts in agent-based modelling of financial stability and the IMF, as in Chan-Lau, J. A. (2014), Chan-Lau, J. A. (2015) and Demekas, M. D. G. (2015).

2.1 Introduction

The 2007-2009 global financial crisis highlighted the vulnerabilities and interdependencies in the financial system, bringing about a revision of financial regulations. The crisis also exposed the deficiencies of Basel II, showing that the regulatory measures had fallen victim to regulatory capture by large international banks, failing to ensure sufficient capital buffers (Lall, 2010, p.15). The subsequent regulatory framework revisions finally coalesced into the publication of Basel III in December 2010. Basel III is intended to increase the banking system's resilience by redefining what constitutes the regulatory capital, raising the current capital ratios and adding new ones (BCBS, 2010). It also adds measures for increasing the banks' liquidity so that they are better able to withstand transient shocks. Although we can expect the new measures to bring minor improvements, there are several reasons why ideal regulation is still wanting and not yet achievable (Teplý, 2010, p.2). First, it is necessary to eliminate the political and institutional pressures that influence global financial operations. Second, the parameters of the regulatory measures should be an outcome of rigorous research rather than lobbying by large financial institutions and the systemic character of the banking system should be taken into account.

In this paper, we contribute to the discussion for better regulation by shedding light on systemic risk and by showing a way how regulatory measures can be tested in a virtual environment. Our method stems from the research on systemic risk using the network approach, which became a trendy topic after the recent financial crisis. An overview of the network character of the crisis can be found in Sheng (2010), in the risk assessment framework for systemic linkages provided in IMF (2009) and in the recent advances in modelling systemic risk using network analysis provided in ECB (2010). More recently, Frait and Komárková (2011) or Geršl and Jakubík (2010) present systemic risk in the context of financial stability and macroprudential policy from a view of the Czech National Bank. On a related note, a detailed literature survey of research focused on the interconnected financial structures is provided by Allen and Babus (2009).

Current research can be divided into two categories, the empirical studies and theoretical models. The empirical studies are focused on modelling of the real-world interbank exposures and the banking systems' disposition to crisis caused by contagion effects. These models usually describe local banking systems as documented by Boss, et al.

(2004) for the Austrian interbank market or Upper and Worms (2004), Wells (2004), Van Lelyveld and Liedorp (2006) or Muller (2006) for other countries. However, a frequent problem of the empirical approach is that the data on the individual interbank exposures is unavailable to the researchers who often rely only on the aggregate balance sheet data. For this reason, the majority of empirical studies use the maximum entropy assumption, which supposes that the banks spread their lending as evenly as possible given a certain sum of their interbank assets (Upper, 2011, p.6). Clearly, this assumption is rather unrealistic and it often underestimates the potential for contagion (Mistrulli, 2011) or underreported inventory of bad loans carried on the books.

The theoretical models examine how system behavior is influenced by its general characteristics. The first such model was constructed by Allen and Gale (2000) who showed that the structures with more interbank links are more resilient to initial shocks. Another early analysis is provided by Freixas, et al. (2000), who studied contagion in systems where some banks are systemically important. The simple framework is extended in Cifuentes, et al. (2005) and Shin (2008), who add a mechanism for price decrease of illiquid assets as a second channel of contagion. Finally, there are models using simulations on random networks such as Gai and Kapadia (2010), who find out that the interbank exposures serve as a good shock absorber initially but when a crisis occurs, they can cause a larger negative impact. Our paper is inspired by Nier, et al. (2007), who built an agent-based model of interbank systems and finds non-linear dependencies on certain parameters when performing comparative statics exercises.

The paper is structured as follows: In the second section, we build a model of a banking system that allows us to perform scenario stress analysis under various settings of structural properties and regulatory environments. The third section presents detailed results of our simulations. In the fourth section, we provide a results summary and discuss further opportunities for our research. Finally, the last section concludes the paper and states the final remarks.

2.2 The Model

In this part, we provide a high-level overview and detailed description of the model construction. Furthermore, we explain an impact of shocks to bank balance sheets and discuss effects of systemic risk on bank capital regulation.

2.2.1 Basic Description

We create a system that comprises a number of banks interconnected by exposures and claims they hold against each other. Our interbank system is characterized by a graph where the banks are represented by nodes and their exposures by oriented edges. Such system may represent an interbank market, a network of over-the-counter (OTC) derivatives or payment systems. In order to be able to study the relationship of the system behavior and its characteristics, and because the data on interbank exposures are mostly unavailable, we perform our simulations on a generic random network as described by Erdös and Rényi (1959). Hence we assume identical and independent probability of interbank exposures across all ordered pairs of banks. However, if in the future the data were available, the model is applicable to any interbank network.

The interbank network is examined under a simulated stress scenario, when one or several banks receive a negative shock to the asset side of their balance sheet. The shock is then transmitted to the rest of the banks through one of the two main mechanisms described in Brunnermeier et al. (2009, p. 15): the *"domino"* effect meaning the transfer of losses through the edges of the network.[19] As the model represents only a very short period of collapse, we assume that the banks are not capable of borrowing any extra funds and that no edge can be added to the interbank network, and that the banks do not make any profits during the simulation. In our study, we also restrict the possibility of state aid in the form of bank bail-outs. Our analysis is based on comparative statics experiments where the simulations are performed under varying combinations of input parameters. These parameters are summarized in tab. 1 along with their base values used in Nier et al. (2007) which we use for our simulations unless stated otherwise.

In contrast to Nier et al. (2007), our model is also able to capture rules that represent several types of banking regulation contained in Basel III[20]. Namely, in this paper we apply a situation where the regulator deprives a bank of its license because of a low capital ratio. To our knowledge, we are the first to study the effects of regulation in an agent-based interbank network model.

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[19] The second contagion channel called the *"asset price spiral"* effect, which represent the asset price decline under low liquidity of the system, will be left for further research.

[20] For more details on Basel III and its predecessor Basel II see, for instance, Klinger (2011), Lall (2010), Matejašák et al. (2009), Rippel and Teplý (2011) or Teplý et al. (2007).

Table 2.1: Input parameters of the model

Parameter	*Base value*	*Interpretation*
$\boldsymbol{N}$	25	Number of banks in the system*
$\boldsymbol{p}$	0.2	Probability of connecting two banks with a directed exposure*
$\boldsymbol{E}$	100 000	Total sum of external assets in the system*
$\boldsymbol{\theta}$	0.2	Interbank asset ratio (interbank/total assets)*
$\boldsymbol{\gamma}$	0.05	Capital ratio (net worth/internal + external assets)*
$\boldsymbol{CAD1}$	0	Capital ratio limit that triggers bank's removal by the regulator
$\boldsymbol{shock_{random}}$	1	Shock on a random bank (in percentage of external assets)*
$\boldsymbol{shock_{others}}$	0.1	Shock on all other banks (in percentage of external assets)
$\boldsymbol{iterations}$	500	Number of iterations under one set of parameters

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

2.2.2 Model Construction

On the level of an individual simulation, the model is built as follows: first, the interbank network is initialized along with the individual banks' balance sheets. Second, we shock the system by wiping out a portion of certain banks' assets and several rounds of defaults and loss transmission unfold. The model runs in several laps (rounds of defaults) until the shock dissipates in the banking system and is not propagated further.

2.2.2.1 Interbank Network Creation

The interbank network is based on two main parameters, which are set at the beginning of a simulation run and which define the form of the random graph:

1. Node count N, which determines the number of banks in the network,
2. Probability p_{ij}, with which there is an oriented edge between node i and node j in the graph, i.e. the probability that the bank i is exposed to the bank j. We expect this number to be fixed among all edges between nodes (i, j) and denote it as p. There can be two links between a pair of edges, each in different direction.

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

2.2.2.2 Initialization of Balance Sheets

Next, we initialize the individual banks' balance sheets for the given network realization. This is done in such manner that the variables conform to the aggregate level identities as well as the bank level identities. First, we calculate the global variables of the system. On the aggregate level, the total value of assets is a sum of interbank assets (constituted by all the loans represented by the edges of the interbank network) and external assets (constituted by individual banks' exposures outside the network, e.g. securities and loans to other entities such as households, sovereigns or non-financial institutions).

1. The sum of external assets in the system (denoted by E) and the ratio of interbank assets to total assets (denoted by θ) are given as input parameters. The total value of assets in the system (denoted by A) is calculated as

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

2. The total sum of interbank assets is then determined as a portion of total assets.

$$I = \theta A$$

3. If we denote the sum of outgoing edges from all the banks in the system as Z, the value of one individual edge is calculated as

$$w = \frac{I}{Z}. \tag{1}$$

Subsequently, individual banks' balance sheets are initialized:

4. An individual bank's interbank assets (i_i) and liabilities (b_i) are calculated according to the interbank network structure:

$$i_i = w \cdot number\ of\ incoming\ edges_i,$$
$$b_i = w \cdot number\ of\ outgoing\ edges_i.$$

5. The value of an individual bank's external assets is a little more difficult to determine. We use the same two-step algorithm as Nier, et al. (2007):
   a. First, each bank's difference between the internal liabilities and internal assets is balanced by a certain amount of external assets $\tilde{e}_i$.

$$\tilde{e}_i = b_i - i_i \quad \text{if} \ \ b_i - i_i > 0,$$

$$\tilde{e}_i = 0 \qquad\quad \text{if} \ \ b_i - i_i \leq 0.$$

   b. The rest of the total sum of external assets is then distributed uniformly among the banks. Finally, it holds that

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

6. Each bank's net worth is calculated as a portion of total assets according to the following capital ratio:

$$n\_w_i = \gamma a_i.$$

7. External liabilities are calculated so that the balance sheet identity holds:

$$d_i = a_i - n\_w_i - b_i.$$

Finally, as the balance sheets are populated, the whole system is initialized and ready for the simulation.

Table 2.2: Balance sheet of an individual bank in the model

a_i...*TOTAL ASSETS*	l_i.... *TOTAL LIABILITIES*
i_i....interbank assets	b_i.....interbank liabilities
e_i....external assets	d_i......external liabilities (deposits) n_w_i..net worth

Source: Authors

2.2.2.3 Shock

After the initialization, the system is in inertia until we induce an adverse shock, which initiates the first lap of the simulation. There are two types of shocks we can examine:

- A certain portion (most often 100%) of external assets is wiped out from the balance sheet of a random bank - we call this a *"local shock"*.
- The external assets drop in value. This means that the percentage loss is applied to all banks – we call this a *"global shock"*.

2.2.2.4 Shock Impact on a Bank's Balance Sheet

The initial shock may result in knock-on *"domino"* effects, where in each lap of the simulation, the set of banks that suffered losses transmit the shock further in a cascade effect. Let us consider one representative 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 owners' equity gets eradicated[21], then claims of other creditors). Let us suppose that the bank suffered a shock of size Δ and hence it holds that

$$l_i - a_i = \Delta_i.$$

The external behavior of the bank then depends on the size of the shock:

a) In the first place, the shock hits the bank's net worth. If $n\_w_i > \Delta_i$, which means that the bank is able to cover the losses from its own funds, then the whole shock is absorbed by the bank's capital and it is not propagated further.

b) If $n\_w_i < \Delta_i$, the residual shock further spreads to the interbank liabilities b_i, which means that it is uniformly transferred onto the creditor banks up to the

[21] As mentioned earlier, we simulate only a short period of banking system stress. Thus the net worth behaves only as a shock absorber and cannot be replenished during the simulation, e.g. by accumulating retained earnings.

value of the interbank liabilities. Hence, if there are m creditor banks, in the next round each creditor bank receives a shock of

$$min\left(\frac{\Delta_i - n\_w_i}{m}, \frac{b_i}{m}\right).$$

As the propagating bank is not able to honor its debt, it defaults and it is removed from the system. The creditor banks evaluate the received shock in the next lap of the simulation. The simulation ends with a lap when no bank propagates the shock further. Additionally, it holds that:

i. If $b_i > \Delta_i - n\_w_i$, there is no residual shock to be transferred to the depositors.

ii. If $b_i < \Delta_i - n\_w_i$, the shock remainder is compensated by the external liabilities which means that the residual loss is covered by the depositors.

2.2.2.5 Effects of Capital Regulation

Capital regulation is modelled by a rule which measures whether a bank meets a strict capital adequacy ratio and in case of non-compliance it deprives the bank of its license. If $\frac{n\_w_i}{a_i} < CAD1$, where $CAD1$ is the strict capital adequacy requirement, the bank is removed from the system similarly as if it defaulted :

a) In order to repay its debt, the bank sells all its assets. Subsequently, it settles its debts from the funds it obtains by the asset sale. First, this pool of funds is used for the repayment of external liabilities. Second, the creditor banks are compensated by the repayment of interbank liabilities. If the bank is not able to repay its interbank liabilities, it uniformly transfers the loss onto the creditor banks. Finally, in the case that there are any funds left after settling all the bank's debt, they disappear from the system.

b) To be able to finally remove the bank from the system, we also have to ensure that it does not have any claims against other banks. As mentioned above, we assume that the bank in liquidation sells all its assets. Since the claims on the debtor banks are sold to some external entity, these banks move the equivalent amount from their interbank liabilities to their external liabilities.

As the capital ratio varies in all simulations, the $CAD1$ ratio cannot be set directly. Instead, we need to express the $CAD1$ ratio as a percentage of the initial capital ratio by using the following parameter:

$$removal\_ratio = \frac{CAD1}{\gamma} \quad (2)$$

In our simulations, this parameter reaches values from 0 to 1, and can be interpreted as the relative gap between the initial capital endowment to the critical $CAD1$ level. If the removal_ratio equals zero, no banks are removed as the regulation is switched off. If, on the other hand, the $removal\_ratio$ equals unity, it means that the capital the banks are initialized with equals the $CAD1$ requirement and thus a bank is removed immediately when its capital ratio falls below the initial level. Given a particular value of γ and removal_ratio, we can always calculate the exact $CAD1$ requirement.

2.2.3 Model Control

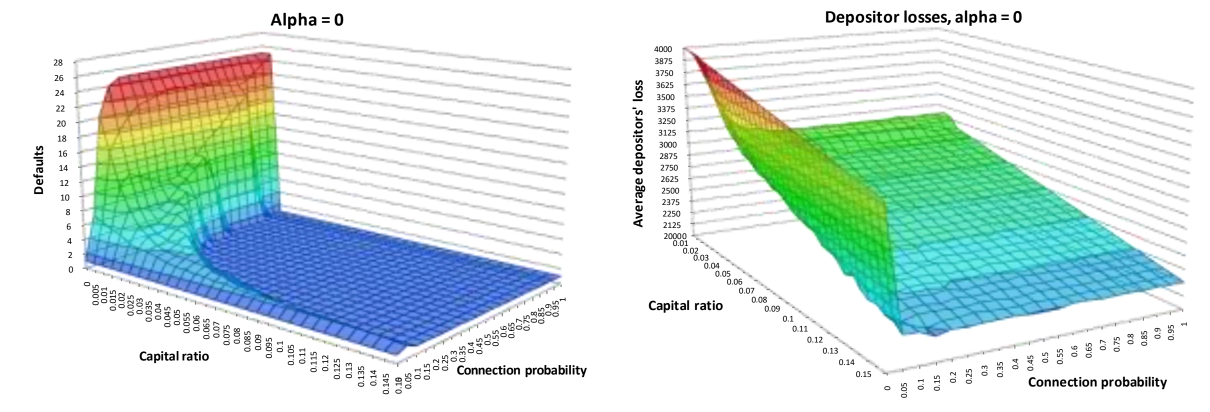
For each comparative statics experiment, the model is run under several parameter settings which vary in predefined ranges. These intervals from which we draw the parameter combinations then form the axes of the charts. To obtain the observed values, for each parameter combination we run the model in several iterations, each with a different realization of the random network, and we average the result into a single data point.

2.3 Simulation Results

2.3.1 Basic Behavior under Several Types of Shocks

First, we run the model in the basic setting. All the parameters are left at values stated in tab. 1 apart from n_w_i and p, which are on the axes of the charts, and α, which equals zero for the first experiment and unity for the second one. Similarly, to Nier et al. (2007) or Gai et al. (2010), we hit a random bank in the system by wiping out all of its external assets. The results of the first experiment are similar to Nier et al. (2007). On the left-hand chart of Figure 2.1, we see that the model behavior is non-linear in both parameters. First, we look at the comparative statics under varying capital ratio. When these ratios are sufficiently high, at reasonably high connectivity levels, the only bank which defaults is the one on which we imposed the original shock. When the capital ratio is between 1% and 4% (depending on the connectivity), the loss buffers of the first line of the initial banks' creditors are large enough to absorb the losses, which is the reason the number of defaults stays almost constant. However, if the capital ratio falls below this range, the first-line creditor banks default as well, spreading the losses in further laps of failures.

