Charles University in Prague

Faculty of Social Sciences
Institute of Economic Studies

MASTER THESIS

Inter-sector credit exposure:

Contingent claims analysis in the Czech Republic

Author: **Bc. Josef Brechler**

Supervisor: **PhDr. Michal Hlaváček Ph.D.**

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Declaration of Authorship

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Abstract

Linkages between economic agents in form of financial assets might contribute to transmission of shocks between different parts of the economy. Aim of this thesis is to enrich the ongoing discussion about the spread of contagion through the economy. We provide an analysis of financial interlinkages in the Czech economy and using the contingent claims analysis (CCA) model we attempt to quantify risks in the system that that are implied by the existence of these linkages. We use different techniques within the framework of the model to obtain various indicators that can be used to assess stability of the system. Using simulations we find that size of losses due to riskiness of debt depends strongly on the origin of a shock and it is higher for shocks originating in the household sector than for shocks originating in the sector of the non-financial corporations. We also find that size of a decrease in capital of the banking sector needed to cause a distress in the system as relatively high and stable in time.

JEL Classification	E01, E44, G01, G12, G20
Keywords	Balance sheet contagion, financial accounts, network models, contingent claims analysis, systemic risk

Author’s e-mail	josef.brechler@gmail.com
Supervisor’s e-mail	michal.hlavacek@cnb.cz

Abstrakt

Vztahy mezi ekonomickými agenty existující na základě držených finančních aktiv mohou přispívat k přenosu šoků mezi různými částmi ekonomiky. Záměrem této práce je obohatit probíhající diskusi ohledně šíření nákazy v ekonomice. Nejprve jsou analyzovány finanční vztahy v rámci české ekonomiky a následně je použit model podmíněných nároků (contingent claims analysis) ke kvantifikaci rizik která vyplývají z existence výše zmíněných vztahů v systému. V rámci použitého modelu jsou pak získány různé indikátory, na jejichž základě je posouzena stabilita systému jako celku. Na základě simulací je zjištěno, že velikost ztrát způsobených kreditním rizikem závisí silně na zdroji šoku. Tyto ztráty jsou vyšší v případě, že zdroj šoku leží v sektoru domácností oproti ztrátám spojeným se šokem pramenícím ze sektoru nefinančních podniků. Dále je zjištěno, že velikost poklesu kapitálu v bankovním sektoru nutná ke způsobení finanční tísně některého ze sektorů je relativně vysoká a stabilní v čase.

Klasifikace	E01, E44, G01, G12, G20
Klíčová slova	Nákaza rozvahy, finanční účty, síťové modely, analýza podmíněných nároků, systémové riziko

E-mail autora	brechler@centrum.cz
E-mail vedoucího práce	michal.hlavacek@cnb.cz

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Acronyms

CNB Czech National Bank

CCA Contingent claim analysis

IMF International Monetary Fund

DD Distance to distress

PD Probability of distress

ECB European Central Bank

VaR Value at risk

VAR vector autoregression

CDS credit default swap

EWS early warning system

NFC Non-financial corporations

CB Central bank

OMFI Other monetary financial institutions

OFI Other financial intermediaries

FA Financial auxiliaries

INS Insurance corporations and pension funds

GOV General government

HOU Households

NPI Non-profit institutions serving households

ROW Non-residents

LB Large scale banks (Česká spořitelna, Československá obchodní banka, Komerční banka, UniCredit Bank)

MB Middle scale banks

SB Small scale banks

FB Foreign banks branches

BS Building societies

MMF Money market funds

CU Credit unions

Master Thesis Proposal

Institute of Economic Studies
Faculty of Social Sciences
Charles University in Prague

Author:	**Bc. Josef Brechler**	Supervisor:	PhDr. Michal Hlaváček, PhD.
E-mail:	josef.brechler@gmail.com	E-mail:	michal.hlavacek@cnb.cz
Phone:	725 717 500	Phone:	
Specialization:	*Economic Theory*	Defense Planned:	June 2013

Proposed Topic:

Inter-sector credit exposure: contingent claim analysis in the Czech Republic

Topic Characteristics:

Linkages between economic agents in form of financial liabilities might contribute to transmission of a shocks between different parts of an economy. Aim of this thesis is to enrich ongoing discussion about the spread of contagion through the economy. This discussion put on weight especially after the recent financial crisis.

We will use Castrén and Kavonius (2009) methodology which combines inter-sector exposure analysis with contingent claim analysis (CCA). Thanks to this methodology we can get a picture of how the shock transmits through the economy, evaluate the stability of individual sectors and obtain several indicators useful for assessment of financial stability of the economy.

Another contribution will be demarcation of data used in the model. While the original CCA model (Merton, 1974) used relatively easily definable balance sheet items, application of the methodology to inter-sector analysis might cause different problems. As an example we can mention a problem of definition of „capital“ for those sectors which do not underwrite shares or a problem of volatility calculation in an enviroment of relatively under-developed financial markets.

We will use several sources of data in our work. First, it is a quarterly statistics of financial accounts published by the Czech National Bank. Second, data from financial markets will be used. Finally, we will make use of data collected by the CNB as part of conduct of financial market supervision.

Hypotheses:

H1: Economic development during recent years suggests that Czech financial sector is relatively resilient in situations when the economy is hit by a shock, e.g. in a form of asset prices decrease, as saw in the second half of 2008. Contingent claims analysis enables to run simulations and to test whether the financial sector contributes to absorption of the shock that spreads through the economy or whether the intra-sector linkages lead to accumulation of more losses that even strengthen the shock transmission.

H2: While the opinion about positive relationship between securitization and credit risk dispersion formerly prevailed, financial distress of 2007/2008 revealed shortcomings of this method of financing (Shin, 2009). The thesis aims to contribute to the discussion and to analyze whether a relationship exists between a size of financial leverage and stability of particular sector of the economy.

H3: What is an impact of Basel III regulation from contingent claim analysis point of view? Do these regulatory measures strengthen the Czech banking sector resiliency?

Methodology:

In order to test hypotheses H1, H2 and H3 contingent claim analysis framework will be used. This method was introduced by Merton (1974) who generalized and broadened a model by Black and Scholes (1973) for option pricing based on commonly accessible market data. Merton's generalization rests on using original method to valuate firm's liabilities in general. The model was broadened in a sense that it incorporates risk of counterparty's default.

The model understands firm's default as an owner's decision to exercise a call option on firm's assets. The option is exercised in a situation when market price of assets exceeds nominal price of liabilities. In the opposite case the debt defaults and the difference between the market price of assets and the nominal price of liabilities is a loss for creditors.

The analysis enables calculation of certain indicators usable for assessment of stability of different economy's sectors and the whole system. Among others, distance to distress represents a distance between the market price of assets and the distress points if the firm related to assets' volatility. Probability of default represents a probability that realization of the market price of assets will lie under the distress point.

Using contingent claim analysis to analyze transmission of the shock between sectors is carried out through an iterative process during which an adjustment of the whole system after the initial shock is simulated. Such shock might have various forms; it can be a permanent decrease in share prices in face of worsened growth outlook or it can have a form of losses from loans provided to households (Castren and Kavonius, 2009; Silva, 2010; Plašil and Kubicová, 2012). Important fact for our analysis is that subsequent transmission of shock through the system in form of asset prices decrease can be decomposed into two mutually fuelling effects. First, it is the effect connected to a change in valuation of loss-registering sector and, second, the effect

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Author

Supervisor

1 Introduction

Financial stability has been an issue of rising interest in recent years. It have become a policy goal of many central banks, regulations have been introduced to national legislations dealing with supposed sources threatening the financial stability and a lot of academic work have been done trying to define the financial stability and then to capture and explain factors influencing it. In other words, referring to definitions of the financial stability discussed below, we have been trying to reach and maintain a "situation where the financial system operates with no serious failures or undesirable impacts on the present and future development of the economy as a whole, while showing a high degree of resilience to shocks." (CNB undated)

Such an interest comes after several decades of rising share of financial sector on GDP in both economies around the world which eventually resulted in economic turbulences not seen many times before. Questions have been asked whether to what extent and how the growing size of the financial sector caused the turbulences and if so, what can be done to prevent similar experience in the future. Different models have been developed describing behavior of economic agents inside the financial system or interaction of the financial system with other sectors of the economy. Usually these models consider agents and sectors of the economy to be connected by financial linkages allowing transmission of credit and risk. However, although a certain part of the risk is transmitted intentionally and the counterparties are able and willing to hedge against this risk, some part of the risk transmission is unintended being purely a negative spillover from one agent to another.