Figure 2.1: Number of defaults (local shock, basic parameter setting)



Source: Authors

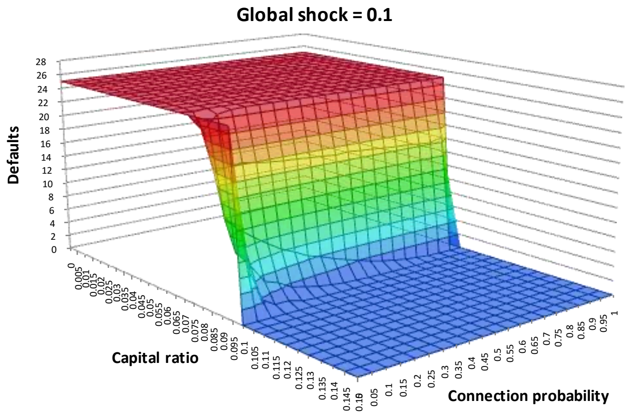
Second, as the probability of connecting two nodes varies while the total amount of interbank assets remains the same, since equation (1) holds, higher probabilities of connection lead to lower interbank exposures and hence lower riskiness that the initial shock triggers further rounds of defaults. Moreover, as we see in the left-hand chart of Figure 2.1, except for the situations with very low connectivity, the interbank system has high potential of absorbing the initial shock. For higher probabilities of connection, the relationship of the depositor losses and capital ratio is almost linear. On the other hand, higher connectivity means that more banks are exposed to the initial shock-propagator, and hence especially for capital ratios close to zero, it results in more defaults as we can see in the left-hand chart of Figure 2.1.

Generally, the smaller the capital buffer, the larger connectivity is needed to prevent a systemic crisis. Again, the left-hand chart of Figure 2.1 shows a "safe zone" of sufficient capital level and reasonably high connectivity, where the only bank to default is the one that is originally shocked. This area presents desirable parameter settings and in reality, both these two parameters are subject to regulation: the capital measures are the main building block of the Basel agreements and the regulation of connectivity is performed by the large exposure limits which ensure that a bank's interbank assets are diversified to reduce the credit concentration risk.[22] Clearly, though, when the capital ratio is too small, the risk cannot be absorbed even with very high connectivity levels. Figure 2.1 also confirms the results by Mistrulli, (2011), who concluded that the ex-ante maximum

[22] Credit concentration risk is addressed by the EU Directive No. 2006/48/EC.

entropy assumption (which in our model equals the assumption that $p = 1$) underestimates the risk of systemic crisis.

Figure 2.2: Number of defaults (global shock)



Source: Authors

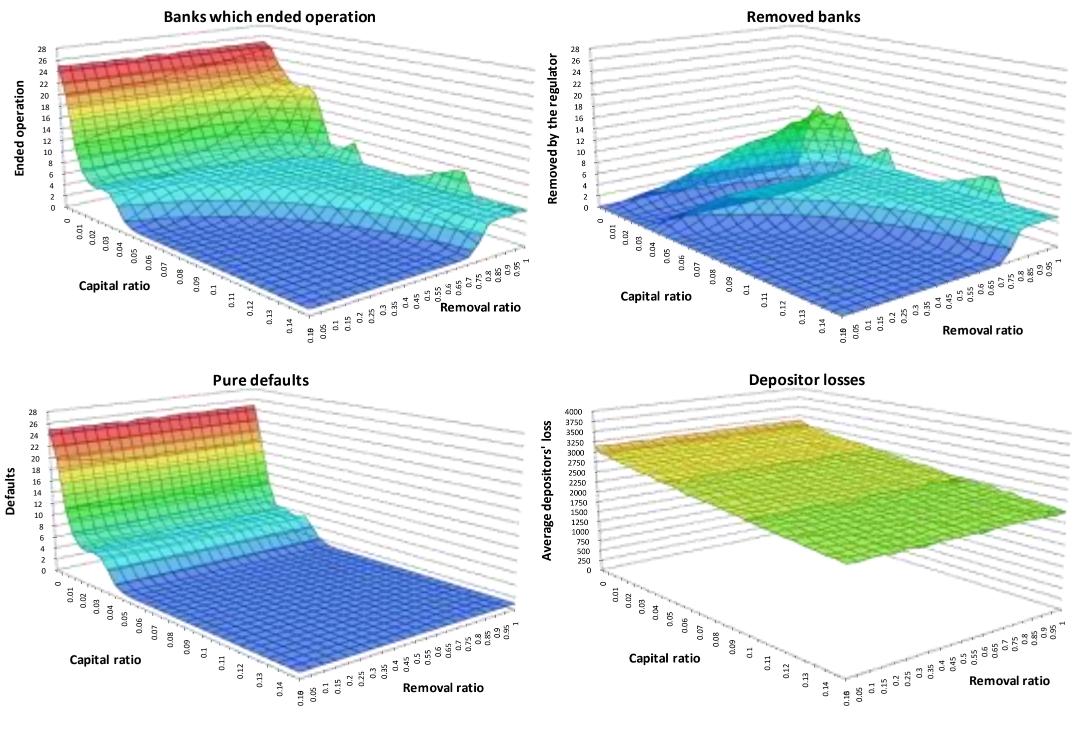
Also, a situation may occur when all banks suffer minor losses, which happens when certain percentage of loans has to be written-off or when an asset which all of the banks possess drops in price. Figure 2.2 displays a short interval of 7.5% to 10% on which increasing connectivity results in shock dispersion and increased system resilience. With even lower capital ratios, there is a threshold level behind which all banks in the system default. The sudden occurrence of systemic break-down is caused by the relative homogeneousness of the banks' balance sheets. Since the only mechanism by which the banks differ from each other is the random network initialization and since the interbank assets account for relatively small portion of the total assets, the banks' capital buffers are of similar size.

2.3.2 CAD1 measure

As to the capital regulation, up until now we have focused only at the capital ratio describing the actual size of the banks' capital buffers. However, it is not possible to simply prescribe a capital ratio and count on all banks' compliance. There must be repressive mechanisms ensuring that all the banks keep their capital levels high enough, such as a ban on operation. Thus, we observe what happens if the banks that do not comply with the regulation are deprived of their license. The results are presented as follows: the top left-hand chart depicts the average number of banks that ended operation, either because they defaulted or because they were removed for not meeting the regulatory requirements, the top right-hand chart presents the number of banks removed by the regulator and the bottom left one the banks that defaulted and imposed losses on the rest of the system. The top right and the bottom left-hand charts result in the top left one when summed up. Finally, the bottom right-hand chart depicts the losses suffered by the depositors. On one axis there is the capital ratio, on the other one there is the removal ratio as defined by equation (2).

First, we examine a local shock hitting one random bank, a situation depicted in Figure 2.3. For high capital levels, the regulation takes out the banks that would not otherwise default, but when the capital buffers are small, the banks default before the regulation manages to remove them from the system. Hence, this measure fails to improve the system resilience and moreover, we see that the same holds for the depositor protection.

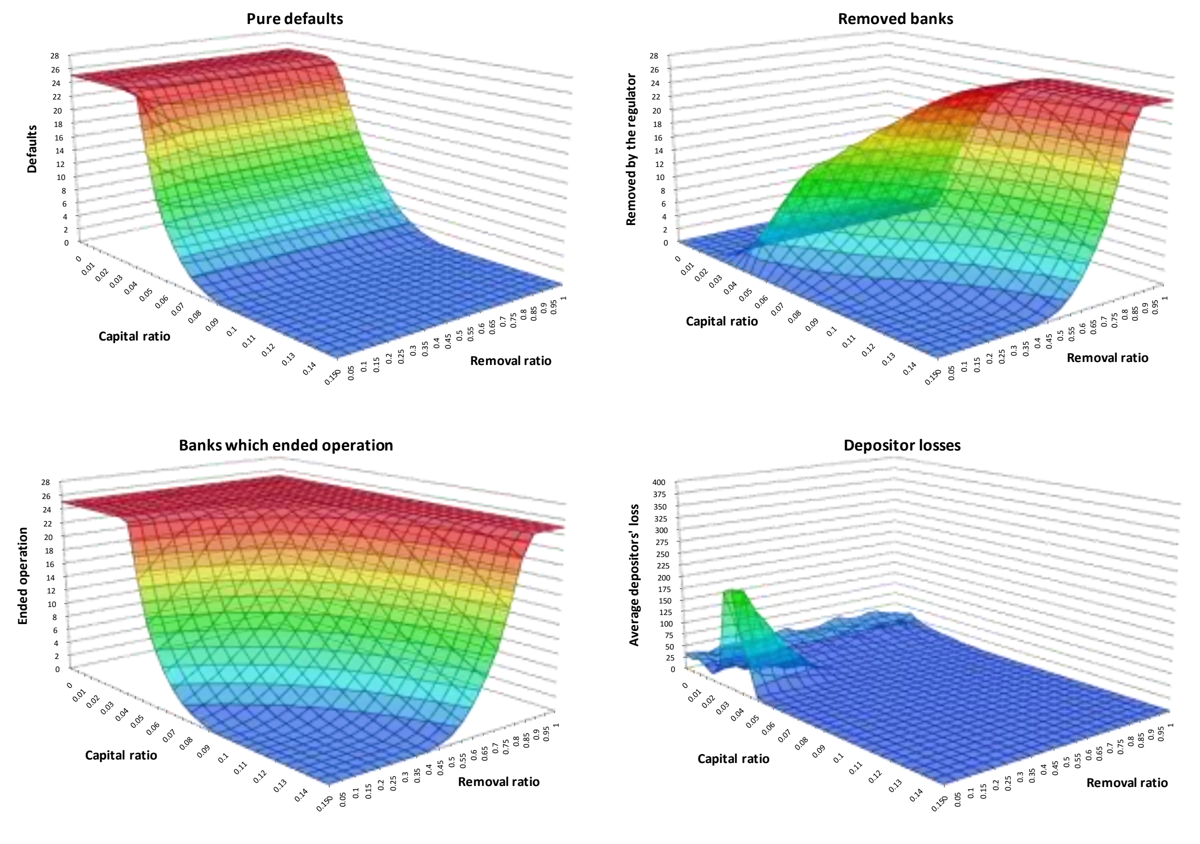
Figure 2.3: CAD1 measure (local shock)



Source: Authors

Next, we study the case of a shock affecting all banks. Figure 2.4 implies that for small capital buffers (until approximately 2.5%), no banks are removed since almost all of them default right after accepting the shock. However, this situation differs from the one of a local shock in two aspects. First, as we can see in the top right-hand chart of Figure 2.4, high removal ratios cause the regulator to remove all banks in the system even though their capital buffers would be large enough for them to withstand the shock, which is clearly a rather unrealistic result.[23] Second, there is an interval of capital ratios (approximately [2.5%, 5%]), where the regulation succeeds in lowering the number of defaulted banks and the depositor losses. However, this result is quite insignificant compared to the number of banks shut down by the regulator.

Figure 2.4: CAD1 measure (global shock)



Source: Authors

Finally, we must repeat that the removal of the troubled banks from the system might be inefficient when a crisis emerges, but it is very important as a coercive measure to ensure that the capital buffers of the banks are large enough. Clearly, without the threat of a ban on operation, the banks would be much less willing to limit their leverage. When we think about the $CAD1$ measure as a necessity for ensuring certain capital buffers, i.e. when we fix the removal ratio and consider the inverted relationship $\gamma =$

[23] In reality, the removal threshold does not account for 100% of the capital the banks ought to have (for example, according to The Act on Banks 21/1992 Coll., the Czech banks should end their operation when their capital ratios fall below one third of the original Basel requirements). Also, we would expect many of the institutions to be bailed out instead of deprived of their licenses.

$removal\_ratio_{fix} \cdot CAD1$, we see that there are obvious effects on the system's resilience.

2.4 Summary of simulation results and further research opportunities

Table 2.3 presents a summary of the simulation results. First, it is obvious that the levels of individual banks' capital buffers are crucial for systemic stability. Moreover, the relationship between the capital ratio and the number of defaults in most of the situations appears to be of a "step-like" shape with sudden occurrence of a systemic break-down rather than of a gradual nature. Hence, the regulatory protection needs to be scaled for much larger shocks which may not be very likely to occur but when they do, once the stress situation breaks through the capital barriers and triggers a system-wide crisis, the impact is devastating.

Second, once a crisis breaks out, the ad-hoc discretionary measures alone, forcing the troubled banks to end operation (or sell a part of their assets, even though this possibility is left for further research), have almost no or very little effect on improving the situation. Moreover, when the illiquidity is high, any measure which increases the number of removed banks and assets sold in the market would only aggravate the breakdown and be rather counter-productive. However, since CAD1 contributes to maintaining the overall capital ratios, it is worth the extra costs it generates. The best option would seem to be to use it as preventive measure that forces the banks to have enough capital but do not use it in major distress. On the contrary, during the crisis, measures that prevent the banks from propagating the shocks through the network are more appropriate – such as are state bail-outs. This forms a typical dynamic inconsistency problem and may result in increased moral hazard.

Table 2.3: Results summary

Experiment	*Shock*	*Result*
Basic behavior	Local	• Large capital buffers are the essential means to ensure systemic stability.] • Given a fixed value of interbank assets, the more is the system intertwined, the more resilient it is against total breakdown. • On the other hand, higher number of interbank connections makes the system more fragile when the capital levels are low. • There are "safe zones" where sufficiently high capital buffers and enough connectivity ensure that the shock is absorbed in the system.
	Global	• On a small range of capital ratios when the crisis is phasing in, the interbank connections have shock dispersion effects and reduce the number of defaults. • The more heterogeneous are the banks' balance sheets, the larger interval of capital ratios it takes for the system to break down.
CAD1 measure (bank removal)	Local	• For high capital levels, the regulation takes out the banks that would not otherwise default • When the capital buffers are small, the banks default before the regulation manages to remove them from the system. • This measure fails to reduce the number of failed banks as well as the amount of depositor losses
	Global	• High removal ratios cause that the all banks are removed even though their capital buffers would be large enough for them to withstand the shock. • There is a very small interval of capital ratios where the regulation succeeds to lower the number of defaulted banks and the depositor losses.
	Local, global	• When we think about the CAD1 measure as a necessity for ensuring certain capital buffers, we see that it has obvious positive effects on the system's resilience.

Source: Authors

Several further research opportunities exist since the basic modelling framework presented in this paper is very flexible and easily used for simulations of financial systems behavior in different institutional and regulatory environments. Firstly, it is interesting to explore other parameter combinations as well. For example, the number of banks and particularly the interbank assets ratio are parameters that also have effect on the stability of the banking system. Nier, et al. (2007) describe how the system behaves under different interbank assets ratios and finds that increasing this parameter up to a certain level leads to enhanced shock propagation. Moreover, it would be interesting to endogenize this ratio and study how the system would be affected if the banks were reluctant to renew their loans to counterparties whose capital ratio fell below a certain level.

Second, our model can be easily extended to capture regulatory measures incorporated in Basel III such as liquidity regulation or capital conservation buffer. Also, we are working on the implementation of a systemic surcharge for the too-interconnected-to-fail banks.

Unfortunately, due to the scope of this paper, not all the aspects of the model could have been described. In addition, our model assumes a random interbank network, which is an assumption that can be replaced by more sophisticated network structures that are closer to reality, e.g. the small-world networks or scale-free tiered structures. The occurrence of the systemic breakdown would be also probably less sudden and more gradual if the modelled banks were more heterogeneous – in this case it is possible that given a certain shock size, regulatory measures would prove efficient on a wider range of overall capital ratio. Ideally, the effects of regulation may be studied on the real-world interbank network data. Moreover, because of its agent-based nature, it is possible to extend the model with other features, such as endogenous network creation or more types of agents, such as central banks, hedge funds or individual depositors.

2.5 Conclusion

As a result of the recent global economic crisis, a revision of the current regulatory framework was necessary. The latest set of standards, Basel III, should increase the system's resilience by redefining current capital requirements and adding new measures. In order to better understand the effects of regulation on the systemic risk, we have constructed an agent-based network model of a banking system and used it for stress-testing of several different settings of regulatory environment. First, our simulations confirm that sufficient capital buffers of individual banks are crucial for protecting the stability of the whole system. Second, we see that the regulatory measures work best as a preventive measure which ensures that the banks possess sufficient capital buffers. However, they are not very effective once the system is collapsing, and if the overall market liquidity is low, they can even worsen the situation. Finally, there are issues with data availability. Since even the regulators do not usually precisely know how the real-world interbank exposures look like and because the maximum entropy approach used for estimation of these data underestimates the systemic risk, it is necessary that the banks provide more detailed data on their exposures so that the banking system models may be more efficient in exposing potential weaknesses. Were the interbank relationships more transparent, it would be much easier to pinpoint the potential weaknesses and devise targeted regulatory measures for systemic stability protection.

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3 The Nexus between Systemic Risk and Sovereign Crisis [24]

Abstract

This paper focuses on the relationship between the financial system and sovereign debt crisis 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: 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

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[24] The essay was published in an impact-factor journal Czech Journal of Finance as Klinger, T., Teply, P. (2016): *The Nexus Between Systemic Risk and Sovereign Crises,* Czech Journal of Finance, Vol. 66, No. 1, pp. 50–69.

3.1 Introduction

The recent global financial crisis emphasized the importance of the link between the financial and the sovereign debt. 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, recapitalization, state guarantees and asset relief or provision of funding liquidity. European Commission (2012) estimated 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. The bailout costs are priced into the sovereign's credit risk and cost of borrowing. Thus, aggressive bailout packages that stabilize the financial system in the short run ignoring the ultimate taxpayer cost might end up being a Pyrrhic victory (Acharya, Drechsler and Schnabl, 2014). From the onset of the financial upheaval, the topic of sovereign crisis 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) analyze behavior 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 crisis 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) analyze 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 crisis and bank crisis, 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.[25] 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 crisis 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 analyze 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,

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

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.