Our work aims to enrich the discussion about mutual exposure of agents in the economy and related risk transmission that threatens the stability of the system. A basic structure of the framework is following. First, we model the credit risk and incorporate it into balance sheets of the economic agents. Second, we use the balance sheet exposures to study propagation of shocks through the economy when the risk materialize. The first element of the framework, the risk modelling, is done using the contingent claims analysis (CCA), a generalization of the Black and Scholes' (1973) option pricing theory that allows for modelling of the liabilities of an agent as options. The second element of the framework, the analysis of the shocks propagation, consists of modelling how the losses originating in a certain part of the economy are recorded in balance sheets of its counterparties and how the whole system evolves in time. Two channels of the shock propagation, so-called equity channel and a risk channel, are distinguished to describe better the transmission process.

Significant part of the work is devoted to processing the data that were obtained from several sources. Matrix balancing methods are employed to get possible missing information about counterparties of the financial linkages in the system. We enrich the existing literature by disaggregating the financial sector to separate banks, groups of banks and other institutions. Heterogeneous group of agents is separated by this step, making us able to better capture existing risk in the system, because aggregation of agents into larger groups wipe out their idiosyncratic risks.

We construct and describe the risk-adjusted balance sheets using the data from 2007 to 2012. Several indicators useful for the financial stability analyses such as the distance to distress (DD) or risk-adjusted leverage are obtained and their development during the studied period is discussed. It allows us to asses which sectors or institutions were resilient to possible shocks and, by contrast, which sectors were risky in terms of a weak balance sheet situation and relatively high probability that it will get under financial distress. Next we perform simulations of a shock transmission using different scenarios. Under certain assumptions a shock is sent to the economy and different indicators are studied to asses to what extent the financial stability was threatened and what exactly were the sources of this threat. Such source can be for example a specific structure of mutual exposures in combination with a weak balance sheet situation in a certain sector. At the end we introduce a concept of stability frontier which allows for distinction between shocks that can lead to a distress in the system and those that do not have such consequences. Moreover, we use this concept for assessment of a sector's riskiness in a sense of its role as a shock originator.

Our work has the following structure. The second chapter summarizes framework for financial stability by its general description and definition of its key concepts. Its relation to monetary policy is briefly described as well as some existing models explaining systemic risk. In the third chapter the CCA model is applied to individual sectors and several risk-based indicators are calculated and their development is discussed. The fourth chapter is devoted to simulations of shock. Mechanism of the shock transmission is explained in detail and impact of two separate scenarios in analyzed. The fifth chapter starts with an explanation of the stability frontier concept. Afterwards this concept is applied to our data and result are discussed. The sixth chapter concludes.

2 Framework for financial stability

The following chapter summarizes framework for financial stability by its general description and definition of its key concepts. Its relation to monetary policy is briefly described as well as some existing models explaining systemic risk.

2.1 Basic definitions

2.1.1 Macroprudential policy and financial stability

Contrary to the case of monetary policy, consensus about the exact definition of macroprudential policy has not been reached in the literature. According to a broad definition *macroprudential policy* is a policy with a goal of maintaining financial stability (IMF 2011, Galati and Moessner 2011). Narrower definitions delimit macroprudential policy in terms of its task to face systemic risk (BOE, 2009). As we stick to the former definition it is necessary to define financial stability.

Definition of *financial stability* varies in literature, although central banks usually focus in their definitions on financial system maintaining its functions and being resilient to shocks. We quote following three definitions of central banks.

- European Central Bank: "*Financial stability can be defined as a condition in which the financial system – comprising of financial intermediaries, markets and market infrastructures – is capable of withstanding shocks, thereby reducing the likelihood of disruptions in the financial intermediation process which are severe enough to significantly impair the allocation of savings to profitable investment opportunities.*" (ECB undated)

- The Riksbank (central bank of Sweden): "*The Riksbank … define financial stability as meaning that the financial system can maintain its basic functions and also has resilience to disruptions that threaten these functions.*" (The Riksbank 2012)

- Czech National Bank: "*The CNB defines financial stability as a situation where the financial system operates with no serious failures or undesirable impacts on the present and future development of the economy as a whole, while showing a high degree of resilience to shocks.*" (CNB undated)

It is interesting that other definitions of financial stability, usually defined as opposite of *financial instability*, can be found, which focus on other aspects of the problem. For example Borio and Drehmann (2009) define financial instability as *"…a set of conditions that is sufficient to result in the emergence of financial distress/crises in response to normal-sized shocks. These shocks could originate either in the real economy or the financial system itself.*" Financial crisis/ financial distress is then defined as "*an event in which substantial losses at financial institutions and/or the failure of these institutions cause, or threaten to cause, serious dislocations to the real economy, measured in terms of output foregone.*" (Borio and Drehmann 2009, p. 4). Two comments are worth mentioning when comparing this definition with definitions mentioned above. First, the latter definition stresses that the financial system is unstable already in the moment when a possibility exists that the system can get under financial distress as a consequence of a shock. Financial system showing signs of distress is therefore not a necessary but a sufficient condition to find itself under financial instability. Although the three definitions by central banks also embody resiliency to shocks, an extension of the ECB's definition casts some shadows in its unambiguity[1]. Frait and Komárková (2012) use the term financial instability in the same connotation as financial crisis, whereas situation in which system is not resilient to shocks, but does not exhibit distress, is labeled as *financial vulnerability*. The second issue stressed in the definition is resiliency to normal-sized shocks. This requirement somewhat relaxes the definition of financial stability as it does not account for possibility of superior shocks.

A different definition of financial stability embraces wide range of economic agents possibly experiencing financial problems, not only financial system. It describes episodes of financial instability as "*episodes in which a large number of parties, whether they are households, companies, or (individual) governments, experience financial crises which are not warranted by their previous behavior, and where these crises collectively have seriously adverse macro-economic effects*" (Allen and Wood 2006, p. 160).

[1] "*The financial system should be in such a condition that it can comfortably absorb financial and real economic surprises and shocks. ... If (condition above) is not being maintained, then it is likely that the financial system is moving in a direction of becoming less stable, and at some point might exhibit instability.*" (ECB 2012)

2.1.2 Systemic risk, cross-sectional and time dimension

The concept of systemic risk plays an important role in the whole discussion about macroprudential policy. Here again a broad consensus has not been reached as different explanations can be found, but generally speaking it is a risk that is being experienced by the financial system as a whole. De Bandt and Hartmann (2000) emphasize conditionality of failure of one institution in the system on failure of other institution although being fundamentally solvent ex ante. In these situations *contagion* spreads through the system as more institutions get into trouble as a consequence of initial limited ("idiosyncratic") shock into a single institution. This chain of failures is also referred as *systemic event*. Systemic risk is then defined as the risk of experiencing systemic events in the strong sense. Borio (2003) argues that although systemic event can arise from a chain process described in the previous definition, most of the experienced major crises actually arise from common exposures to macroeconomic risk factors across institutions. In order to better understand origins of systemic events, focus should be shifted to explain how the common exposures build up. The author recognizes in this phase a pattern roughly common across different crisis episodes; booming economic conditions, benign risk assessments, a weakening of external financing constraints, notably access to credit and buoyant asset prices. These factors constitute dynamic interaction between the financial system and the real economy and its inspection should be stressed. Similar way of definition is used in Acharya (2009, p.225) who defines systemic risk as "*the joint failure risk arising from the correlation of returns on asset side of bank balance sheets*".

Based on aforementioned we can see that up to now literature has been siding to two possible sources of systemic risk. The first source is cross-section interlinkages between economics agents. The second source is common exposure of these agents to possible sources of shocks. While some former definitions assume rather mutual exclusivity of the two sources, Carauna (2010) indicates both sources as being equal. He then puts them together into cross-sectional dimension of systemic risk. The other dimension is the time dimension.

The *cross-sectional dimension* therefore reflects vulnerability of the financial system at given point of time. This vulnerability arises from a danger of the amplification of the potential shock to the financial system due to both character of linkages within the financial system and their common exposures, as described above. Cascading effect following a shock can take place in form system-wide liquidity squeeze, runs and asset fire-sales (IMF 2011).

The *time dimension* of systemic risk reflects cumulative and amplifying mechanism operating within the financial system as well as between the financial system and the real economy. This mechanism, referred as procyclicality, is based on increasing risk-taking by economic agents during the boom phase of a financial cycle followed by their excessive risk-aversion during the bust phase. Excessive leverage of economic agents and maturity mismatches in the financial sector, which cumulate during the boom phase, lead to vulnerability of the financial system. As consequence a period of financial instability can take place as the economy is hit by a shock, either endogenous or exogenous (IMF 2011). Carauna (2010) mentions financial innovation during the boom periods as the other source of procyclicality. New, untested instruments are created as economic agents feel (over)confident in taking risk and experimenting. Credit expansion and asset price increases mutually reinforce each other, but real value of underlying credit instruments is often hard to asses. This lead to build-up of risks that are hidden and underpriced as the systemic risk is created endogenously by the financial system. As Borio (2003) points out, upswings are characterized by a decline in indicators of a risk perception, in some cases even reaching their minimum close to the peak of the financial cycle. But these points turn out to be those where the risk is the greatest.

A principal mechanism that leads to the procyclical behavior of financial intermediaries is explained as the interaction between funding illiquidity due to maturity mismatches and market illiquidity (Brunnermeier et al 2009). *Funding liquidity* describes the ease with which it is possible to obtain funding by investors and arbitrageurs. A leveraged institution, which possesses an asset of a certain price, can borrow money using the asset as collateral. But not the entire price can be borrowed. Funding liquidity is reflected in size of *margin/haircut* lowering the amount the borrower can borrow.

Institutions often use short-term borrowing to finance assets that mature in a long term. Due to the maturity mismatch the institution is exposed to market liquidity risk. This risk takes several forms:

1. Margin/haircut funding risk – materializes when a size of margin changes, threatening the ability of the bank to raise funds

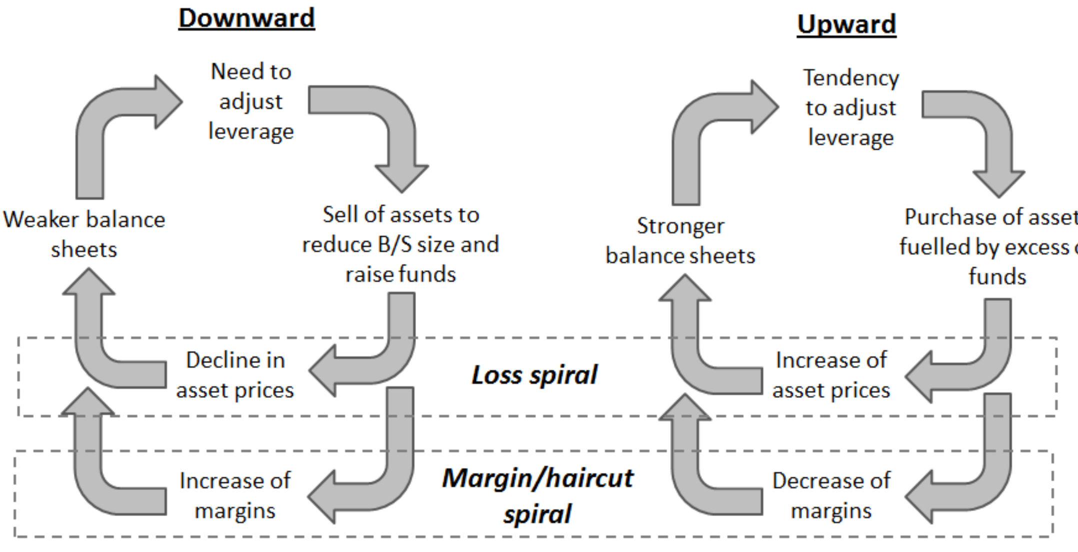
2. Rollover risk – is closely connected to margin funding risk and reflects bank's inability to roll over short-term borrowing due to increased price of funding.

3. Redemption risk – reflects a possibility that demand depositors or equity holders seek to withdraw their funds from the bank, creating pressure to shrink the liabilities side of the bank's balance sheet.

Whereas funding liquidity reflects the ability of the bank to raise money through lending, *market liquidity* is connected to the ability of rising funds via selling its assets. Market liquidity is low in a situation when the bank is unable to do so due to low prices and any effort to sell the assets puts further downward pressure on the asset prices.

If the financial system experiences a drop in prices of the assets, it can get to a situation of a *downward liquidity spiral*. More specifically, we can decompose the whole process into two effects. The first effect is referred as a *loss spiral*. Let us assume that balance sheets of banks are marked to market. In such situation the decrease in the asset prices leads to a deterioration of the funding liquidity manifested in a low ability to raise money through lending. Moreover, because the asset prices went down, the bank experiences losses that are offset by a decrease in equity on their balance sheet. This decrease in equity cushion is higher (understood in percentages) than the reduction of value of the assets due to the leverage and leads to a decrease in capital-to-assets ratio. In order to restore this ratio, the bank might want to raise funds by trying to sell part of its assets. However, if we assume alike portfolios of financial institutions throughout the system, then all the institution might take the same step, leading to excess of supply of assets over demand, and creating downward pressure on the price of the assets. The decrease in the price of the assets further depresses the balance sheets of the institutions and the whole process repeats. The second effect is referred as *margin/haircut spiral* and manifests itself in demand for higher margins requirements as observed during times of large price drops (Brunnermeier et al 2009). Deleveraging is fuelled as prices of the assets are disconnected from their fundamentals and rather reflect willingness of few investors ready to buy the assets in a short horizon. In such situation, collective tendency to sell at one moment increases risk measures and decreases risk appetite. Figure 2.1 shows the whole process of the downward liquidity spiral as well as a reverse process that takes place during the boom periods. During this reverse process the prices of the assets are fuelled by a high demand, which is a consequence of high asset prices and strong balance sheets. Overall optimism also leads to a decrease of margins.

Figure 2.1: Downward and upward liquidity spirals



Source: Author based on Brunnermeier et al (2009) and Brunnermeier and Pedersen (2009)

It is worth mentioning that the whole process of the liquidity spiral described above does not assume any mutual exposures between the financial institutions. Instead, main precondition for the process to take place is common exposure of financial institutions in the system to same type of assets with prices moving together. From this we can see how the cross-sectional and the time dimensions are connected together.

2.2 Relation to monetary policy

Mainly in the recent years central banks have acquired new tools into their portfolio allowing them to fight risks that endanger the financial system as a whole. As these tools of the macroprudential policy are shaped into a concrete form and anchored into national legislations, questions arise what will be the impact of these changes in competences and policies of central banks on the conduct of the monetary policy.

Although monetary policy in form of inflation targeting has produced positive results in terms of price stability, this policy setup is now exposed to intense discussions by both academics and policymakers. Frictions in financial system may lead to significant welfare losses and a question arises whether the price stability alone is the optimal target given the impact of the monetary policy on a creation of credit and other attributes of the economy related to the financial stability. And even if the tradeoff between well-anchored inflation expectations and possible use of monetary policy to fight instability in the financial system is too high and inflation targeting is found worth preserving in its current form, issues might arise from mutual interaction with newly introduced instruments of the macroprudential policy.

Various channels have been identified through which changes in policy interest rates impact the financial stability. Moreover, character of the influence is highly diverse and the result depends on various factors, both time-varying and country-specific, like overall position of the economy within a financial cycle, situation of individual sectors of the economy, institutional setup, openness of the economy and others. Let us mention some examples of these externalities. First, increase in policy interest rates can negatively influence balance sheet positions, making credit too expensive for some agents and increasing likelihood that they would default. Second, margins of financial intermediaries can be reduced due to an increase in the interest rates, forcing them to expose themselves to a higher risk. Third, capital inflows might induce excessive borrowing in a foreign currency, making the system vulnerable in a situation of a sudden depreciation. On the other hand, a decrease in the policy interest rates can lead to an exorbitant expansion of credit, underestimation of risk and creation of price bubbles, beside others.

Direction of the influence between the two policies can be also reverse as various macroprudential policy measures can affect transmission channels of the monetary policy into the real economy. For example, loan-to-value and debt-to-income caps can reduce interest rate elasticity of residential investments. Dynamic capital requirements can lower the likelihood that monetary policy hits its lower bound and they can keep the space for standard monetary policy measures.

Other questions arise in relation to possible use of monetary policy for macroprudential purposes within a currency and political union like the Eurozone. Beside possible tradeoffs between the price stability goal and the financial stability goal, the monetary policy might face dilemmas due to heterogeneity of the union's members. Asymmetric impact of the policy conduct might result from different positions of the member states within a financial cycle. For example, while one member state finds itself in an expansion phase of the cycle and tightening monetary policy would be suitable to suppress an accumulation of risks due to an excessive credit growth, accommodative monetary policy might be suitable for another member's economy with weak balance sheet positions of its agents.

2.3 Systemic risk measurement

2.3.1 General framework

Suitable framework of systemic risk measurement should be introduced by policymakers when macroprudential policy comes into operation. Complexity of the problem however leads to difficulties with modeling of the systemic risk. Borio and Drehmann (2009) consider a structural model of the economy that would ideally fulfil several goals. First, it would allow for the ex post identification of the financial instability by decomposition the past into exogenous "shocks" and endogenous response of the system. Second, ex ante probability distribution of possible outcomes, and hence of financial distress, would be generated. This would be accomplished though shock simulation or though generation of scenarios. Third, such model would help to design appropriate policy by indicating behavior of the system under different configurations. This ideal model is however difficult to reach. Compared for example to monetary policy, there is lack of satisfactory models linking balance sheets in the financial sector to macroeconomic variables. Policy instruments usable for financial stability are rarely included, and if so, it is the interest rate with primary function to achieve price stability.