3.2 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, here we add four state support measures to the banks in trouble, construct the 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 laps until the initial shocks completely dissolved and are not further transmitted onto other agents.

3.2.1 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[26] 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 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 with any of the banks are removed from the system and the number of sovereigns left is denoted as N^s.

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

3.2.2 Initializing the Balance Sheets[27]

Next, the model constructs balance sheets of individual banks for the given network realization 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 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:

$$Q = \theta A.$$

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:

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

---

[27] 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 behavior of individual balance sheet variables, it is merely an algorithm for the system initialization *before* the simulation is launched by an initial shock.

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.[28]

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:

[28] 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 its total assets (a_i) times 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 created, the system is initialized. The final setting of banks' balance sheets is depicted in Table 3.1.

Table 3.1: 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

For sovereigns, the model does not require balance sheet identities 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.

3.2.3 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:

a. *"Local shock"*: A share of external assets is deducted from a random bank's balance sheet.

b. *"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.

c. *"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 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 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:

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

iv. 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.

3.2.4 Liquidity Risk Modelling

Generally, there are two types of liquidity issues that can affect a stressed financial system: market illiquidity and funding illiquidity.[29] 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.

3.2.4.1 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

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

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.[30] 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

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

[29] 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).

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

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.

3.2.4.2 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.

3.2.5 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*.

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 Risk Metrics 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, $\tau = 1$).[31]

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:

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

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.

[31] 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.

3.3 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 efficiency of the individual support measures given that the states have unlimited access to funds. Fourth, we describe the system behavior 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.

3.3.1 Model Control

Monte Carlo simulations are based on comparative statics experiments where the simulations are performed under varying combinations of input parameters.[32] 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. (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 generally used 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 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.

[32] 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.

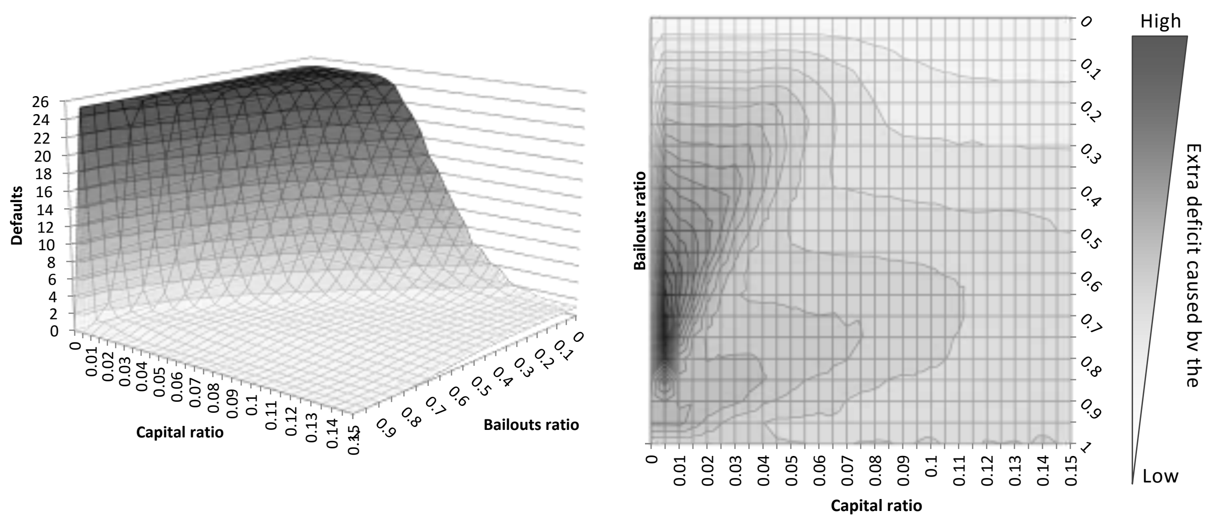
3.3.2 Sovereign Assistance

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 illustrate the analysis on *bailouts and recapitalization* of institutions that are receiving negative shocks. As mentioned in Section 3.2.5, 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 3.1A 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 3.1B 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: positive up to a certain bailout ratio behind which it becomes negative, with 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 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.

Figure 3.1: Bailouts and recapitalization effects

Panel A: Total defaults - Capital vs. Bailouts ratio Panel B: Total cost - Capital vs. Bailouts ratio



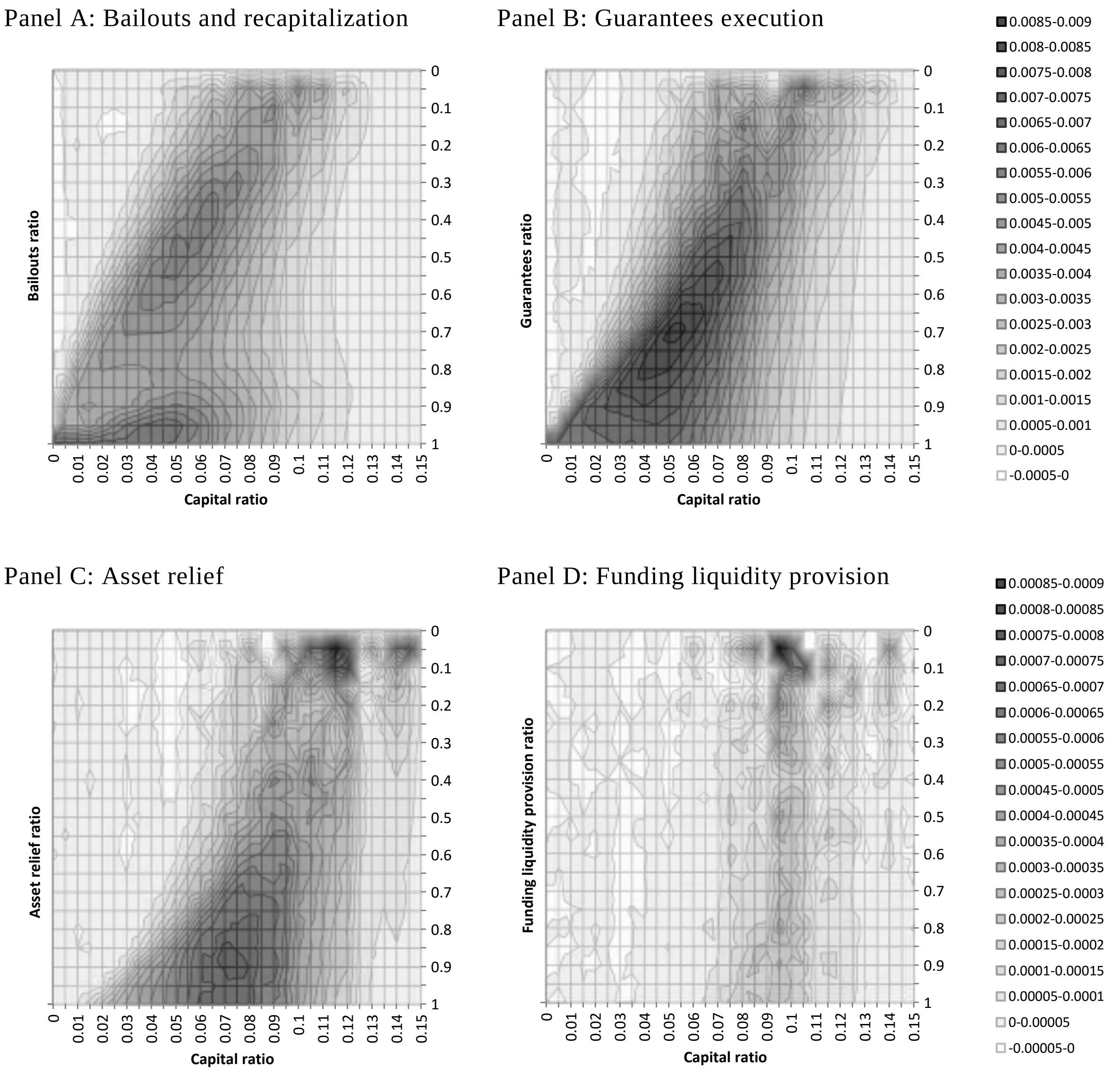
Source: Authors
Note to Panel A: Our modelling network consists of 25 banks. The vertical axis ticks are spaced by two defaults so the maximum tick on the axis amounts to 26.
Note to Panel B: Darker color indicates a higher extra deficit caused by the measure.

3.3.3 Cost Efficiency of the Support Measures

Individual support measures may be compared in terms of cost-benefit efficiency, as shown in Figure 3.2. 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 3.2 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 aim only on the resulting liquidity issues. Due to such disproportion in effectiveness, in Figure 3.2A and Figure 3.2B, the support efficiency is plotted on ten times higher scale than in case of Figure 3.2C and Figure 3.2D. Second, on both Figure 3.2A and Figure 3.2B, we see a diagonal pattern where the state support is most efficient. This corresponds e.g. with the diagonal area in Figure 3.1A 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 3.2C 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 3.2D that given this parameter setting, funding liquidity provision is not an effective support for systemic stability.

Figure 3.2: Cost-benefit analysis of state support measures



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 color indicates higher efficiency of state support for a particular measure.

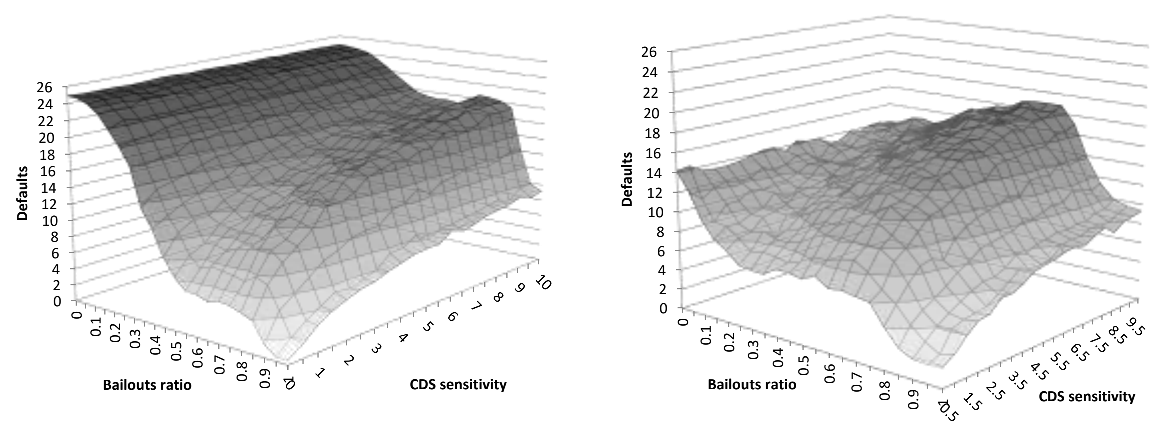
3.3.4 Feedback Loops

Putting together the results of banking crisis, 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 3.2.5, 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 3.3: 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 3.3 shows the behavior of the system when the crisis is tackled by *bailouts and recapitalization* of the troubled banks. Figure 3.3A 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 3.3B 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.

3.3.5 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 one 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 systemic stability as a result of different regulatory settings, here we expand our research to four support measures to the banks in trouble, which we discuss further: bailouts and recapitalization, guarantees execution, asset relief and funding liquidity provision. Table 3.2 provides the summary of these support measures.

Table 3.2: 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

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

Source: Authors

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.

3.3.6 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.

3.4 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 crisis. 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 crisis and sovereign crisis 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.

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4 Systemic risk and sovereign crisis[33]

Abstract
This paper focuses on the link between financial system and sovereign debt crisis through sovereign support to banks on one hand and banks' exposures to weak sovereigns on the other. We construct an agent-based network model of an artificial financial system to analyze the effects of state support on systemic stability and feedback loops of risk transfer back into the system. The model is calibrated to real-world data (4Q 2011) using a unique dataset put together from various sources and tested with various parameter settings in Monte Carlo simulations. Our analyses yield the following key results: Firstly, in the short term, all support measures improve systemic stability. Secondly, in the longer run, the effects of state support depend on several parameters but still there are settings in which it significantly mitigates the systemic crisis. Finally, there are differences among the effects of different types of support measures.

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

Keywords: agent-based models, bailout, contagion, financial crisis, financial stability, liquidity risk, network models, systemic risk

[33] The essay was published in a peer-reviewed journal ACTA VSFS as Klinger, T., Teply, P. (2014): *Modelling interconnections in the global financial system in the light of systemic risk*, ACTA VŠFS - University of Finance and Administration, No. 1, pp. 64–88. Modified version of this essay was also published as conference proceedings of Second International Conference on Electrical, Electronics, Computer Engineering and Their Applications, Manila (Philippines) as Teplý, P., Klinger, T. (2015): *Monte Carlo Simulations: A Case Study of Systemic Risk Modelling*, ISBN 978-1-5108-0887-4.

4.1 Introduction

The recent global meltdown started as a failure of the credit system, continued as a liquidity crunch and with negative sentiment and overall market slowdown, finally transformed into an economic crisis. In the earlier stages, the sovereigns took an active role, supporting the economic system through bank aids, deposit guarantees, quantitative easing and economic stimuli packages. However, large state support for the financial system as well as for the economy, represents a huge burden on government finances and in some cases, mainly in Europe, it has already resulted in a sovereign debt crisis. Moreover, losing their status of risk-free borrowers and facing increasing prices for credit, the sovereigns too are now significantly weakened and some are in threat of default. Since a large portion of sovereign debt is held by the banking system, there is a danger of the crisis feeding back to where it began in a vicious circle of transferring the toxic debt back and forth between the sovereign and the financial sector.

The overall aim of this paper is to contribute to the discussion on sovereign debt crisis and bank crisis, which has been recently going on both at the EU and at the international level. The main research question is how the stability of the financial system is affected by state aid, how and when a systemic crisis can translate into sovereign crisis and how and when a sovereign crisis can feed back into the system through sovereign debt exposures. The main idea is that banks represented by their balance sheets form nodes in a financial network. Using a computational model, we simulate progression of shocks in the network given various types and levels of state aid. Our approach stems from the recent advances in agent-based network modelling of financial systems, mostly from Nier, et al. (2007).

The second section will focus on the description of the link between the financial institutions and the sovereigns, mostly with regards to the recent financial crisis. The third section will present the used concepts and literature review of the modelling techniques that form the grounds for our analysis. In the fourth section, we construct an original model of a financial system which will be used for testing the impact of the sovereign assistance to banks and researching the feedback loops that may arise when such assistance weakens the sovereigns. In the sixth section, we calibrate it to a unique dataset collected from various sources in order to gain more insight into the current situation and outline some practical implications for setting new policies in case of a systemic banking crisis. Finally, we close the paper with a conclusion summarizing our research and findings.

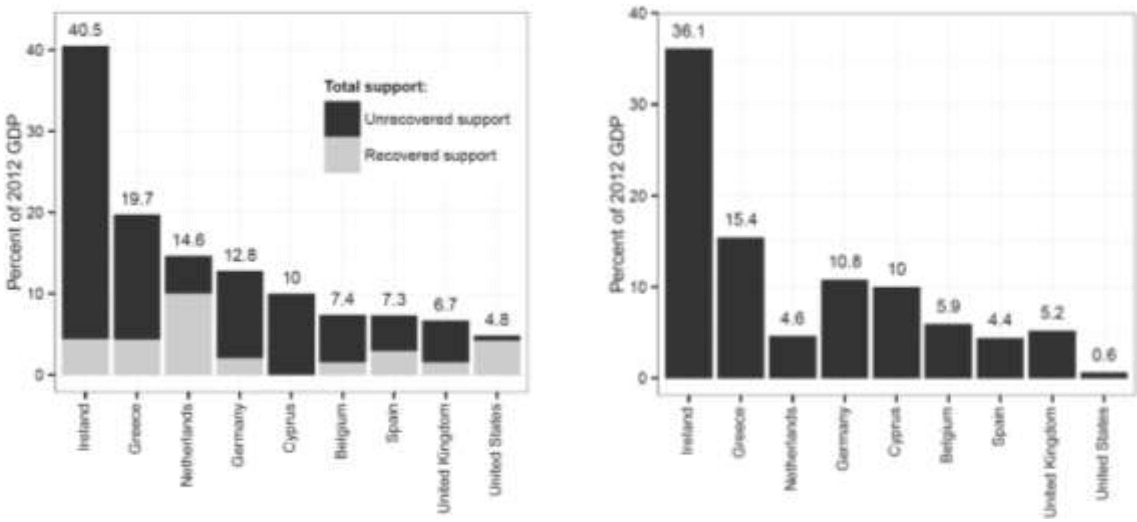
4.2 The Current Financial Crisis

The true mark of the systemic crisis outbreak was the failure of Lehman Brothers on 15 September, 2008. Even though its bankruptcy meant a very significant shock to the interbank system, the other reason for the crisis to finally break out was psychological. Understanding that state aid is no longer guaranteed even for large, systemically important banks, the share prices of the banking sector plummeted as the investors were no longer willing to consider financial institutions as an investment opportunity. Moreover, the market of bank debt funding froze and liquidity evaporated from the interbank market. The banking system thus found itself in a deadlock where it was not able to roll over the short-term debt it used to finance most of its operations, but at the same time, the individual institutions held unsettled overdue claims against each other. Moreover, due to the increased cost of lending and severe credit shocks, the banks' capital buffers did not suffice to prevent the system from collapse. Had they not been replenished, a large portion of the banking system would have failed.