From the point of view of the ongoing discussion, available measurement tools might be classified along following three dimensions. First, to what extent is the certain tool forward-looking so it can provide leading measures of the financial distress? Second, to what extent behavioral interactions that underline episodes of the financial distress are taken into account? These interactions play an important role in episodes of the financial distress and their non-inclusion can easily underestimate the likelihood of the financial distress. Third, a model that "tells a story" might earn higher confidence when producing output and improve effectiveness in communicating the risks.

Classification of tools used to measure systemic risk is rather ambiguous as shown for example in Borio and Drehmann (2009). They describe several groups of approaches, but these groups are not mutually exclusive as they capture quite different elements of the analysis. These groups are: (i) indicators of financial distress based on balance sheet and market indicators, (ii) early warning indicators, (iii) indicators based on Vector Autoregression Models (VARs) and (iv) macro stress tests. We are going to briefly discuss the first two groups.

2.3.2 Indicators of financial distress based on balance sheet and market indicators

The first group of the indicators, those based on balance sheet items, is the simplest set of tools that can be used to measure financial stability. Their main shortcoming is that they are derived from accounting values and therefore they do not provide much forward-looking information. The information they provide is backward-looking, or, at best, the contemporaneous one. Other issue related to their usage for purpose of macroprudential policy analysis is that they are related to a single institution. They are therefore useful rather as inputs for further, more sophisticated analysis (Borio and Drehmann 2009)

Most of the Financial Soundness Indicators (FSI), created by the International Monetary Fund, is part of this group. They include both indicators for the banking sector and indicators characterizing other financial and non-financial institutions, households, market liquidity and the real estate market. Examples of these indicators are loan loss provisions, non-performing loans or levels of capitalization (IMF 2012 - *web*).

Ratings constitute more advanced group of the indicators as they incorporate more information, e.g. some confidential information provided to rating agencies. They might be designed as forward-looking, but in practice tend to incorporate new information only with a lag (Galati and Moessner 2011). Other limitations also have to be taken into account. To a great extent they relate to individual institutions taken in isolation, omitting possible mutual interactions and common exposures, which might influence outcome of the institution to a great extent during periods of financial distress. They also tend to filter out the influence of the business cycle over time, providing rather idiosyncratic determinants of the default (Borio and Drehmann 2009).

Indicators based on the market information constitute the other group. Advantage of this approach is that market information is often publically available which facilitates construction of these indicators. On the other hand, this type of information is an aggregation of beliefs of individual market participants which are often subject to influence of herding behavior. Such type of indices produces rather measure of actual distress than accumulated systemic risk. Example of such indicator is Financial Stress Index introduced by Illing and Liu (2006). They incorporate bid-offer spread on 90-day Government of Canada treasury bills as proxy for liquidity risk in debt markets, the covered Canada–U.S. 90-day treasury bill spread is used to proxy uncertainty in the domestic government debt market and exchange rate volatility, beside other variables. Other example is “price of insurance against systemic distress” developed by Tarashev and Zhu (2008), based on banks’ CDS spreads.

Market information is also used in measures based on Contingent Claim Analysis (CCA), such as Distance to distress or Probability of default. Advantages and shortcomings of this approach are discussed in the following chapters.

2.3.3 Early Warning Systems

Early Warning Systems (EWS), or Early Warning Indicators, are designed to produce forward-looking signals of possible upcoming financial distress. In most cases they connect set of variables to zero/one variable of financial distress episode and try to select those variables that have the best predictive power. Alessi and Detken (2009) use data for OECD countries and find that global measures of liquidity are among the best performing indicators. Moreover, they find that financial variables contain more information for predicting the price booms than tested real indicators, and that the global indicators perform better than the domestic ones. The results strongly depend on relative preference of missed crises and false signals. Babecký et al. (2012) use a two-model system to identify the early warning indicators of both the timing of crisis occurrence and the intensity of the impact of crises on the economy. Using dataset for the EU and the OECD countries they identify rising house prices, external debt and some global variables as the indicators that perform well in predicting the crises.

Rose and Spiegel (2009) use a continuous form of EWSs to connect the intensity of the impact of 2008 financial crisis with possible causes of the crisis using countries cross-section. However, they fail to identify any indicator significant over the whole cross-section, which leaves them skeptical about accuracy of the early warning systems for the potential crises. Possible shortcomings in the methodology mentioned in their article might however impact their results. Gosh at al (2009) point to diverse character of triggering event of a crisis (political turmoil, terms of trade shock, market collapse etc.), which has fundamental implication for what can EWSs actually accomplish. Because the triggering event is unlikely to be able to forecast, more suitable goal for EWS might be to identify underlying vulnerabilities that make crises possible to unwind. In other words, “*there is no guarantee that the past relationship will hold in the future*” (Borio and Drehmann 2009).

3 The data and the inter-sector credit exposure

3.1 Dataset structure

This chapter describes the process of building the dataset that is used in later chapters for construction of risk-adjusted balance sheets, calculation of CCA indicators and simulation of shock transmission in the economy. A dataset form needed for separate analyses differ, for example to run the simulations we need to have data in form of matrices of bilateral exposures. Moreover, one matrix for the junior claims and one matrix for the senior claims in each period is needed. Although a construction of the risk-based CCA balance sheets on empirical data uses aggregation over each sector and does not require information about exposure counterparties, complete dataset with information about the counterparties is useful for a description of the linkages within the economy and it is needed as a starting point for the shock transmission simulations. Quarterly data are used, starting from 1Q 2007 and ending at 2Q 2012, a period covering twenty-two quarters. The economy is broken down into nineteen individual sectors (or institutions) as described later, therefore the matrices of bilateral exposures have 19x19 dimension.

Each column in a matrix of bilateral exposures represents a *creditor* sector (a holder of a claim) and each row represents a *debtor* sector (a sector against which the claim is held). Because each of the nineteen sectors is included in the matrices both on the creditor and the debtor side, the dataset fully describes sectors' balance sheets in terms of the junior and the senior claims on both the assets and the liabilities side. General case is shown in equation 3.1.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1N} \\ \vdots & \ddots & \vdots & & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{iN} \\ \vdots & & \vdots & \ddots & \vdots \\ x_{N1} & \cdots & x_{Nj} & \cdots & x_{NN} \end{bmatrix} \tag{3.1}$$

where

$$\sum_{i=1}^{N} x_{ij} = a_j \qquad\qquad \sum_{j=1}^{N} x_{ij} = l_i$$

Bilateral exposures matrix $\boldsymbol{X}$ is composed from typical elements x_{ij} which represent exposure of sector *j* to sector *i*. Sum of the column elements therefore represents asset holdings a_j of sector *j* and sum of the row elements correspond to liabilities l_i of sector i.

There are two sources of data about the bilateral exposures used in this work. First, the quarterly financial accounts (QFA) statistics compiled by the Czech national bank captures financial linkages between sectors in the Czech economy (and between the rest of the world). The linkages are classified into different financial instruments and they are tracked over time. QFA provide a basic disaggregation of the economy into several sectors. See Section 3.2 for a detailed description. Second, in order to describe the economy in a more detail we employed also the data collected from banks and other financial market participants. Data from the second source have a form of balance sheets with a limited information about the counterparties of the financial instruments. For detailed information about the balance sheet data see Section 3.3.

Different structure of data from the two sources above give rise to a problem of connecting the two together. Because of the limited information about the counterparties in the banks' balance sheets data, matrix balancing methods were employed. These methods have been used for example in the input-output table construction (e.g. Lenzen at al., 1999) and also in modelling financial system networks and contagion, see Castrén and Kavonius (2009) for literature overview. Purpose of these methods is to obtain missing elements of a matrix by using all the available information. In former applications this information had a form of row and column sums. Algorithm RAS is an example that solves the problem (see Fofana et al., 2005). Later modifications of this algorithm introduce constrains in different forms. Not only row or column sums can be used, but also information about any subset of the matrix can be considered in calculations. We use the GRAS algorithm (Junius and Oosterhaven, 2002) that that solves the following problem:

$$G\,a = c \tag{3.2}$$

In the equation above matrix a represents a vectorized form of the matrix we need to calculate, i.e. $a = \{a_i\}_{i=1\ldots N^2}$. Matrix $G(N^2 x N_{\ C})$ contains coefficients linking N^2 variables to $N_{\ C}$ constraints. Values of these constraints are stored in vector c.

In our case there are $N^2 = 19^2 = 361$ variables in the matrix a and they are obtained from 181 conditions in case of senior claims matrix and 133 condition in case of junior claims matrix. Detailed description of these conditions is provided in the following parts along with information about sources of data.

Volatility of equity is modelled using the Prague stock exchange index for the NFC sector, volatility of 10Y Czech government bond is used for GOV, HOU and NPI and the rest is modelled using corresponding sub-indeces of European STOXX index.

3.2 Quarterly financial accounts

The quarterly financial accounts statistics (QFA), compiled by the Czech National Bank, captures financial relations within the economy. The whole economy is broken down into sectors and instruments and given the character of these instruments the whole system is closed, i.e. each item recorded on the assets-side of a sector's balance sheet can be matched with a corresponding record on the liability-side of the counterparty's balance sheet.

Methodology of the QFA is based on the ESA 95 (European System of Accounts) directive. Due to compliance with the directive, which impose statistical standards and classifications, the QFA is consistent with the overall system of national accounts and allows for international comparability. In accordance with the ESA 95 methodology, the records in the QFA are included at their market price. If only the nominal price is available, the market price is estimated. The transaction are recorded on the unconsolidated bases which means that transaction that take place within a sector are included in the data. Classification into sectors is done on several levels. At the highest level, territorial classification divide the sectors into residents and non-residents. At the second level, the residents are then divided into five sectors. The financial corporations and general government sectors are further divided into subsectors allowing for more detailed description. Our analysis use the financial corporations division and neglects the general government division. Table 3.1 captures the classification structure together with the ESA 95 codes and an abbreviation used throughout our analysis.

One enrichment of the analysis compared to Plašil and Kubicová (2012) introduced in this work is disaggregation of the *Other monetary financial institutions* subsector (S.122) into ten separate parts and therefore the analysis is made on the more detailed dataset. Detailed description of this disaggregation is provided in Section 3.3.

Classification of the transactions into the instruments reflects their liquidity and legal basis. All the instruments are included in both the assets and the liability sides given the fact that all the financial transactions have two counterparties. The only exception is monetary gold and special drawing rights, which have no counterpart liabilities in the system of resident sectors. However, these instruments are omitted in our analysis. Similarly to the sector classification, the instrument classification is done on several levels. Only the highest level of the classification is used in our analysis. Table 3.2 provides classification of instruments on this level together with ESA 95 codes.

Table 3.1: Sectorial classification of the quarterly financial accounts

	Sector	**Code**	**Abbr.**
	National economy, total (Residents)	(S.1)	
	Non-financial corporations	(S.11)	NFC
	Financial corporations	(S.12)	
	Central bank	(S.121)	CB
(disaggregated)	Other monetary financial institutions	(S.122)	OMFI
	Other financial intermediaries	(S.123)	OFI
	Financial auxiliaries	(S.124)	FA
	Insurance corporations and pension funds	(S.125)	INS
	General government	(S.13)	GOV
(not used)	*Central government*	*(S.1311)*	
(not used)	*State government*	*(S.1312)*	
(not used)	*Local government*	*(S.1313)*	
(not used)	*Social security funds*	*(S.1314)*	
	Households	(S.14)	HOU
	Non-profit institutions serving households	(S.15)	NPI
	Non-residents	(S.2)	ROW

Source: Author, CNB quarterly financial accounts methodology (CNB, undated-b)

Unlike the sectorial classification the ESA 95 instrument classification is not preserved throughout the whole analysis. We only provide a graphical analysis of sectors' balance sheet structure in Appendix 1. Construction of the risk-based balance sheets using the CCA model is carried out using only data on senior and junior claims. Therefore an aggregation is done and only two categories are preserved: the debt and the equity, which are used later in a construction of the junior and senior claims. Whereas the equity corresponds to the *Shares and other equity* instrument (AF.5), the debt is obtained as a sum of the rest, i.e. (AF.2), (AF.3), (AF.4), (AF.6) and (AF.7). However, as some sectors do not issue equity, notably HOU and GOV, junior claims are instead defined in line with previous literature (Plašil and Kubicová,

2012) as net financial wealth plus equity, where the net financial wealth is the difference between the sector's financial assets and financial liabilities. Only for the disaggregated OMFI sector we consider junior claims to be equal to equity because the other definition above results in negative equity for some sectors.

Table 3.2: Instruments classification in quarterly financial accounts statistics

	Instrument	Code	Aggregation category
(not used)	*Monetary gold and SDRs*	*(AF.1)*	
	Currency and deposits	(AF.2)	D
	Securities other than shares	(AF.3)	D
	Loans	(AF.4)	D
	Shares and other equity	(AF.5)	E
	Insurance technical reserves	(AF.6)	D
	Other accounts receivable/payable	(AF.7)	D

Source: Author, CNB quarterly financial accounts methodology (CNB, undated)

3.3 Balance sheet data

Detailed balance-sheet data on the Czech financial system allowed us to disaggregate the *Other monetary financial institutions* subsector (S.122). The motivation behind this step is to better describe the group of economic agents that constitutes the largest block in the QFA statistics in terms financial assets[2] and to capture possible differences in exposures formation and capital structure which might lead to differences in risk profiles.

In order to accomplish this task we utilized data collected by the Czech National Bank. The S.122 subsector is disaggregated into ten groups/institutions (see Table 3.3) from which we obtained data about eight of them. Data for the remaining two sectors are calculated using the GRAS algorithm. As discussed in Section 3.1 this algorithm can exploit limited information from the balance sheets to calculate missing information about counterparties of financial linkages. For each of the eight sectors we imposed conditions using value of debt against (i) central banks, (ii) credit

[2] By the 2Q 2012 the financial assets of the S.122 subsector were CZK 4.7 trillion. The second largest block were non-residents and the third largest were households, with financial assets equal to CZK 4.5 trillion and CZK 3.8 trillion respectively.

institutions, (iii) central government, (iv) non-residents and (iv) others both on the liabilities side and on the assets side. For the junior claims only the information about exposure to residents and non-residents was available.

Table 3.3: Overview of the OMFI sector disaggregation

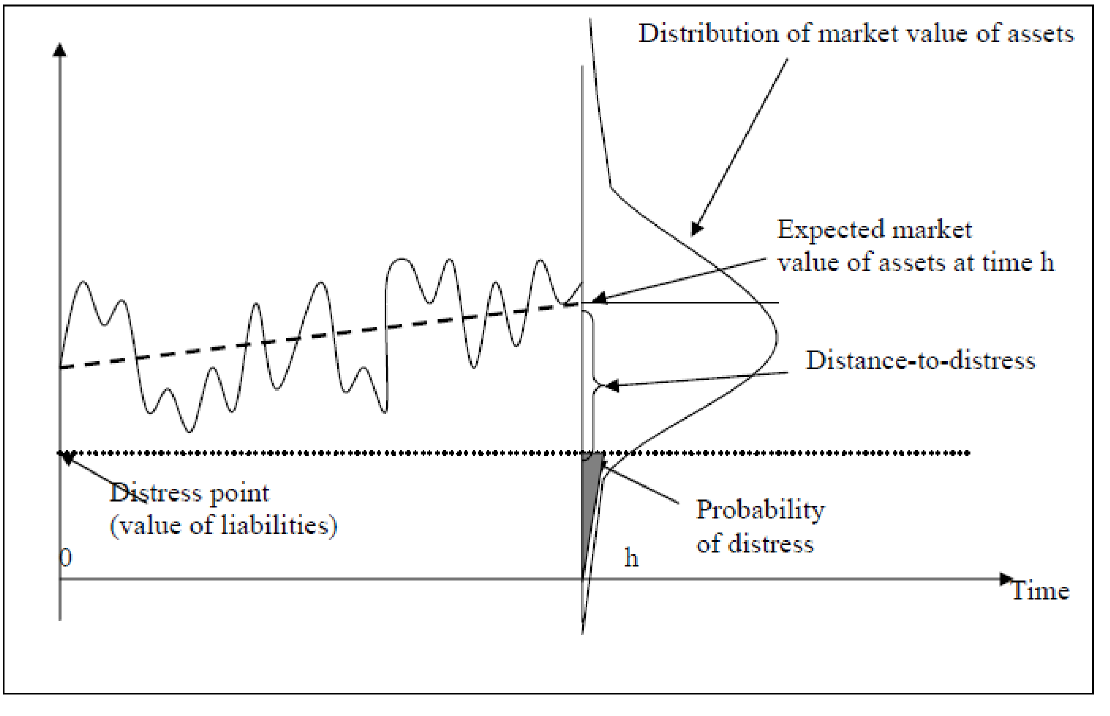
Block	Abbrev.	Source
Česká spořitelna	LB	Balance sheet data
Československá obchodní banka		Balance sheet data
Komerční banka		Balance sheet data
UniCredit Bank		Balance sheet data
Middle scale banks	MB	Balance sheet data
Small scale banks	SB	Balance sheet data
Foreign banks branches	FB	Balance sheet data
Building societies	BS	Balance sheet data
Money market funds	MMF	Calculation
Credit unions	CU	Calculation

4 Contingent claims analysis

4.1 Theoretical model

We follow Castrén and Kavonius (2009) in explanation of the model. Figure 4.1 illustrates intuition behind CCA. Vertical line shows firm's assets and liabilities against time on the horizontal axis. Nominal value of debt is represented by the dotted line and it is repaid at the time of maturity *h*. This value is fixed over the whole horizon. In contrast to the debt, the nominal value of the assets fluctuates as it is assumed to follow a stochastic process with the asset drift represented by the dashed line. Because of this property, assets' value is uncertain at the moment of maturity, with a whole distribution of possible outcomes. In order to fulfill its obligations, value of the firm's assets has to be above the nominal value of the debt at the time of maturity. If not, value of firm's equity is wiped out and the firm defaults on its debt. Distance between expected value of assets and distress point is referred as *distance to distress* (DD). Probability that the firm will default on its debt is represented by the grey area and this measure is referred as *probability of distress*.