Figure 4.1: Financial sector support in selected advanced economies, 2008 – Jul 2012

Panel A: Total direct support

Panel B: Unrecovered support – impact on public debt



Source: IMF (2013a)

At this point, the states started playing an active role, introducing a number of measures to support the troubled financial institutions. Amongst these measures were strengthening of the deposit insurance, state guarantee schemes, outright bail-outs for bank recapitalization or loans to alleviate the severe lack of liquidity (Liikanen, 2012). Mostly in Europe, several states introduced bad loan buy-outs or complete bank nationalizations (Petrovic & Tutsch, 2009).

Figure 4.1 shows the financial sector support in advanced countries as a fraction of the 2012 GDP along with its recovery values. The top rank in terms of GDP fraction belongs to Ireland followed by Greece. In March 2013, Cyprus bailed out its banks using the EUR 10 billion in funds provided by the European Central Bank and International Monetary Fund as the fifth European country to receive such assistance (ECB, 2013). In the short run, the support measures had a positive impact on systemic stability. Panetta, et al. (2009) states that government support managed to lower the banks' credit default swap (CDS) premiums, which is the main indicator of failure risk. The first drop came when a support measure was announced and subsequently, the premiums fell even further when each of the measures was implemented. Moreover, the larger the amount of funds employed in a support measure, the sharper was the decrease of CDS premiums. Finally, there were positive spill-over effects of these measures illustrated by falls of CDS premiums in countries other than the one deploying the measure.

However, the above-mentioned support actions proved to be very expensive and progressively, the situation started deteriorating for the sovereigns. As the balance sheet weaknesses moved from the banks to the sovereigns and the tax revenues dropped, the fiscal deficits began to surface. In late 2009, fiscal revenues in Ireland and Spain fell much more quickly than GDP, increasing their deficit/ GDP ratios sharply. Greece in 2009, revised their budget deficit forecast from 6% to 12.7%, an extreme violation of Euro fiscal norms (Lane, 2012). As the individual countries' creditworthiness crumbled and the rating agencies pointed out the associated risks, the investors began panicking and losing confidence even in the sovereign states. As a result, sovereign bond yields and CDS spreads rose and the access to new funding became increasingly more expensive. In a situation like this, when a sovereign guarantee is exercised or a large bank needs to be fully or partially bailed out and on top of that a country finds itself in an economic downturn, the public accounts are in serious trouble.

Unfortunately, the sovereigns did not prove to be anything else than other type of agents in the same financial system and thus by taking the risk on themselves, it did not vanish.

Instead, it returned in form of feedback loops from the sovereigns back to the banks later when the sovereigns found themselves in crisis and their own balance sheets were deteriorating. In this manner, the risk and the losses oscillated between the privately-held banks and "publicly-held" sovereigns.

4.3 Modelling approach

The modelling framework is based on two central concepts, network theory and agent-based modelling. Network theory is particularly useful for description of connected structures and the pattern of their relationships. A network is a set of nodes connected with edges.[34] Nodes may represent individual agents, for example servers and websites when we study computer networks or people in case of social networks. In the framework of finance, they may represent banks, sovereigns, depositors, companies or other entities in a financial system. Edges contain data on connection of any two particular nodes in the network, determining whether there is a link between two nodes and what is its value and direction. When the network theory is applied to modelling of financial systems, such properties allow us to define the creditor/debtor relationships as well as the size of the mutual claims of individual banks (Klinger, 2011). Network theory proved to be a particularly interesting means of studying impulse transmissions, which includes transmission of negative shocks. We use this methodology for simulating credit shocks in banking systems since when one bank fails and there are no supporting mechanisms such as bail-outs or state guarantees, the losses are transmitted to its creditor banks.

Agent-based modelling is a bottom-up approach that examines how numerous subjects that are each equipped with basic set of data and behavioral rules are interacting in a virtual environment. According to Tesfatsion (2006, p. 835), *"[an agent] refers broadly to bundled data and behavioral methods representing an entity constituting part of a computationally constructed world."* The individual agent's actions finally lead to certain aggregate behavioral patterns on the systemic level. Probably the most well-known paper describing macro-level effects stemming from micro-level behavior is the one by Schelling (1969), who described how a simple set of individuals' preference of the composition of their neighborhood may lead to a pattern of segregation on a systemic

34 More rigorously, network is a graph defined as $G = (N, E, f)$, where N is a set of nodes, E is a set of edges and $f: E \to N \times N$ is the mapping function which plots the edges onto individual pairs of nodes (Lewis, 2009).

scale. In our model, the agents represent individual financial institutions or sovereigns, the basic data they hold are their balance sheets and a set of behavioral rules such as when to default, when to sell of a particular amount of assets or when to bail out a certain institution.

Current research applying the previously mentioned methods to the field of financial or banking system stability divides into two main streams: empirical research and theoretical models. Several studies concentrate on the real-world interbank exposure modelling. For example Boss, et al. (2004), Upper & Worms (2004), Wells (2004), Van Lelyveld & Liedorp (2006) or Muller (2006) analyze the banking systems of Austria, Germany, the United Kingdom, the Netherlands and Switzerland respectively. Recently, Halaj and Sorensen (2013) tried to approximate a network of the banks who reported during the 2010 and 2011 EBA stress tests. However, most of the researchers face the problem of virtually non-existent reliable data on individual interbank exposures.

Theoretical models examine how system behavior is influenced by its general characteristics. The first such model was constructed by Allen & Gale (2000) who studied contagion of funding liquidity shocks. Another early analysis was carried out by Freixas, et al. (2000), who studied contagion in systems where some banks were systemically important. Cifuentes, et al. (2005) and Shin (2008), add a market liquidity contagion channel decreasing the price of illiquid assets. Finally, there are studies that analyze systemic stability by simulation experiments on random networks such as Gai & Kapadia (2010), or Nier, et al. (2007). Finally, Klinger & Teply (2013) add regulatory aspects into this framework. This paper combines theory and empirics as the model is calibrated to the real-world data.

4.4 The Model

For each individual simulation, our model is defined in several steps. First, the network of banks and sovereigns is initialized together with the balance sheet data of individual agents. Second, the system is stressed by a credit shock, which may originate from a particular bank in the network. Following the initial shock, the stress propagates through the network and may trigger actions of the particular agents such as bank or sovereign defaults, asset fire-sales or state assistance to troubled banks. The simulation continues in several laps until the initial shocks completely dissolve and are no more transmitted further onto other agents.

First, the network is built from the calibration dataset. The total value of all assets in the system 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 (e.g. households, businesses or foreign sovereigns) or derivatives.

The final setting of banks' balance sheets is depicted in

Table 4.1 below.

Table 4.1: 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

When the network is prepared, the system is inactive until we impose a shock event initiating the first simulation lap. Similarly, at the beginning of each next lap, each bank may receive a total asset-side shock of $\Delta = CreditShock + PriceShock + GovtShock$, where

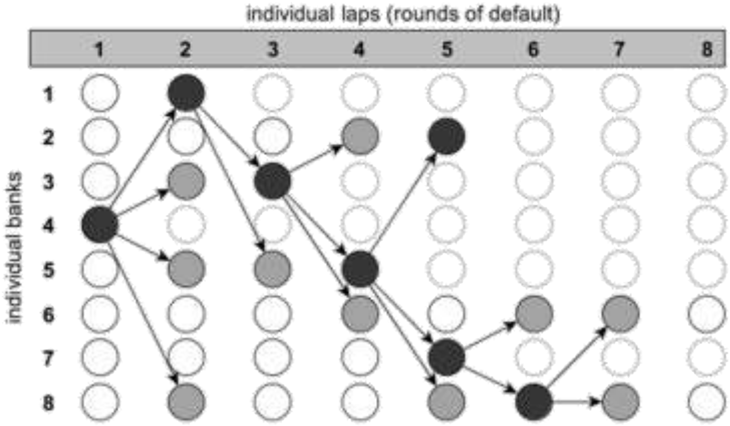
- $CreditShock$ represents losses that banks incur due to default of another bank in the network to which they hold an exposure.
- $PriceShock$ represents losses that banks incur due to overall drop in asset prices caused by market liquidity effects.
- $GovtShock$ represents losses that banks incur due to default of a sovereign in the network to which they hold an exposure.

These individual components are described in detail on the following pages.

4.4.1 Shock Reaction and Contagion

If the banks affected by the primary shock do not have sufficient capital buffers, a process of cascade contagion effects may unfold, where in each lap of the simulation, the banks that default transmit the shock further onto other banks in the system. Figure 4.2 depicts the mechanism of shock propagation; the shock-transmitting banks are colored grey whereas the failed banks are depicted in black.

Figure 4.2: Scheme of banking system contagion



Source: Klinger (2011) inspired by Sell (2001)

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 has to write off an equal value of liabilities. Firstly, the shocks are absorbed by owners' 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 an initial shock, 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 the shock is smaller than the bank's capital reserve which means 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 the capital reserve is not large enough, the residual shock overflows to the interbank liabilities, in which case its value up to the value of the interbank liabilities is uniformly divided into losses of all creditor banks which receive a *CreditShock* proportional to the size of their exposure to the failing bank. As the failing 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 the shock is smaller than the sum of the bank's capital reserve and its interbank liabilities, it is absorbed completely by these two balance sheet items
   ii. If the shock is larger than the sum of the bank's capital reserve and its interbank liabilities, the shock overflows to external liabilities, meaning that the residual loss is covered by the depositors.

4.4.2 Market Liquidity Risk Modelling

Market illiquidity, described firstly by Kyle (1985), represents a situation when transactions in which the assets are sold have a negative impact on the asset prices.[35] Along with Gai & 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 the external assets, which takes the form of

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

Where N^b is the number of banks in the system, $x_{i,t}$ is the total value of assets (external and interbank) sold by the i-th bank in the system in the current lap, α represents the market 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.[36] The additional losses caused

[35] Market liquidity is usually measured by indicators such as market depth, resiliency, tightness, and volatility. These indicators may be aggregated into liquidity indices, which then can be used to quickly compare markets in time and cross-sectionally. Examples of market liquidity indices are found e.g. in Gersl & Komarkova, (2009) or Teply, et al. (2012).

[36] Upon the system's initialization, the price is set to $P(x)_0 = 1$.

by the asset sales are then added to the initial shock on i-th bank in the current lap and transmitted accordingly. Furthermore, assuming marking to market accounting, 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 in a price shock of $PriceShock_{i,t+1} = e_{i,t}(P(\boldsymbol{x})_{t-1} - P(\boldsymbol{x})_t)$ to all banks.

4.4.3 The role of sovereigns

As a means of a sovereign to support its domestic banks, we introduce two possibilities of sovereign assistance. These include:

a. *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.

b. *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, Equation 1 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.

As we mentioned previously, sovereign assistance may work very well for short-term banking system stabilization, but it puts significant pressure on the intervening sovereigns. According to Acharya, et al. (2012), 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. 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.

The sovereign credit risk in the model is represented by probability of default, which under a certain assumed recovery rate may be roughly approximated from the CDS spreads. Credit default swaps are contracts insuring against credit events on bonds in case the counterparty defaults. The buyer pays periodically to the seller until either the CDS matures or until a credit event occurs, in which case the buyer of the insurance is entitled to sell to the seller of the insurance the insured bonds for their face value (Hull, 2008). As our model is of short-term character and later on, we calibrate it to yearly data, we chose to implement the probability that a given sovereign defaults in one year. 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 the widely used approximation according to J.P. Morgan and Company & RiskMetrics Group (1999):

$$p_{k,t}^{default} = \zeta\left(1 - \frac{1}{\left(1 + \frac{CDS_{k,t}}{1 - RR}\right)^{\tau}}\right), \qquad (2)$$

Where $p_{k,t}^{default}$ is the probability that a given sovereign defaults in one year, $CDS_{k,t}$ is the annual CDS spread, RR is the recovery rate and τ is the number of years for the cumulative default probability calculation (in our case, $\tau = 1$ and in line with common practice, $RR = 0.6$).

The link between sovereign deficits and credit risk is documented by econometric studies such as Attinasi, et al. (2009) or Cottarelli & Jaramillo (2012). Also, based on their analysis of sovereign bond spreads, Modi & Sandri, 2011 conclude that low growth potential and high public debt ratios increase a sovereign's bond spreads, raising the amount of debt it has to finance, resulting in high probability of default.

We use the following equation to update the sovereign CDS spreads at the end of each simulation lap (parameter β is later on referred to as the CDS sensitivity):

$$CDS_{k,t+1} = CDS_{k,t} + \beta\frac{deficit_{k,t}}{GDP_k}. \qquad (3)$$

Putting the previous points together, at the end of each lap the model collects the total amount of each sovereign's deficit and feeds it into Equation 3 which is then plugged into Equation 4. At the beginning of each simulation lap, a sovereign k may default with probability$p_{k,t}^{default}$. In that case, each creditor bank receives a $GovtShock$ equal to the size of exposure to the defaulting sovereign multiplied by $1 - RR$. The sovereign debt on its balance sheet is then revalued accordingly.

4.5 Empirical Analysis

In this section, we calibrate our model to real-world banking data in order to contribute to the current debate on systemic stability and the link between banks and sovereigns. As documented by many authors (e.g. Mistrulli, (2011)), the data on individual banks' mutual exposures is not available. Therefore, we resort to proxy data inferred from available sources to build the interbank network. Instead of individual banks, the agents in our study represent banking systems of countries which report their banking positions to BIS (referred to as subsystems since they are all part of the global banking system) and these agents' balance sheets are composed of aggregated figures of all banks reporting in their domestic countries. The "interbank" exposure data are complemented with banking system data collected from several sources to provide a complete picture of the global banking system.

4.5.1 Data Definition

To calibrate the model to the real-world figures, we collected balance sheet data and other data from several sources. Table 4.2 shows the main items which we describe further in greater detail.

Table 4.2: Banking system balance sheet with data sources

Total Assets (EBA Database, Central banks)	
Domestic government debt (Arslanalp & Tsuda (2012), IMF IFS Database)	External liabilities (Calculated)
Interbank assets (BIS International Statistics)	Interbank liabilities (BIS International Statistics)
External assets (Calculated)	Equity (BankScope)

+GDP (World Bank), CDS Spreads for the individual countries (Bloomberg)

Source: Authors

4.5.1.1 Interbank Assets and Liabilities

The interbank exposure dataset describes the inter-linkages in the global banking system. These are collected from the banking section of BIS International Financial Statistics (BCBS, 2013), where the central banks report compiled national aggregates calculated from data on individual banks' in their jurisdiction (BCBS, 2013). To form the interbank exposure matrix, we employ data from the consolidated statistics of foreign claims on immediate borrower basis. The selection of countries whose banking sectors we included in the analysis was based on data availability and includes Australia, Austria, Belgium, Brazil, Canada, Denmark, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.[37]

The consolidated data provides information on exposures of domestically-owned parent banks on the highest consolidation level and hence they include external exposures of own foreign offices and exclude all internal inter-office positions in the consolidation group (BCBS, 2009). For example, UniCredit SPA headquartered in Italy, which is the global ultimate owner of all banks in the UniCredit group, will report to Banca d'Italia (Italian national bank and member of the Eurosystem) all exposures of its own and of its branches and subsidiaries against banks that are not members of the UniCredit group. The exposure of UniCredit Bank AG (German subsidiary) against Erste Group Bank AG headquartered in Austria, which is not a member of the UniCredit group, is accounted for in the statistics. On the other side, an exposure of UniCredit Bank AG (German subsidiary) against UniCredit Bank Czech Republic AS is netted out as well as the exposure of UniCredit SPA against UniCredit Romania SA. This way, any exposure external to the group is assumed to be an exposure of UniCredit SPA and adds to its total risk position. In contrast, the locational data provides information on gross positions of banks in selected major banking centres against banks located in other countries on residence or nationality principle and even though it is better for international banking activity monitoring, it does not capture the total risk positions so well.

On the other hand, we realize several shortcomings of our approach. First, using the consolidated statistics further underestimates the real risk positions and complexities of the global financial system and thus increases the inaccuracy caused by using aggregate

[37] Czech Republic was not included in the analysis as it does not report its international banking exposures to BIS.