Figure 4.1: Principle of the CCA



Source: Castrén and Kavonius (2009)

The following three factors affect the probability that value of the assets will be below the distress point:

- Share of assets debt on assets, which changes the vertical position of the distress point relative to value of assets
- Slope of the asset drift, affecting a mean value of the distribution over time
- Volatility of the assets which corresponds to amplitude of fluctuation of asset value, affecting variance of the distribution

In order to express the model computationally, a model developed by Merton (1973) is used. In his work he showed how capital structure of a company can be characterized using options leading to so-called put-call parity. Following notation used in Castrén and Kavonius (2009) let us assume that market value of assets *A* equals market value of senior claims D (debt) and junior claims *J* (equity and net financial wealth).

$$A = J + D = J + B - P \quad (4.1)$$

Because a probability exists that debt will not be repaid in its full amount, book value of debt *B* might be different from its market value *D* which might be lower by value of term *P*. This term represents the expected loss to debt creditors.

Explanation is based on put-call parity (Hull 2009), as value of junior claims *J* can be represented by call option on firms' assets with strike price equal to nominal value of debt. At the time of debt maturity equity holders decide whether to pay the debt back or not. They will do so if the market value of assets exceeds the nominal value of debt, because only then they will end up with positive equity after paying the debt. If the market value of assets does not excess nominal value of debt, option is not exercised and the firm defaults on its obligations. Given this, creditors of the debt will be regained either the full value of debt *D* if market value of assets exceeds the debt, or they will be repaid to the amount of assets' value. This corresponds to put option *P* on firm's assets with strike price equal to nominal value of debt.

Under assumptions given by the Black and Scholes (1973) model, value of sector's assets can be modeled as a geometric Brownian motion process, which yields following solution for implicit put option:

$$P = Be^{-rt}\big(N(-d_2)\big) - A_0\big(N(-d_1)\big) \quad (4.2)$$

$$= \left[-\frac{N(-d_1)}{N(-d_2)}A + Be^{-rt}\right]N(-d_2)$$

where

$$d_2 = \frac{ln\left(\frac{A_0}{B}\right) + \left(\mu - \frac{\sigma_A^2}{2}\right)t}{\sigma_A\sqrt{t}} \quad (4.3)$$

and

$$d_1 = d_2 + \sigma_A\sqrt{t} \quad (4.4)$$

Term d_2 corresponds to distance to distress and $N(-d_2)$ is therefore probability of default. In the last three equations, A_0 stands for the assets. For the purpose of simulation A_0 represents value of assets at the beginning of the simulation and this value is used throughout the rest of simulation. A_0/B is therefore the inverse of a leverage ratio. σ_A represents assets' volatility and *t* is time to maturity. $N(d)$ is the cumulative standardized normal distribution function. μ is the expected rate of growth of assets and it can be derived from *r* representing the risk-free interest rate using the following formula.

$$\mu = r + \lambda\sigma_A \quad (4.5)$$

Junior claims corresponding to the call option can be expressed in the following form.

$$J = A_0N(d_1) + Be^{-rt}N(d_2) \quad (4.6)$$

Finally, to obtain the solution, the volatility of assets is calculated from the volatility of junior claim using relationship

$$\sigma_J = \frac{N(d_1)A}{J}\sigma_A \quad (4.7)$$

Solving set of equations (4.6) and (4.7) yields solution values of *A* and σ_A.

Because d_2 is one of the key measures obtained from the analysis, Castrén and Kavonius (2009) analyze more closely its comparative statics vis-à-vis leverage *A/B* and assets volatility σ_A.

$$\frac{\partial d_2}{\partial \frac{A}{B}} > 0 \qquad \frac{\partial d_2}{\partial \sigma_A} < 0$$

$$\frac{\partial^2 d_2}{\partial^2 \frac{A}{B}} > 0 \qquad \frac{\partial^2 d_2}{\partial^2 \sigma_A} > 0$$

$$\frac{\partial^2 d_2}{\partial \frac{A}{B} \partial \sigma_A} > 0 \qquad \frac{\partial^2 d_2}{\partial \sigma_A \partial \frac{A}{B}} < 0$$

The first line provides the results that were already mentioned above. DD is decreasing both in the leverage and the assets' volatility as both the measures have a negative impact on the credit risk of the company. Based on the second row we can see that the model is nonlinear. Rate of decrease of DD is accelerating both with increasing leverage and volatility of assets.

4.2 Estimation of the sector-level CCA Outputs

4.2.1 Leverage

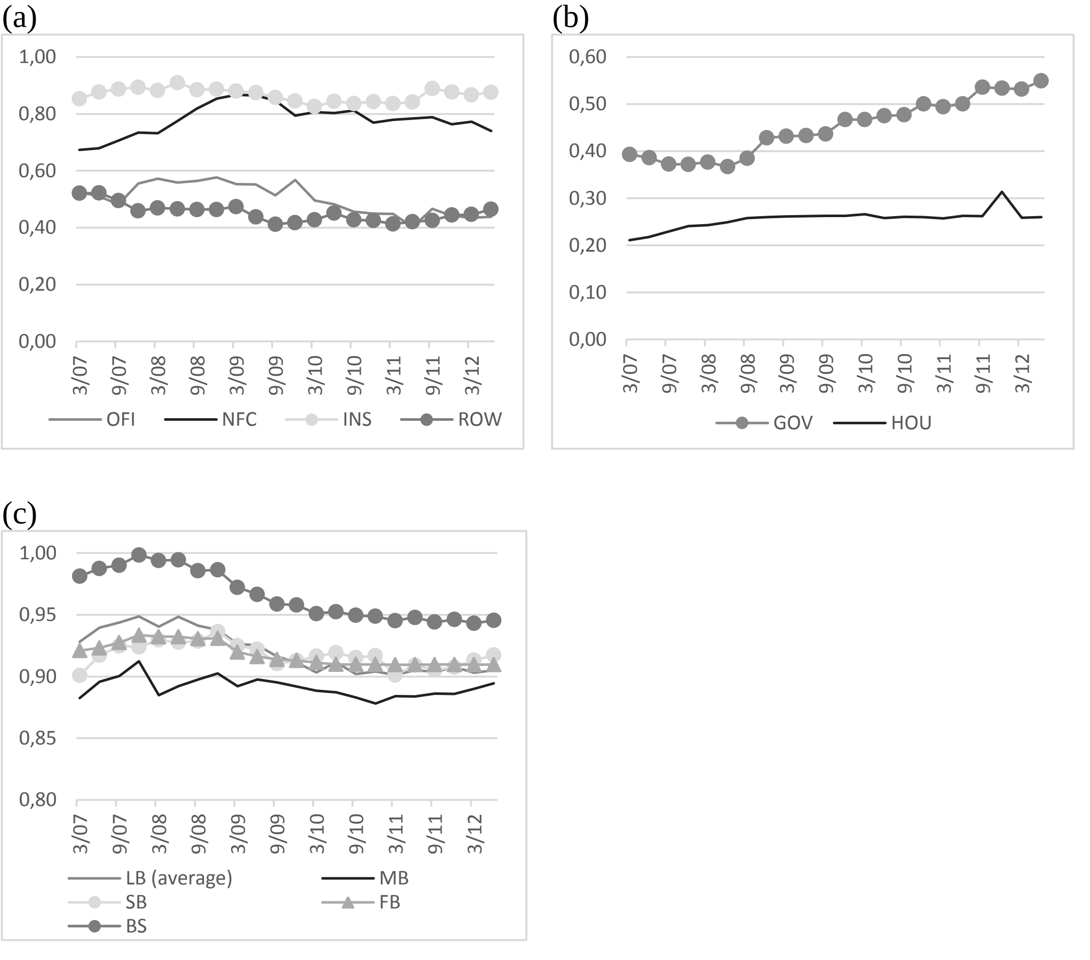
One of the direct outputs of the model in the market value of the assets. However, as the absolute value of assets is not comparable between sectors, former studies have discussed leverage defined as

$$leverage = {}^{B}\!/_{A_0}$$

where B refer to nominal value of debt (the distress barrier) and A_0 is value of risk-based assets. Figure 4.2 depicts development of leverage for selected sectors. It is important to stress that the level of leverage is sensitive to an assumed value of the distress barrier. Section 4.2.5 is devoted to a sensitivity analysis of impact of changes in the distress barrier level on a level of the leverage.