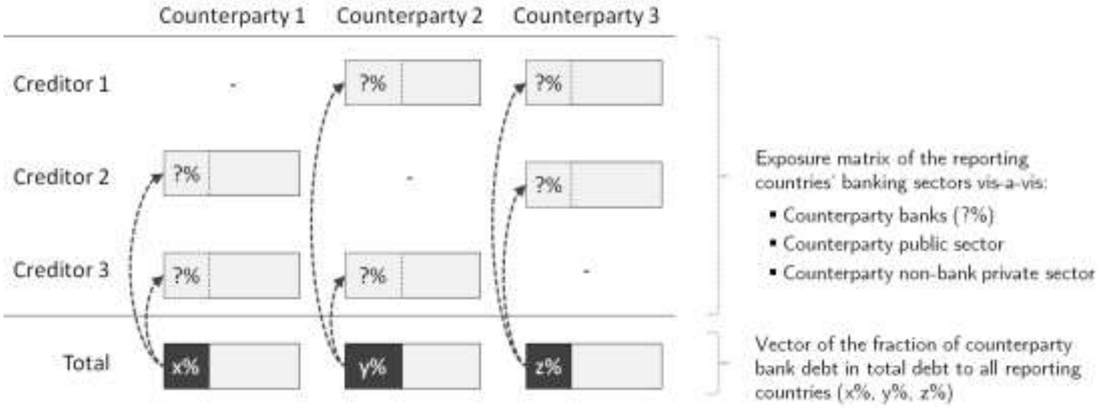
data. Second, in many instances, the domestic supervisors of the host countries require that the foreign subsidiaries are ring-fenced so that the parent bank does not have full access to its subsidiary's resources (Chan-Lau, 2010). This is prevented by both controls on dividends that must not jeopardize a subsidiary's stability and liquidity and on credit exposures where supervisory limits apply for intra-group transactions (Cerutti, et al., 2010). Still, implementing the locational data would cause greater inconsistencies, as accounting for the intra-group flows would lead us to a false conclusion that exposures between two countries where large subsidiaries belonging to the same group pose more significant risk than the external exposures. The use of the consolidated data is consistent with Chan-Lau (2010).

The consolidated claims of the reporting countries are collected in several categories: (i) cross border claims, (ii) local claims of foreign affiliates in foreign currency, and (iii) local claims of foreign affiliates in local currency. While categories (i) and (ii) together are called International claims in the BIS terminology, categories (i), (ii) and (iii) together are called foreign claims. As all the mentioned categories are relevant for capturing the risk exposures of individual banking sectors, the latter group is employed in the analysis.

The consolidated statistics of foreign claims are then further divided into data on immediate borrower basis vs. ultimate borrower basis. While the former one considers the counterparty as the one where the original risk lies, the latter recognizes the one who is ultimately liable for the funds borrowed. For example, if a German bank lends to a French one and secures the transaction by CDS or a guarantee issued by an Austrian bank, the immediate borrower statistics would record the German banking system as the creditor and the French one as the counterparty. In contrast, the Ultimate borrower basis statistics would record the Austrian banking system as the counterparty since that is where the risk of the transaction was transferred. For this reason, using the Ultimate borrower statistics may be superior for modelling situations where the risk materializes by a counterparty default. However, the exposure data is not available on a bank-to-bank basis as the aggregate exposures of the reporting countries include also bank-to-public-sector and bank-to-non-bank-private-sector claims. Hence, trying to infer the risk transfer exposures and trying to implement them in the analysis would add another layer of approximation and along with Chan-Lau (2010), we consider it inappropriate and use the Immediate borrower basis data.

Nevertheless, as it is not possible to obtain directly the pure bank-to-bank exposures between the individual countries' banking sectors, some level of approximation is inevitable. To estimate the bank-to-bank exposures from the reporting banking sectors' pool of total claims, we employ another dataset of the BIS statistics, which is the total claims on each country's banking sector by all the reporting sectors, grouped by the type of the debtor institution (i.e. whether it is a bank, public sector or a non-bank private sector. By taking a fraction of bank debt on the total debt, we obtain proxy variables for individual counterparties. Finally, we multiply the whole column of the exposure matrix representing the given counterparty's debts by this variable to calculate the estimated interbank network. Figure 4.3 visualizes this calculation.

Figure 4.3: Estimation of the bank-to-bank exposures



Source: Author

When the network is created, it can be plotted as in Figure 4.4.[38] For better readability, we provide two different views for the same dataset. In Panel A, we show the edges of the network (interbank exposures) colored according to the source of funds (i.e. the creditor, the bearer of the risk). For example, there is a strong exposure of Switzerland against the United States and it is coloured blue according to the colour of Switzerland. On the other hand, Panel B provides the situation from the counterparty viewpoint and hence the exposures of all parties to the United Kingdom are coloured in green, as well as the UK itself. These visualizations provide an efficient overview of the situation and a quick grasp of the basic relationships. For example, in the centre of the network, we see

[38] As the model will be calibrated for 2011, Figure 4.4 shows the interbank network as of Q4 2011. Nevertheless, historical network visualizations as well as the most up-to-date one for Q3 2012 are presented in the Appendix.

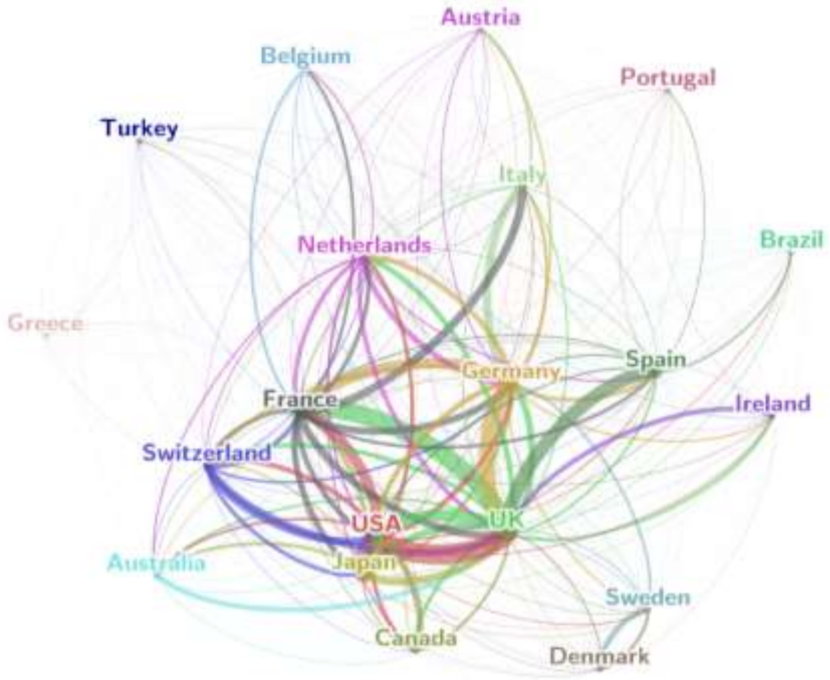
the “core” sectors, (highly interlinked nodes such as the United States, the United Kingdom, Japan, France, Germany or Switzerland) and around them there are more “peripheral” banking systems. Also, as the visualization algorithm39 takes into account the relationships in the network and places the nodes accordingly, we can see patterns that are in line with our anticipation based on the individual countries' location or cultural relationships. Note for example the pairs of countries being placed together, such as Sweden and Denmark or Turkey and Greece. Also, the clusters of related countries are placed logically together, such as Italy, Spain and Portugal forming the Southern Europe cluster with proximity to Brazil. Also note that after its default, Greece is placed on the edge of the network with very low connection to other banking systems.
4.3 depicts the same data aggregated for each country's banking system. The bars in positive values represent the aggregated value of its exposures against other countries in the interbank network, the bars in negative values represent the aggregated value of claims the other network members hold against it. The black dots stand for net positions of the given countries. We see that the most negative banking positions are held by the United Kingdom, France and Canada. These positions have to be offset by claims external to the network, such as loans to private sector or purchases of derivatives and other securities. The most positive positions are then held by the United States, Germany and, perhaps surprisingly, Spain. Again, these positions are offset externally by taking deposits or selling securities. However, most of the countries' banking systems have their positions relatively balanced, even in case of Japan, which is involved quite heavily in the interbank network.

The interbank debt structure hints that in case of the UK's default, the system would be hit most severely, whereas the United States is likely to get the largest shock given a default of other countries. However, these are shocks in absolute value and do not imply any information about vulnerability of the individual countries. To be able to model the systemic risk on the interbank network, we need to introduce other variables.

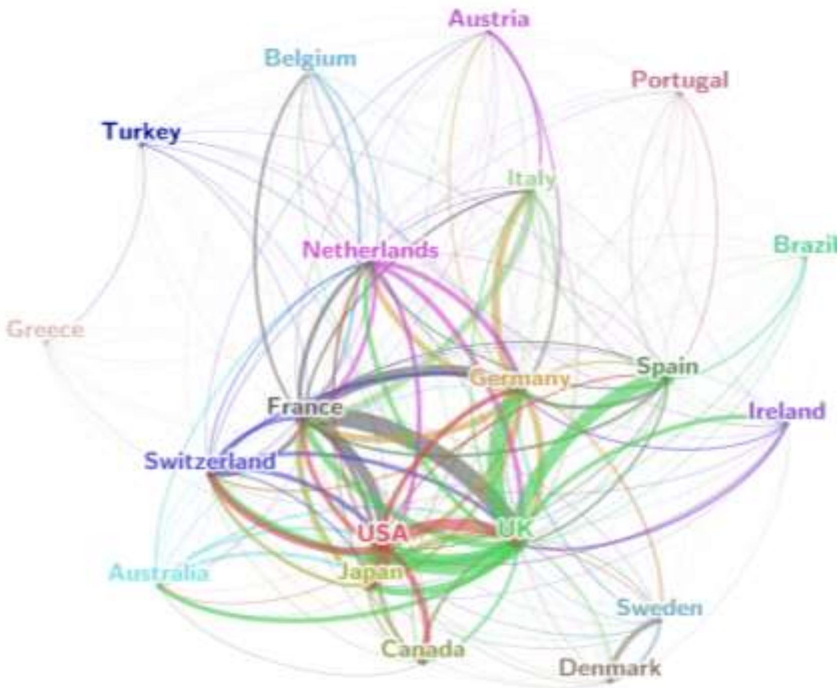
[39] The visualizations were prepared in Gephi software. For the calculation of the node layout, we used the Force Atlas algorithm, which places the nodes in the graph according to the values of edges in the network matrix. While the scientific article on Force Atlas algorithm is still awaiting acceptance and publication, interested reader may find more information on graph clustering and layouting in Noack (2007).

Figure 4.4: Interbank network of the selected countries as of Q4 2011

Panel A:



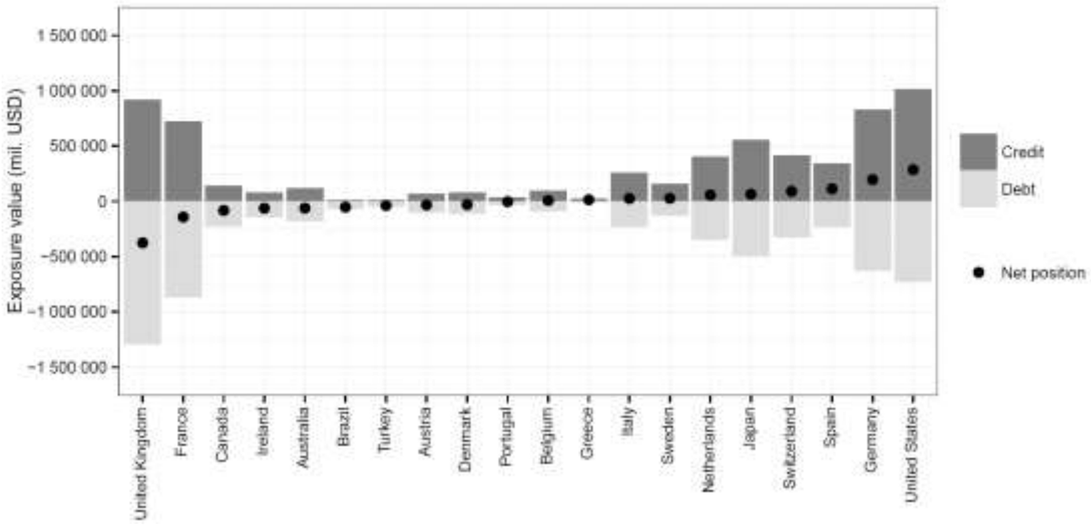
Panel B:



Source: Authors based on data from BIS International Financial Statistics

Note: Panel A shows the edges colored by the creditor node (e.g. exposure of Switzerland against the United States is colored in blue, which is the color of Switzerland on the chart) whereas in Panel B, they are colored according to the debtor node (e.g. exposure of Germany against the United Kingdom is colored in green as well as the UK node).

Figure 4.5: Positions of selected banking systems as of Q4 2011



Source: Author based on data from BIS International Financial Statistics

It is also necessary to mention that this dataset provides information only on interbank lending and not on external financing of banks by sovereigns or central banks, which may be quite significant, especially in the Euro system. On the same note, these data do not provide information on balances in the TARGET2 system, which has been lately discussed in Cecchetti, et al. (2012) and which now form a significant part in the mutual exposures of the Eurosystem banks. The above-mentioned facts mean that Figure 4.4 does not provide the entirely complete picture of the global banking system, and in our model, bank financing of this type is captured in the rest of the bank's balance sheet, in particular in the external assets. However, we will see that the large disproportion between the relatively small interbank assets and the rest of the total assets value captured in external assets is one of the main shortcomings of interbank network models such as Chan-Lau (2010).

4.5.1.2 Total Assets

The banking systems' total assets represent another important input into the model as it is used for calculation of capital, external assets and external liabilities of the individual banking sectors. Despite it being an important variable for comparison of banking systems in time as well as in cross-section, the data on sums of total assets is not readily available and vary significantly across data sources.[40] To keep our dataset as consistent as possible, the main source we used is the Banking Sector Statistics database of the European Banking Federation (EBF, 2013), which provides data on all European countries in the sample. The data on countries not represented in this primary source were taken from the databases of the individual central banks. The data is summarized in Table 4.3 along with visualizations of their time-development and cross-sectional context. There, we can see a clear rise of the asset volumes consistent with the initial risk build-up. Also, the data show the effect of the crisis on the total amount of banking assets, mainly in the financial centres such as Switzerland, the United Kingdom and the United States where the deleveraging is most visible. Looking at the 2011 figures and comparing them across the individual banking sectors, the countries with the largest banking sectors are France, Germany, the United Kingdom and the United States. On the other hand, Greece and Turkey have the smallest banking sectors, which are each more than twenty times smaller than the one of the United States.

Table 4.3: Total assets of individual banking systems in USD billion

	2005–2011	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	2011
Australia		1 097	1 404	1 957	1 890	2 387	2 801	2 954	
Austria		849	1 040	1 301	1 474	1 483	1 312	1 303	
Belgium		1 248	1 484	1 914	1 774	1 667	1 521	1 546	
Brazil		738	973	1 428	1 257	1 876	2 308	2 485	
Canada		1 764	2 051	2 622	2 608	2 739	3 082	3 586	
Denmark		880	1 081	1 428	1 516	1 591	1 515	1 477	
France		6 457	8 147	10 467	10 718	11 026	10 492	10 825	
Germany		8 094	9 444	11 161	10 971	10 708	11 128	10 828	
Greece		338	424	576	646	709	690	615	
Ireland		1 363	1 920	2 445	2 407	2 353	2 046	1 693	
Italy		3 067	3 789	5 009	5 135	5 395	5 078	5 244	
Japan		7 480	7 494	7 686	8 133	8 003	8 148	8 511	
Netherlands		2 003	2 433	3 187	3 102	3 192	3 028	3 133	
Portugal		426	525	647	670	749	749	740	
Spain		2 605	3 335	4 418	4 739	4 963	4 651	4 700	
Sweden		778	1 032	1 257	1 261	1 348	1 431	1 471	
Switzerland		2 170	2 624	3 072	2 873	2 596	2 908	3 002	
Turkey		284	346	484	460	537	657	643	
United Kingdom		9 976	12 911	14 656	12 131	12 901	12 295	12 524	
United States		10 879	11 862	13 034	13 841	13 087	13 319	13 892	

Source: Author according to the Banking Sector Statistics Database from the European Banking Federation and according to individual central banks.

[40] E.g. taking the same data from BankScope, the differences in some cases were significant. We explain this by the fact that BankScope is not the best source for total sums of variables for individual banking sectors Bhattacharya (2003), and resort to the aggregated data from EBF and the central banks.

4.5.1.3 Equity

As seen in the Monte Carlo simulations section, the size of the capital buffers is the main determinant of the stability of the individual banks as well as the whole system. In contrast to the total assets data, in case of banking sector capitalization, we are interested in the proportion of capital to total assets rather than the total sum and hence, the capital ratios were taken from the BankScope database. BankScope offers several types of capital ratios used for regulatory purposes and should provide good information on the banks' capitalization, e.g. Tier 1 or Total regulatory capital. However, these series are very incomplete and sometimes reaching values that seem unreliable and too high compared to the interbank network data. Hence, we adopted a more conservative approach and chose common equity (common shares plus retained earnings) to total assets as the proxy for banks' capitalization. This variable is easily available for all banks in the database and ultimately, our approach is consistent with the latest opinion of the Bank for International Settlements that: *"It is critical that banks' risk exposures are backed by a high quality capital base. The crisis demonstrated that credit losses and write-downs come out of retained earnings, which is part of banks' tangible common equity base"* (BCBS, 2010, p. 2).