Not surprisingly the most leveraged institutions are banks and building societies, which makes them vulnerable to shocks in the financial system as possible shock to asset prices might quickly deplete their equity pillow. On the other hand and in line with the previous results (Castrén and Kavonius, 2009, Silva, 2010) their leverage ratio is also relatively stable, indicating their flexibility in adapting their balance sheets to changes in market price of the assets by deleveraging in bad times and taking on more debt at good times. However, such flexibility is somewhat limited and delayed, which can be illustrated by the leverage of the banks going up at the beginning of the crisis at 2007 as the asset prices went down. The highest leverage can be observed in case of the building societies. Among other segments of the banking sector only middle-sized banks stand on the side with leverage somewhat lower than other groups of banks.

Figure 4.2: Risk-adjusted leverage of selected sectors



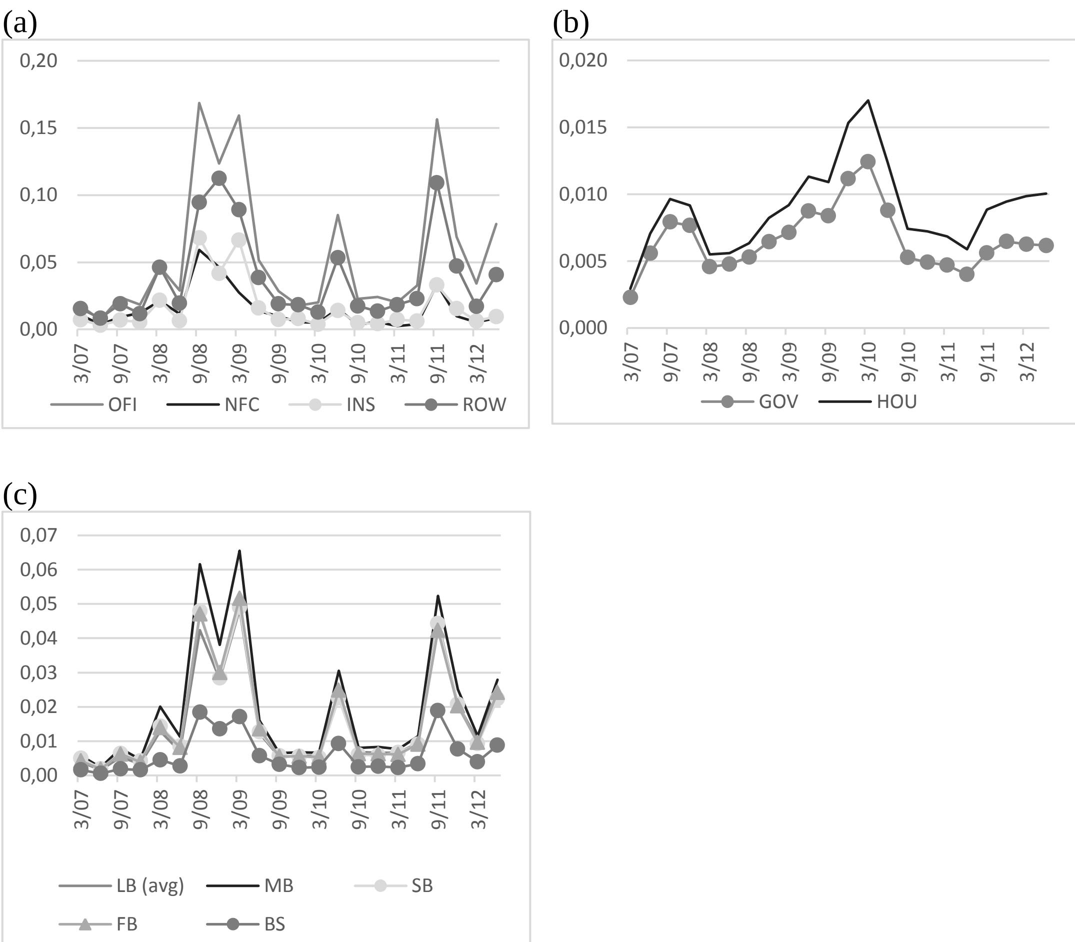
(in % of risk-adjusted assets)
Source: Author's calculations

Regarding the central government a gradual increase has been observed after the crisis, similar to findings to both the Portuguese data (Silva, 2010) and data for the whole Eurozone (Castrén and Kavonius, 2009). Such an increase in leverage is usually due to issuing of government bonds to finance increasing budget deficits. Leverage of the households is relatively low compared to other sectors given that they finance part of their assets by their net worth. For the non-financial corporations leverage peaked later compared to other sectors. Decrease in indebtedness of the NFC followed fast decrease in the asset prices only with some delay.

4.2.2 Volatility of assets

An increase in estimated asset volatility in 2008 is closely related to an increase in volatility of the junior claims based on foreign stock indices entering the model (Figure 4.3). Somewhat lower peak can be observed in 2010 when financial markets were first hit by concerns about indebtedness of the Eurozone's south wing. Raised levels of assets volatility since 2011 are connected to spreading of the sovereign debt crisis across the European economies and a slowdown of the economic activity in the European Union. Castrén and Kavonius (2009) give increase in leverage before 2007 to a connection with low level of assets volatility during that period. They state that risk management indicators such as VaR encourage risk-taking during periods when the volatility is low. As mentioned above choice of data to model the junior claims volatility might be questioned as cross-border transmission of shocks to the Czech financial system should be limited to some extent. On the other hand the PX50 index saw similar fluctuations during analyzed period.

Figure 4.3: Volatility of assets of selected sectors



Source: Author's calculations

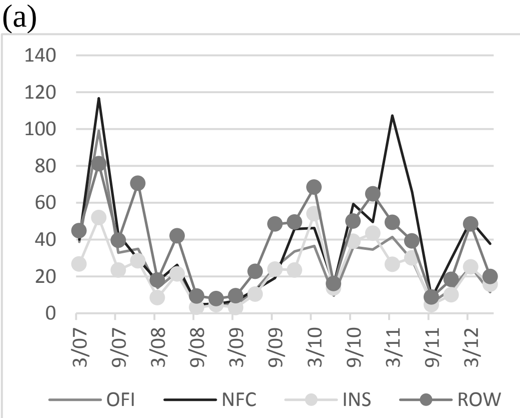
The highest asset volatility can be observed for the other financial intermediaries and the rest of the world, two sectors with rather low leverage and relatively high volatility of junior claims. In comparison to this result volatility among different groups of banks, i.e. sectors with high leverage, remained low. Among them the group of the middle-sized banks display the highest asset volatility. Households' and government's asset volatilities follow similar pattern as these sectors use same junior claim volatility as input and the level of their asset volatility remains low.

4.2.3 Distance to distress

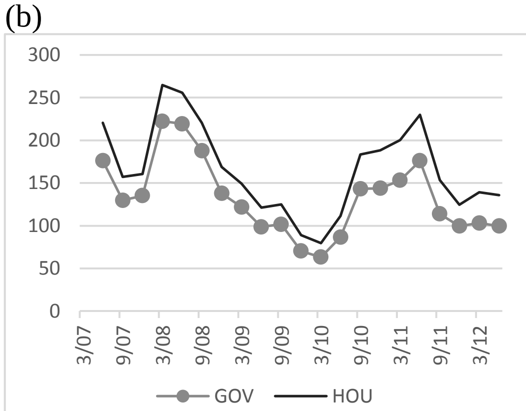
Shocks into junior claims volatility, changes in capital structure and in other input variables might decrease market price of the assets and bring the sector close to the distress barrier, as measured by the distance to distress (DD). Lower the DD is, higher the danger that the sector will run out of its equity and default on its debt obligations. Because the DD is measured in standard deviations it is comparable between different sectors.

Figure 4.4: Distance to distress (DD) of selected sectors

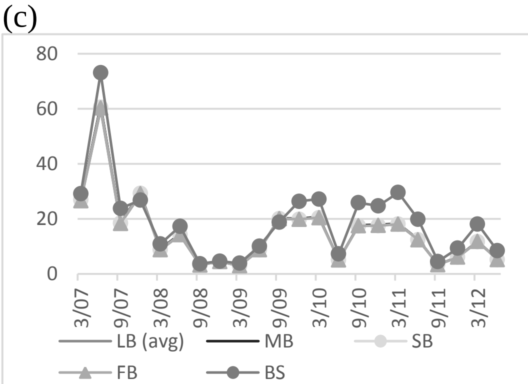
(a)



(b)



(c)



(In standard deviations)
Source: Author's calculations

We can observe high values of the DD at the beginning of the examined period with a significant drop at the end of 2008 (Figure 4.4). Highly leveraged institutions like the banks and the insurance and pension funds companies were hit the most, but also other sectors experienced a substantial drop, namely the OFI and the NFC. This is in line with findings of Castrén and Kavonius (2009) and Silva (2010) who observe the lowest DD for the other monetary financial intermediaries in the same period of time. Interestingly, beside the building societies, the DD of different groups of banks follows almost identical pattern. Households and general government display relatively high values even at the trough.