Table 4.4: Equity to asset ratios of individual banking systems

	2005-2011	2005	2006	2007	2008	2009	2010	2011	2011
Australia		5.49%	5.34%	5.85%	5.79%	6.21%	6.27%	5.40%	
Austria		5.21%	6.20%	6.44%	5.64%	6.38%	7.05%	6.73%	
Belgium		3.85%	4.12%	4.56%	3.04%	4.10%	4.40%	3.97%	
Brazil		9.01%	9.41%	9.44%	7.73%	7.79%	7.81%	7.83%	
Canada		8.04%	9.96%	9.71%	10.60%	13.00%	15.02%	14.79%	
Denmark		4.27%	4.49%	4.22%	3.85%	4.09%	4.22%	4.34%	
France		4.02%	4.14%	3.83%	3.16%	4.01%	4.19%	4.05%	
Germany		3.87%	3.93%	4.03%	3.48%	3.66%	4.09%	4.92%	
Greece		5.98%	6.86%	8.25%	6.34%	7.49%	6.83%	0.18%	
Ireland		2.95%	3.19%	3.41%	2.28%	2.14%	1.46%	5.36%	
Italy		7.63%	7.80%	7.87%	7.34%	8.15%	8.17%	7.16%	
Japan		3.25%	4.29%	4.72%	4.08%	3.04%	4.18%	4.51%	
Netherlands		3.56%	3.55%	3.55%	2.77%	4.00%	4.12%	4.14%	
Portugal		4.72%	5.46%	4.95%	4.73%	5.50%	5.10%	4.71%	
Spain		5.75%	5.98%	6.15%	5.56%	6.23%	6.33%	6.31%	
Sweden		4.17%	4.33%	4.27%	3.91%	4.46%	4.54%	4.23%	
Switzerland		3.65%	4.05%	4.01%	3.48%	4.55%	4.65%	4.49%	
Turkey		12.65%	11.72%	12.62%	10.92%	12.17%	12.57%	11.28%	
United Kingdom		4.06%	4.04%	3.88%	2.64%	4.29%	4.68%	4.75%	
United States		7.92%	7.95%	7.52%	6.80%	8.55%	8.60%	8.99%	

Source: Author's calculations according to the BankScope database

Table4.4 presents the obtained figures, which were calculated as weighted averages of equity-to-assets ratios where the weights are the individual banks' total assets in the given year.[41] The most-capitalized banking sector is the one of Canada, which corresponds to the fact that no Canadian bank needed recapitalization during the recent crisis (Ratnovski & Huang, 2009). On the other hand, the least capitalized is the Greek banking sector which was severely hit in 2011. On a related note, Ireland is at its historical minimum under 1.5% in 2010. Finally, looking at the figures from the time perspective, we see a clear drop in most capital ratios in 2008 with fast recovery in most countries' banking systems as the banks were extensively recapitalized.

4.5.1.4 Sovereign Debt to Banks

To introduce the link between banks and sovereigns into the banks' balance sheets, we collected two sovereign debt datasets which were then added together. These are exposures to the domestic banking system, collected mainly from Arslanalp & Tsuda (2012) and supplemented by data from the IMF IFS database (IMF, 2012), and exposures to other banking systems, collected from the BIS International Financial Statistics (BCBS, 2013).

While the first dataset collection is straightforward, in case of the second one we have to employ a similar calculation as in the case of interbank assets. Again, the data is taken from the consolidated statistics of foreign claims on immediate borrower basis. To estimate the banks' exposures to sovereigns from the reporting banking sectors' pool of total claims, we multiply the whole column of the exposure matrix representing the given state's debts by the fraction of its sovereign debt on the total debt.[42] The same approach was used in Arslanalp & Tsuda (2012) for the calculation of foreign banking sector holdings of sovereign debt. However, we must note that this data provide information only on the individual sovereigns' debt towards the banking sectors in our sample. Thus it does not describe the countries' total debt positions.

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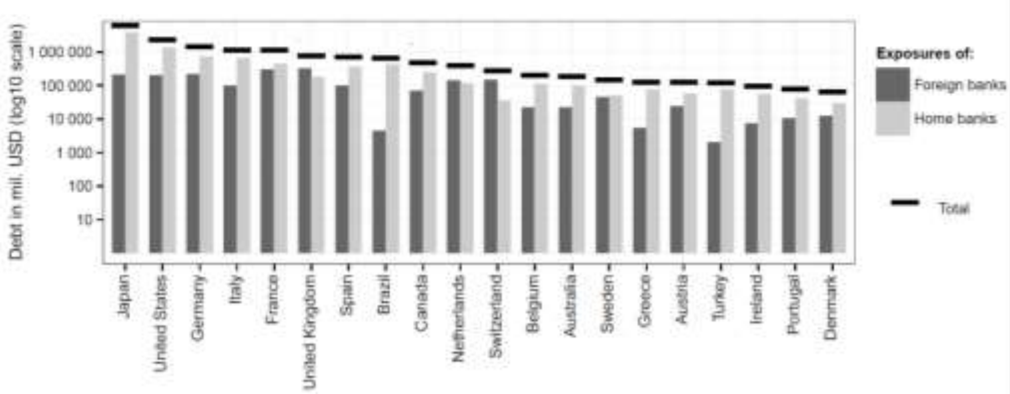
[41] For the analysis, we considered the banks with the following specializations: commercial banks, savings banks, cooperative banks, real estate & mortgage banks, bank holdings & holding companies

[42] The calculation may be visualized by Figure 4.3, only the question marks (*?%*) would now represent the value of the banks' exposures to counterparty public sectors instead of counterparty banking sectors.

Figure 4.6: Selected banking systems exposure to sovereign debt as of Q4 2011



Source: Author's calculations based on data from Arslanalp & Tsuda (2012), IMF International Financial Statistics and BIS International Financial Statistics

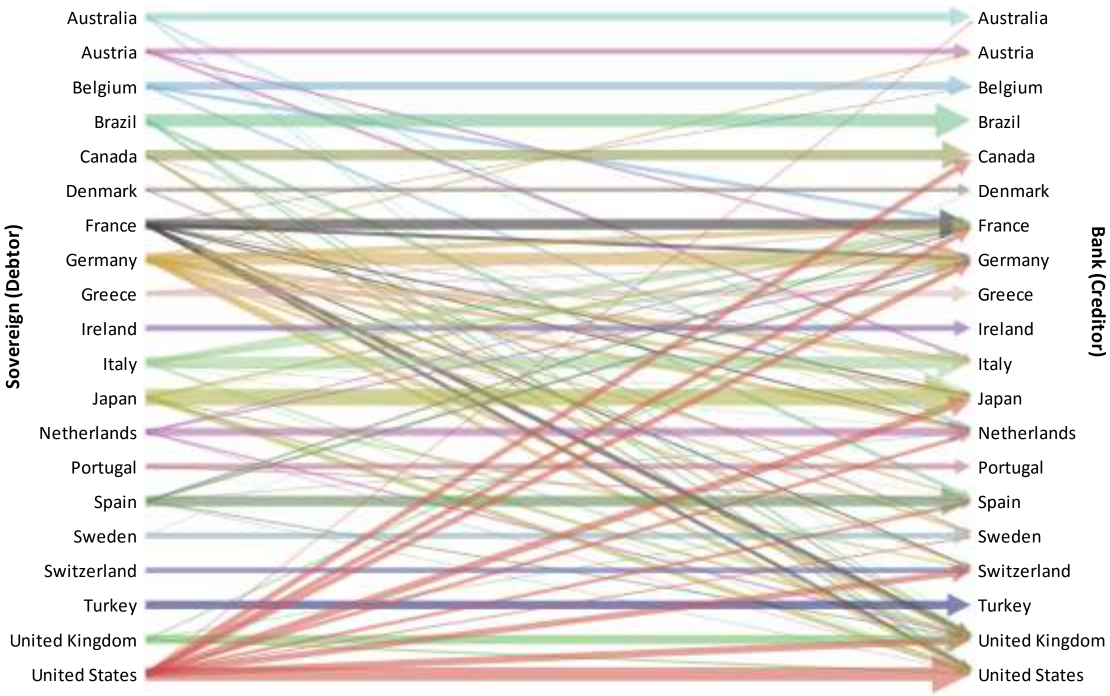
Figure 4.6 visualizes the figures for each sovereign's debt to the foreign as well as to the domestic banks. We see that for all banking systems except of the United Kingdom and the Netherlands, there is a relatively strong bias towards the domestic banks (note the logarithmic scale of the chart). This phenomenon, already documented in Pisani-Ferry (2012), Merler & Pisani-Ferry (2012) or Acharya, et al. (2012), results in a strong link between sovereigns and their domestic banks through balance sheet exposures and is one of the reasons why sovereign risk translates through feedback loops into the domestic banks' risk. With debt to banks amounting to over $4 trillion, Japan is the most indebted sovereign in our sample and also reports the strongest home bias as the overwhelming majority of Japan's large public sector debt to banks is held by the domestic institutions.[43]

For better insight into the inter-linkages between banks and sovereigns, one has to study also the detailed exposures, including the international ones. Figure 4.7 presents this data as a plot of the bipartite network of sovereigns and banking systems in our sample. Similar to Figure 4.4, the edges represent the sovereign debt towards the individual banking system. Here we see again the home bias phenomenon as the largest links are always to the domestic banking system and also for the individual countries, interesting patterns emerge. Again, the debt to foreign banks is determined largely by geographical or cultural proximity of the individual countries. Notice for example that the largest foreign borrowing of Austria is from German and Italian banking systems, Belgium is

[43] According to (IMF, 2013b), Czech Republic is second after Japan in bank holdings of sovereign debt. These amount to over 17% of total banking assets.

connected mostly to France and the Netherlands, Denmark is connected to Sweden and vice versa. As to the cultural proximity, Brazil borrows mostly from Spanish banks and Australia from the UK banking system (and from Japan, which is again close geographically). Also Canada is linked to the United Kingdom and the United States. Finally, there are several “international borrowers”, such as the United States, Germany, France and to some extent also Japan.

Figure 4.7: Detailed banking systems’ exposure to sovereign debts as of Q4 2011



Source: Author’s calculations based on data from Arslanalp & Tsuda (2012), IMF International Financial Statistics and BIS International Financial Statistics

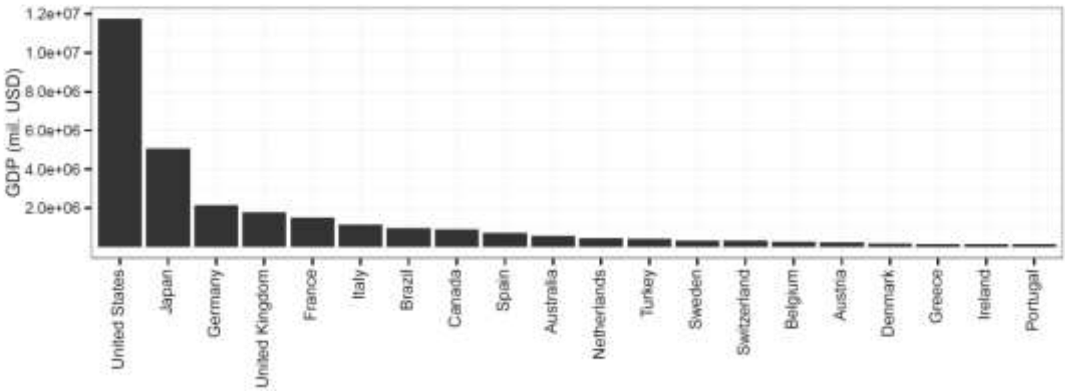
Note: The edges are coloured by the creditor node (e.g. exposure of US sovereign against the Canadian banking system is coloured in red). The edges’ thickness represents the exposure size on a natural log scale and all exposures amounting to less than USD 5 billion were filtered out for better readability.

4.5.1.5 GDP and CDS Spreads

Besides balance sheet data for the individual countries’ banking systems, the model requires two more datasets for complete calibration: GDP and CDS spreads of the individual sovereigns. The gross domestic product data was collected from the World Bank database (World Bank, 2013). From the available series, the one in constant US dollars of the year 2000 was selected in order to prevent exchange rate fluctuations and inflation to bias the data in case of using the model on a time series.

4.8 captures the absolute value of GDP of the analysed countries in 2011and shows large disparities among the economies. The sample mean value of this indicator is $1.45 trillion, approximately the product of France. The US output is far the largest with the value exceeding $11.7 trillion. On the other side of the scale, Portuguese GDP accounts for only 1/100 of the US one and is the lowest from the sample. Also, Portugal experienced the second largest proportional drop compared to the previous year. As expected, the leading position in this matter belongs to Greece whose annual growth rate stood at -7.1%. The fastest growing country was Brazil which was expected due to its status of emerging economy. However, Sweden and Germany also experienced a healthy annual growth rate exceeding 3%.

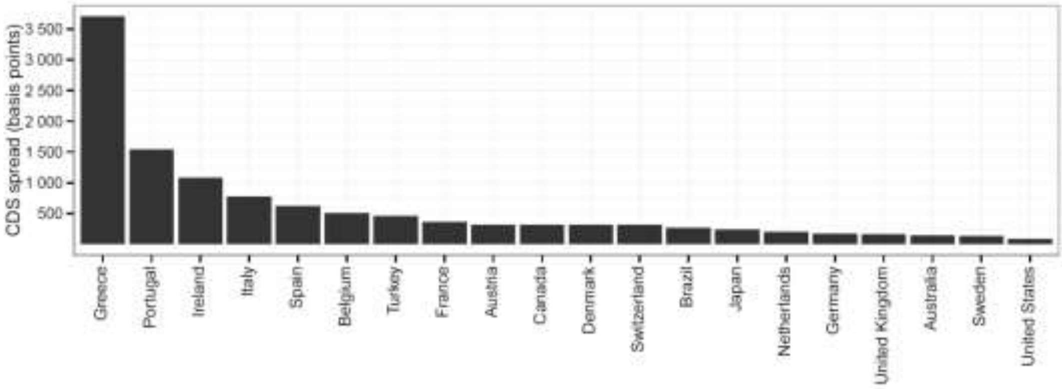
Figure 4.8: GDP of the selected countries in constant 2000 US dollar



Source: Author according to the World Bank database

Data on 5-year credit default swap spreads were obtained from the Bloomberg database. Figure 4.9 captures the average value of CDS spreads for selected countries in 2011. The median value reaches 307 basis points which is approximately the CDS spread of Austria. Apparently, the PIIGS countries are markedly more prone to default as their CDS spreads significantly exceed the common levels, in case of Greece, the value is 11 times higher than the median, in case of Portugal, approximately five times higher. According to the market perception, the United States are the least likely to experience a default.

Figure 4.9: CDS spreads of the selected countries



Source: Author according to Bloomberg

4.5.2 Model Calibration

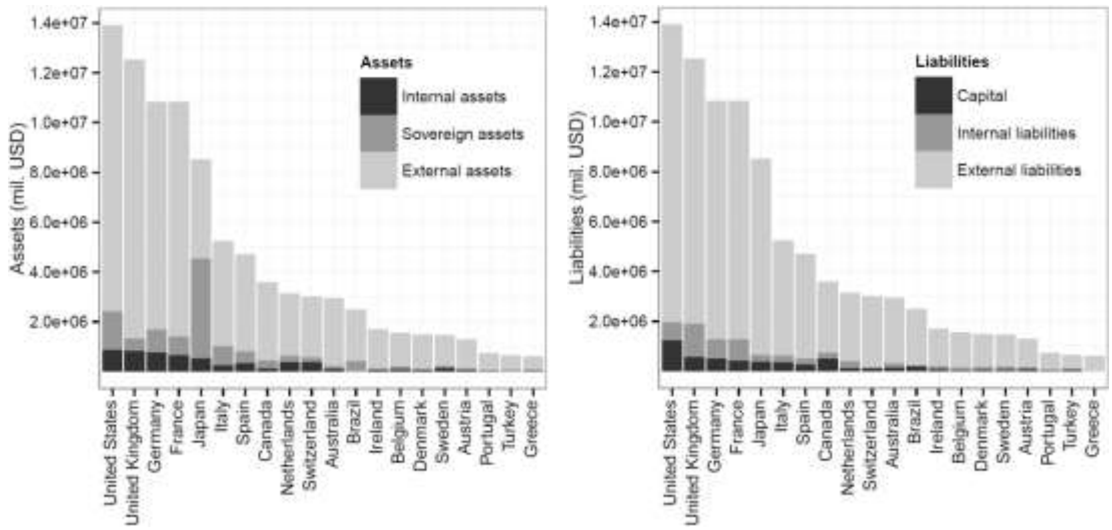
Put all together, the collected data provide a complex picture of the modelled global banking system according to Table 4.2. The internal assets of individual subsystems are calculated as the sum of their exposures to other subsystems; the sovereign assets as the sum of their exposures to sovereigns and the external assets as the total assets minus the internal and the sovereign assets. Similarly, capital is calculated as the collected capital ratios times the total assets of the individual subsystems; their internal liabilities are sums of their debt towards other subsystems, and the external liabilities are total assets minus capital and the internal liabilities.

Figure 4.10 provides the final overview of the calibrated balance sheets which are loaded into the model. As we can see on Figure 4.10A, the external assets constitute the majority of the bank's balance sheets, in fact around 80%, while the sovereign assets account for 12% and the interbank assets only for 8%. Similarly, on the liability side depicted in Figure 4.10B, external liabilities form an overwhelming 86% of the total liabilities while the banks' equity accounts for 6% and the interbank liabilities for 8%. The fact that the interbank network forms only a small portion of the total banking assets value is the main shortcoming of the pure credit contagion approach. It points at the fact that without oversimplified extrapolation of the interbank network to the rest of the banking system, it is difficult to draw any conclusions from works such as Chan-Lau (2010) that study only the effects of the direct contagion and funding shocks and relies solely on the BIS interbank network data. In fact, our finding stresses the significant gap in the knowledge of banking exposures and demands further data collection which would enable us to break the external assets into more detail.

As opposed to Chan-Lau (2010), we incorporate the full size of the banking system and the indirect channel of contagion through market liquidity as described by Brunnermeier, et al. (2009) and Cifuentes, et al. (2005). Given the amount of external assets, we expect that the liquidity channel will play a significant role for systemic stability. This channel is recognized also by authors focusing on the direct credit contagion, as documented by Upper (2011).

Figure 4.10: Balance sheets of the calibrated model as of Q4 2011

Panel A: Banks' assets Panel B: Banks' liabilities



Source: Authors' calculations

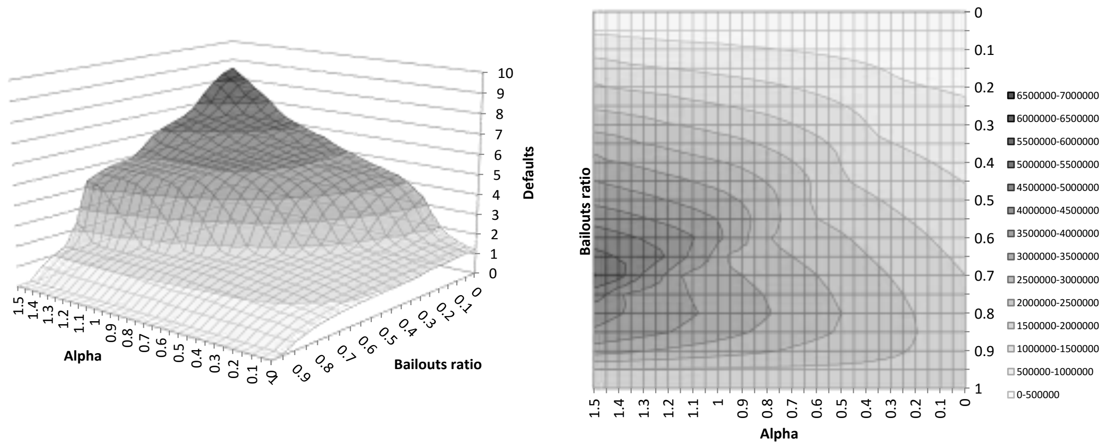
4.5.3 Effects of Sovereign Assistance

In this section, we will explore the effects of sovereign assistance on the calibrated global banking system. We will describe the impact and costs of the two support measures. Please note that in this phase the mechanism of risk transmission from the sovereigns back to the financial system (feedback loops) is not yet implemented.

We first look at the bailouts support measure. Figure 4.11A depicts the number of bankrupt banking subsystems given various levels of market illiquidity (α, referred to as alpha) and various intensities of state support (k^{BR}, referred to as bailouts ratio). The positive effects of this measure are clearly visible and with maximum bailout support, no bank defaults as the shock is captured right at its origin. We see that at low values of alpha, the effect of state aid is very low and almost linear. However, with growing illiquidity, the state support is increasingly important and at maximum alpha, we see a "step-like" dependence where a very small increase in state support may prevent default of three banking subsystems. As to the sovereign deficits caused by this measure, Figure 4.11B demonstrates that at very low levels of alpha, the costs increase almost linearly with the support intensity. However, for low capitalized systems, under high levels of alpha, the costs rise only until some level of support intensity beyond which they fall sharply. This is caused by the support measure effectively blocking the contagion through market liquidity channel and corresponds to the sharp drop of defaults in Figure 4.11 A.

Figure 4.11: Bailouts and Recapitalization effects

Panel A: Total defaults - Alpha vs. Bailouts ratio	Panel B: Total cost – Alpha vs. Bailouts ratio

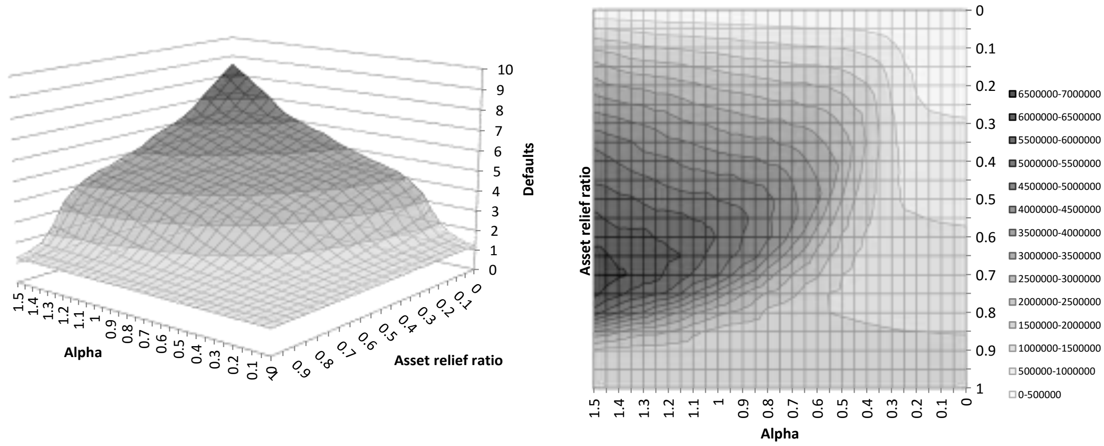


Source: Authors

Secondly, looking at the effects of asset relief programs as depicted in Figure 4.12A, we see that they do not cause such sharp drops in numbers of failed banks as those of outright bailouts, but still are very significant. Because asset relief is tied to the liquidity channel, we see that the shape of the dependence of systemic stability on the support intensity (k^{BR}) is similar to the shape of its dependence on $(1-\alpha)$. Also, in contrast to outright bailouts which may be targeted to the initial propagator, in case of asset relief, the banks which are hit by the primary shock always fail. Looking at the costs of this measure, Figure 4.12B shows that at the peak they are higher than those of the bailouts. Also, except for the area of support intensity of 0.8 to 0.9 where they are smoother, they have very similar shape as the costs of bailouts. The reason for asset relief to prove such efficiency is that external assets form a large portion of total assets of the system and hence the liquidity effects are very strong.

Figure 4.12: Asset relief effects

Panel A: Total defaults - Alpha vs. Bailouts ratio	Panel B: Total cost - Alpha vs. Bailouts ratio



Source: Authors

4.5.4 Effect of Feedback Loops

Finally, we implement the feedback loops of risk transmission back from the sovereigns to the banking system and study the effects of state aid on the complete model. The figures showing results of this analysis (in the appendix) depict the number of failed banking subsystems in dependence on state aid intensity and accounting for different levels of CDS sensitivity.

First, Figure-Appendix 1 demonstrates the effects of bailouts and recapitalization. We see that the measure has large impact on the banking system stability, which may be both positive and negative depending on the initially shocked bank and CDS sensitivity setting. Generally, setting CDS sensitivity equal to zero represents a situation in which the sovereigns are not negatively affected by the state aid as increases in their deficits do not result in growth of their CDS spreads and hence also growth of their implied probabilities of default. With non-zero CDS sensitivities,[44] the feedback loops are in their full function as higher deficit resulting from the state aid increases the default probabilities of sovereigns. In case of bailouts and recapitalization, when the CDS sensitivity is set to zero, the count of failed banking subsystems is a decreasing function of the support intensity.

[44] Our choice of CDS sensitivity values of 1.5 and 3 in the figures is in line with econometric studies such as Sand (2012) or Cottarelli & Jaramillo (2012).

When large subsystems having high systemic importance (France, Germany, the United States and the United Kingdom) are initially shocked, the effects of support come only at relatively high support intensity as the systemic break-down is prevented only at bailouts ratio exceeding 50%. Moreover, for these countries' subsystems, the number of defaults is never significantly higher with the state support than without it, even though at CDS sensitivities of 1.5 and 3 the positive effects come much later at higher support intensity levels. If other banking subsystems are targets of the initial shock, we see that at non-zero CDS sensitivities, the default count usually increases in the middle of the support intensity interval as the state aid is still insufficient to significantly support the banks but already weakens the sovereigns. This pattern is visible throughout the majority of the initially-hit banking systems. Also, even at non-zero CDS sensitivity levels, in case of almost all initial propagators, the system is better off with full state support than without it. The only exception is Belgium, Brazil and Greece, where state support clearly worsens the systemic crisis. The reason is that they are neither too large nor too interconnected systems and supporting them after they are initially hit only adds another channel of contagion through a sovereign crisis.

Third, Figure-Appendix 2 shows the effect of asset relief. In case of zero CDS sensitivity, the positive effects of this measure are less significant than in the case of bailouts. On the other hand, as the CDS sensitivity progresses to higher values, the situation stays very similar and thus for high CDS sensitivity cases, this measure would seem as the most fitting one. However, we suppose that this result is somewhat biased because of the dataset employed. First, high portion of external assets in the system results in overestimating the measure's effectiveness. Moreover, the linkages between sovereigns and their non-domestic banks form a minor portion of the total sovereign assets and each country's banking system is aggregated into a single agent. As a result, even though the sovereign which is performing the asset relief program is severely weakened, its default affects mainly its already failed domestic banking system. If an interbank dataset that more precisely captures the reality was available, we expect this measure to perform significantly worse than bailouts and recapitalization.

4.6 Conclusion

In this paper, we focused on the link between systemic risk and sovereign crisis. We modelled how state support may influence a distressed financial system on a model calibrated to 4Q 2011 data collected from several sources. Our model contributes methodologically to agent-based modelling of systemic stability by adding the sovereign sector and the mechanisms of risk transfer between the banks and the sovereigns.

Table 4.5: Impact of individual support measures on a calibrated model

Measure	Description
Bailouts and recapitalization	▪ At zero CDS sensitivity, the count of failed banks is a decreasing function of support intensity on its whole interval ▪ For systemically important subsystems, state support always improves systemic stability, even though it is effective only at relatively high support intensity. ▪ At higher CDS sensitivities and in the middle of the support intensity interval, the effects are: – Negative when the initially failed subsystem has lower systemic importance – Neutral when the initially shocked subsystem is systemically important, the effects come in the second half of the support intensity interval ▪ At full support intensity, the measure has a positive effect for all countries except for Belgium, Brazil and Greece
Asset relief	▪ Efficient at the whole support intensity interval ▪ At zero CDS sensitivity the effects are less pronounced than in case of bailouts but still significant ▪ At non-zero CDS sensitivity levels, the positive effects stay significant ▪ The model is likely to overestimate this measure's efficiency due to the dataset employed. However, currently there is no better data on interbank exposures available

Source: Authors

The model implements two types of state support to banks: bailout and asset relief. In the short run when the feedback loops are not yet implemented, the effects of both measure types are positive. In the longer run after implementation of the feedback loops through sovereign defaults on bonds held by the banks, we found that a support measure's real efficiency depends on the measure intensity and CDS sensitivity, i.e. the market perception of the increase in sovereign risk. These effects were the most pronounced in case of bailouts and recapitalization, which according to our simulations may significantly improve the systemic stability. However, with higher CDS sensitivity, it depends on which country is initially hit: in case of banking systems that are systemically important, bailouts are effective throughout the whole support intensity interval, whereas for the banks with lower systemic importance, the support may actually worsen the situation. For example, in the case of Greece, even a 100% bailout does not reduce systemic risk (Refer to Appendix 1). Therefore, it would have been better if the Greek banks were allowed to fail. Our findings are in line with the failed bailout attempts of Greece- 2010, 2012 and 2015. Also for Italy, our model shows that a partial bailout would worsen the situation. Atlante, an Italian private equity fund dedicated to recapitalize Italian banks which has raised approx. $4.7BN is insufficient to reverse almost $396BN sour loans held by Italian banks. Even with a 100% bailout, Italy cannot contribute much towards mitigating systemic risk. In Italy's case, it is important for policy makers to weigh the risk and returns of complete bailout. Table 4.5 provides the complete overview of the feedback loops analysis.

In general, the model proves that in the short run without the feedback loops, state aid may significantly support the system and in the longer run with the feedback loop effects, it may be effective or harmful depending on the system's parameters. Moreover, the results are indeed different for each individual type of state aid.

Also, we found that majority of the total assets in our system are constituted by external assets. This points out to the shortcomings of studies that examine the systemic stability only on the BIS interbank network data such as Chan-Lau (2010), as this dataset amounts only to a small fraction of the total banking assets. Using this dataset that assigns only little amount of assets to the interbank network and keeps large portions of the balance sheets outside the interbank network is one of the main assumptions of the calibration. It stresses the need for deeper analysis and more data availability on the structure of the interbank and state-bank exposures as if more assets were internalized to the network, the overall importance of the direct shock transfer would be higher. In our current model, we consider the importance of the liquidity channel as overestimated.

Finally, because of the agent-based modelling approach, we may extend our model in the future with other types of financial market agents such as large multinational institutions, pension funds, insurance companies or even individual depositors. Insurance companies and pension funds with long maturities on liabilities play an important role in transmission channels of systemic risks. Capturing these is difficult and is a potential limitation of the model and an area of future research. Moreover, we may add the real economy along with its input/output flows and observe the effects on individual sectors when one sector is hit by a credit crunch or a drop in output. The flexibility and extensibility of our modelling approach is another strong benefit, which may lead to many more conclusions in the future research.

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Thesis Summary

With the 2008-09 crisis spilling across major world economies, a new set of regulations were published under the Basel III norms. With a redefined capital, higher capital ratios and new leverage and liquidity restrictions, they are expected to protect the financial system from such an event in future. However, constant lobbying from international financial institutions in favor of less stringent rules and extended implementation timelines has created doubts about its success. But these international banking regulations are expected to shape the future industry and are therefore important to understand and decode more scientifically and dynamically.

In order to better understand the effects of regulation on systemic risk and its importance to overall stability, we constructed an agent-based network model of the banking system and used it for stress-testing different regulatory environments. Our findings are three-fold. First, our simulations confirm that sufficient capital buffers of individual banks are crucial for protecting the stability of the whole system. Second, we see that capital adequacy norms work best as a preventive measure However, they are not very effective once the system is collapsing, and if the overall market liquidity is low, they may even worsen the situation. These conclusions might not be revolutionary, but verifying them as a result of a well described model and drawing insights on how the system behaves is an added value.

As it is not only the *a priori* regulation but also the *ex post* state intervention, that to a large extent shapes the systemic stability, we also investigated state aid and its long-term and short-term effects. We analyzed the relationship between financial crisis and sovereign crisis by studying four types of support measures - i) bailouts and recapitalization, ii) execution of state guarantees, iii) asset buy-outs and iv) provision of funding liquidity. We find that in the short term, when the feedback loop of risk transfer from sovereigns to the financial system is not active, all support measures improve systemic stability. When feedback loops are implemented, the effects of state support depend on several parameters. There are some settings in which it significantly mitigates the systemic crisis and others settings in which it contributes to the systemic collapse. Finally, there are differences among rescue measures used by governments and central banks. While bailouts and recapitalization are the most efficient ones 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 very costly for any government. Liquidity support from central banks is of temporary help to banks facing liquidity crunch. It cannot offer itself as a long term solution to solvency related issues. 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.

Two types of state support to banks - bailout and asset relief – were also tested in a calibrated model. Again, our results confirm that in the short run the effects of both the measures are positive but in the longer run a support measure's real efficiency depends on its intensity and on market perception of sovereign risk. These effects were the most pronounced in case of bailouts and recapitalization, which according to our simulations can significantly improve systemic stability. However, with higher CDS sensitivity, it depends on which country is initially hit. In case of banking systems that are systemically important, bailouts are effective throughout the whole support intensity interval, whereas for banks having lower systemic importance, the support may actually worsen the situation. This is evidenced in the impact of bailouts of Greece and US banks. Where Greek bailouts failed in containing systemic risk, bailout initiatives by US were more effective due to their high systemic importance.

Also, we found that majority of the total assets in our system are constituted by external assets. This points out to the shortcomings of studies that examine the systemic stability only on the BIS interbank network data such as Chan-Lau (2010), as this dataset amounts only to a small fraction of the total banking assets. Using this dataset that assigns only little amount of assets to the interbank network and keeps large portions of the balance sheets outside the interbank network is one of the main assumptions of the calibration. It stresses the need for deeper analysis and more data availability on the structure of the interbank and state-bank exposures as if more assets were internalized to the network, the overall importance of the direct shock transfer would be higher. In our current model, we consider the importance of the liquidity channel as overestimated. Finally, because of the agent-based modelling approach, we may extend our model in the future with other types of financial market agents such as large multinational institutions, pension funds, insurance companies or even individual depositors. Insurance companies and pension funds with long maturities on liabilities play an important role in transmission channels of systemic risks. Capturing these is difficult and is a potential limitation of the model and an area of future research. Moreover, we may add the real economy along with its input/output flows and observe the effects on individual sectors when one sector is hit by a credit crunch or a drop in output. The flexibility and extensibility of our modelling approach is another strong benefit, which may lead to many more conclusions in the future research.

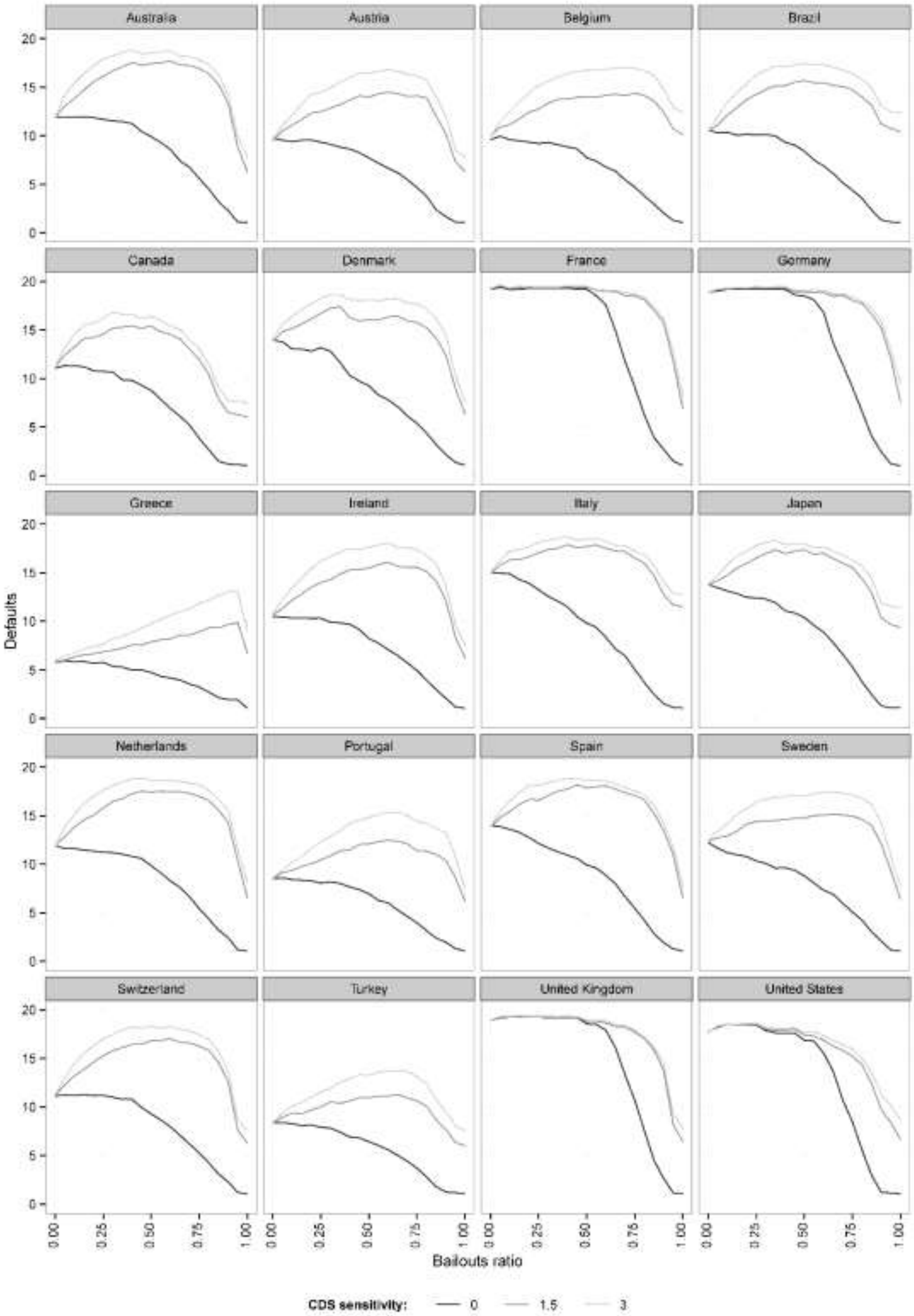
Generally, the proposed agent-based network modelling has shown to be a highly flexible methodology due to its ability to simulate both realistic and hypothetical cases in the market and accounts for key added value of our research. The fact that some of our results are in line with common sense or previous theoretical research proves that usage of these models leads to correct conclusions. However, the fact that the models use different philosophy and are de facto computational simulations of real-world micro-processes, they allow for better insight into the inner mechanics of these processes and better understanding of how these project the macro-behaviour of the system. It also provides means for research of complex interactions that are difficult to solve analytically. The flexibility and extensibility of our modelling approach is another strong benefit, which may lead to many more conclusions in the future research.

Further research can go in two main directions from here. Firstly, since banks are operating in markets that also include other types of financial institutions, it would be valuable to add other types of agents to the model. Such extensions might include insurance companies; pension funds identified as potential economy stabilizers. They are heterogeneous long term institutional investors and can have long term macro-economic effects. The transmission effects and regulation around insurance companies and pension funds can be analysed to understand how they can help in protecting against such crisis and keeping the economy stable. Because of the nature of the agent/based models, this is possible as the complexity of the model does not grow exponentially when introducing more realistic assumptions. This is where we see the main advantage of using computational models to support policy decisions.

The second important research direction is related to the lack of reliable data on interbank relations. Instead of relying on indirect proxy datasets, finding more direct and accurate data could significantly increase the level of detail and accuracy of results. Even regulators do not always know with confidence how real-world interbank exposures look like; it is necessary that banks share more detailed data on their exposures, so that banking system models can be more efficient in identifying potential weaknesses. Were the interbank relationships more transparent, it would be much easier to pinpoint potential weaknesses, devise targeted regulatory measures for systemic stability protection and advise on concrete intervention steps based on a thorough analysis.

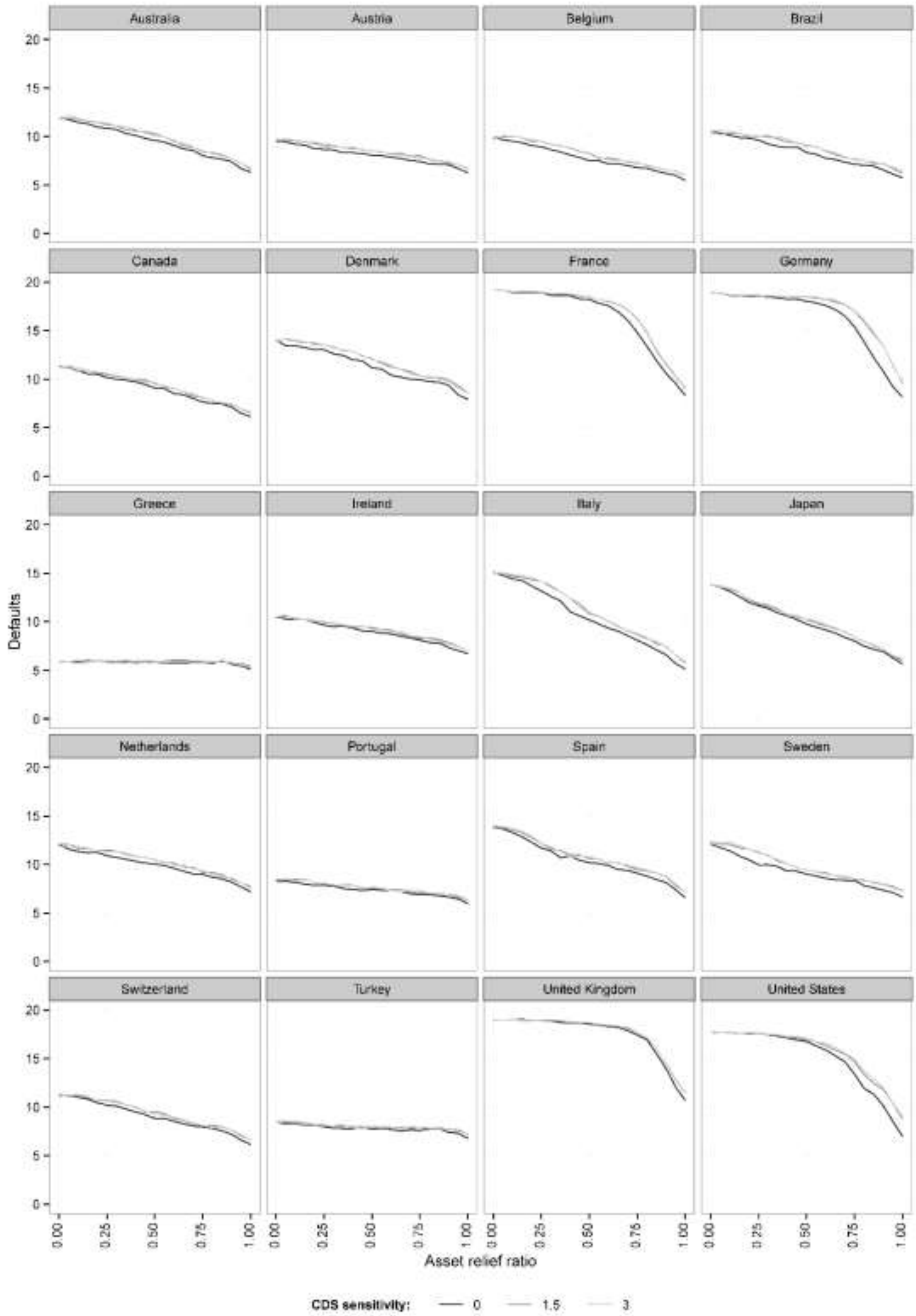
Appendix

Figure-Appendix 1: Bailouts and recapitalization with feedback loops



Source: Authors

Figure-Appendix 2: Asset relief with feedback loops on the calibrated model



Source: Authors

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Note on Implementation of Opponents' Remarks

Professor David Tripe BCA (Hons), MBS, Ph.D., Dip Bank:

- (1): *Add certain suggested references, comment on the literature review of Chapter 1*
  - All the suggested references have been added, partially to the largely extended introduction text which links the dissertation topics to the recent real-world events and partially to the first chapter which has been actualized. Most of them are in the form of literature review.
  - The most interesting suggested references were the recent ones (2013). As the chapter was initially written in 2010-2011, very close to the economic crisis, there weren't enough published journals as some academic texts had not yet been through the review process and published. Hence, we used a number of institutional reports and publications.
- (5): *Support a strong statement by further literature*
  - Mention of the reference, Sutorova and Teply (2013; 2014) has been moved to the summary of Chapter 1 along with supporting reference to Shin (2010). It is in better context there than in the conclusion of the third chapter where, as the reviewer rightly pointed, this result was rather surprising.
- (7): *Add a summary chapter linking the results together*
  - An overall conclusion has been added at the end of the thesis. Also, the introduction has been extended to better link the individual papers together and state the main points of focus more clearly.
- (8): *Add a single list of references*
  - A single list of references has been added at the end of the thesis.
- *Specific required amendments:*
  - Typos in text and references lists have been corrected.

doc. PhDr. Ing. Ing. Petr Jakubík Ph.D. Ph.D.:

- Chapter 1: *Author could further reflect on the latest development in the regulation capturing discussion of macroprudential tools and instruments, adding also relevant references.*
  - A paragraph on recent discussion has been added into the chapter summary with latest references to BIS and IMF publications.
- Chapter 1: *It has become clear that some transmission channels propagating systemic risk within the financial systems lie beyond the banking system. Some short paragraph and references linking the banking regulation with the current debates going beyond banking could be added.*
  - A short discussion on the role of pension funds and insurance companies, along with a reference to the recent EIOPA Financial Stability Report has been added at the end of Chapter 1.
- Chapter 3: *The author could further comment on including other segments into the framework and crucial assumptions which might drive the results obtained.*
  - This is addressed at the end of chapter 4 and in the overall thesis summary as an area for further research. Chapter 3 (as the key part of the dissertation already published and cited) has been left mostly intact, except for a few minor corrections.

- Chapter 4: *Several data sources are used and it might be beneficial for the reader to clearly list and summarize them, e.g. some table listing all data sources used could be added.*
    - A brief overview of data sources has been provided in Table Table4.2
- Chapter 4: *I would recommend adding the whole short section with the data/sample description and some descriptive statistics giving a better overview of all data sources employed.*
    - Based on the opponent's remark, this part of Chapter 4 has been largely extended and now contains several more pages with description of how the dataset has been built along with some summary statistics and charts describing the dataset.
- Chapter 4: *the author could explain the crucial assumptions made to arrive into the conclusion made. He could further elaborate on the possible expected changes in the results under different assumptions.*
    - The assumptions have been explained in the chapter 4 and then reiterated in the conclusion.
- Chapter 4: *Moreover, sovereign debt is hold extensively by non-banking financial institutions, especially life insurance companies and pension funds. ... author could further elaborate on potential limitations of the model and other segments of the financial sector. ... It is clear that while some sectors could trigger a potential financial instability, other sectors by nature rather contribute to the overall stabilization of financial system. The author could connect those discussions to the fourth chapter…*
    - Mentioned briefly in the conclusion of Chapter 4 and addressed in the further research opportunities in the overall conclusion.
- Chapter 4*: Moreover, he could give some examples from the recent history on different state supports undertaken and comment what would be the recommended actions suggested by the results obtained. He could show how to utilize his work for several examples and show when his framework could provide better outcomes compared those which were obtained in practice.*
    - Addressed – added a paragraph in the conclusion of Chapter 4 on recent situations of Greece and Italy (and restated in the overall conclusion).
- Overall: *As a minor comment, I would suggest to state the references to the published chapters not only in the introduction, but also directly below the titles of the each chapter, for example as a footnote.*
    - Added in the form of footnotes

prof. Ing. Daniel Stavárek, Ph.D.:

- *Na druhou stranu je dané téma v současnosti předmětem zájmu mnoha ekonomů a výzkumníků, je proto nutné jednoznačně vymezit klíčový přínos práce.*
    - Vymezeno v přepracovaném úvodu a zmíněno v závěru práce.

- *Zde je nicméně zapotřebí mnohem lépe argumentovat, že využití takových modelů je vhodné a proč jejich aplikace je vhodnější než využití jiných metod, když ve velké míře se dochází k totožným nebo velmi podobným závěrům.*
    - Tato argumentace je částečně uvedena v různých částech textu. Zejména do závěru pak byla přidána diskuze o hlavním přínosu použití multiagentních modelů.

- *V oblasti bankovních krizí a regulace respektive suverénních krizí jsem nicméně nenašel například tyto významné publikace, jež jsou k tématu práce bezpochyby relevantní…*
    - Všechny navržené publikace byly zapracovány do přehledu literatury i do hlavního textu. Největší část byla zapracována v úvodu a v první kapitole.

- *Dizertační práce by společným cílem získala jasný směr i určité zastřešení … Domnívám se, že v integrujícím textu by mělo být ve větší míře zdůrazněno propojení, vzájemné souvislosti, návaznosti a další vazby mezi jednotlivými studiemi, čímž by se dizertační práce dostala do jasně vymezeného kontextu … Jsem přesvědčen, že by dizertační práci velmi prospělo, kdyby i na jejím konci byl vložen integrující text, kde by se objevily shrnující poznatky jak z hlediska metodologického a aplikačního, tak zejména ekonomického či národohospodářského charakteru. Jako optimální délku integrujícího textu považuji vzhledem k rozsahu dizertační práce 20-30 stran.*
    - V disertaci byl zcela přepracován úvodní text, který nejprve více uvádí kontext, ve kterém se výzkum pohybuje, přidává novou literaturu a vybraná aktuální témata, (např. vliv ostatních institucí, jako jsou penzijní fondy, na systémovou stabilitu), ale také zmiňuje hlavní otázky i klíčový přínos práce, kterým je použití multiagentních modelů.
    - Na konci disertace bylo taktéž přidáno celkové shrnutí, které umožňuje náhled na jednotlivé závěry z kontextu celku a zmiňuje další možnosti pro budoucí výzkum.

- *Velice bych uvítal, kdyby v rámci práce byly sjednoceny formální náležitosti, jako je podoba tabulek, grafů či citační norma používána v seznamech použité literatury.*
    - Podoba tabulek byla sjednocena v celé práci, stejně jako citační norma. Práce navíc nyní obsahuje celkový seznam referencí ze všech kapitol.

- *Osobně nejsem nakloněn používání nadpisů až pátého řádu, zvlášť pokud je tomu pouze v jedné kapitole. Pokud by se tyto náležitosti uvedly do souladu, celá práce by se jevila mnohem uceleněji a kompaktněji.*
    - Struktura nadpisů byla přepracována tak, aby se v práci vyskytovaly maximálně nadpisy čtvrtého řádu (včetně číslování hlavních kapitol)

Doc. PhDr. Petr Teplý, Ph.D.:

- *Update references*
    - References have been updated and more than 15 new references have been added.
- *Expand Foreword or create an extra part "Thesis summary" where key conclusions of all four essays will be presented and linked to each other.*
    - The Foreword was largely reworked to better introduce the context, goals and added value of the thesis. Thesis summary section has been added, following the opponent's remark.