4.2.4 Distress barrier, a sensitivity analysis

In the previous sections we calculated CCA risk-based indicators assuming a certain level of debt as a distress barrier. Riskiness of the debt depends on a probability that the market value of the assets will be above this barrier. However, the level of the distress barrier was chosen somewhat arbitrary when we assumed that a sector gets under financial distress when its assets drop below sum of its short-term debt plus 75% of the long-term debt. On the one hand exclusion of a part of the long-term debt from the distress barrier makes sense as it is not necessary to repay it in the short-term horizon and its repayment can be eventually financed from other sources. On the other hand during system-wide events when liquidity dries up it might be very costly for a company perceived as risky to obtain any financing and the point of financial distress might be perceived by market participants at various levels.

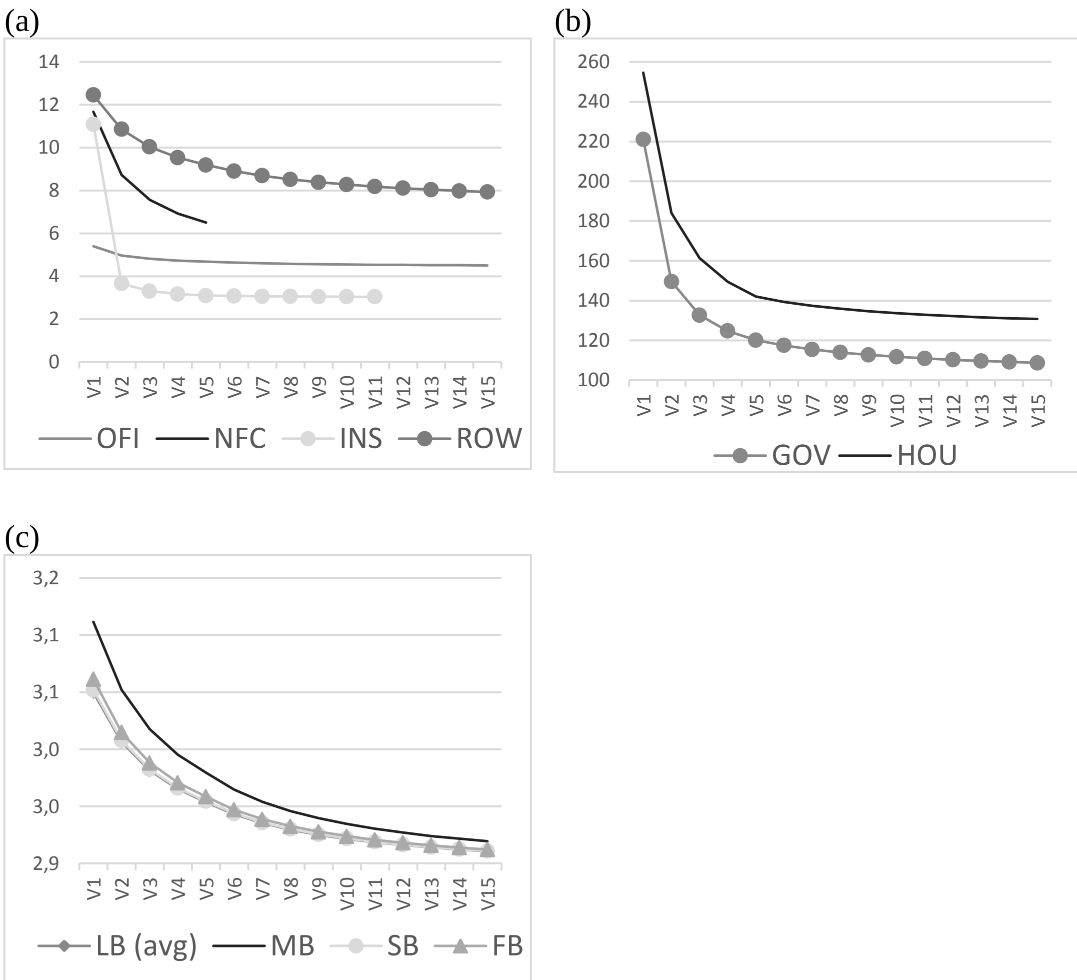
Table 4.1: Parameters for distress barrier sensitivity analysis

<table>
<tr><th></th><th>L1</th><th>L2</th><th>L3</th><th>L4</th><th>L5</th><th>L6</th><th>L7</th><th>L8</th><th>L9</th><th>L10</th><th>L11</th><th>L12</th><th>L13</th><th>L14</th><th>L15</th></tr>
<tr><td>Short-term debt</td><td>1</td><td>1</td><td>1</td><td>1</td><td rowspan="2">1</td><td rowspan="2">1.2</td><td rowspan="2">1.4</td><td rowspan="2">1.6</td><td rowspan="2">1.8</td><td rowspan="2">2</td><td rowspan="2">2.2</td><td rowspan="2">2.4</td><td rowspan="2">2.6</td><td rowspan="2">2.8</td><td rowspan="2">3</td></tr>
<tr><td>Long-term debt</td><td>0</td><td>0.25</td><td>0.5</td><td>0.75</td></tr>
</table>

We use a sensitivity analysis to model impact of different assumed levels of the distress barrier on the CCA risk-based indicators. Recalling Equation 4.3 this influence goes through two different channels. First, the level of $\boldsymbol{B}$ is adjusted directly to the assumed distress barrier level. Second, there is an influence through junior claims. Recall that for some sectors the level of junior claims is calculated as net financial wealth plus equity, where the net financial wealth is the difference between the sector’s financial assets and financial liabilities. In other words, the junior claims are equal to the equity plus the net financial inflow the company will receive in future. In line with discussion about the level of the distress barrier it is intuitive to include only part of these inflows as the company or sector can count on these funds only at certain horizon.

We considered different levels of the distress barrier and calculated the CCA indicators. There are 15 levels considered and for each of them the short-term and the long-term debt is multiplied by a coefficient shown in Table 4.1. The loosest level L1 considers only the short-term debt to be binding whereas the tightest condition L15 takes three times the whole debt. Benchmark level used in the previous analyses is L4.

Figure 4.5: Distance to distress of selected sectors under different sensitivity scenarios

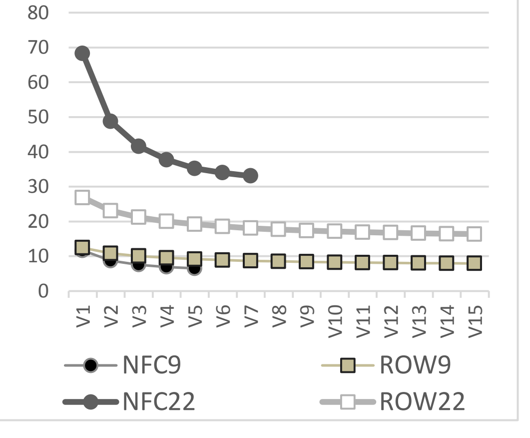


(in standard deviations)
Source: Author's calculations

Results of the analysis are displayed in Figure 4.5 which shows DD at 1Q 2009 for different levels of the distress barrier. Sectors for which the junior claims are calculated using the net financial wealth are shown. In line with expected results the distance to distress is decreasing in the level of distress barrier; with more tightening distress barrier the sectors are more likely get into the distress. Function is convex on the assumed domain, signalizing that the influence diminishes with rising distress barrier level. The INS and NFC sectors domain is limited due to the negative junior claims for higher values. Similar results are observed for banks for which the equity only was used to model the junior claims and therefore the CCA indicators are influenced only through the level of ***B*** (Figure 4.5).

To show sensitivity of the results to different values of the input variables, i.e. mainly the balance sheet data and the junior claims volatility, the same series is obtained for 2Q 2012. Figure 4.6 shows a comparison of the results for the two moments in time for the NFC and the ROW. The whole profile of DDs shifted more for the NFC owing mainly to the higher leverage of the NFC sector and the negative slope of the function increased too.

Figure 4.6: Distance to distress sensitivity analysis, comparison in time



(in standard deviations)
Source: Author’s calculations

5 Using CCA for simulations of shocks transmission

Better understanding transmission mechanisms of shock through the economy can be achieved by simulations. Within the model we developed we can use various scenarios to analyze shocks' impact on different sectors. Moreover, besides analyzing the resulting state of the economy after the variables' convergence (or a collapse of the system) we can check how the shock spreads, what is the situation of the sectors at each moment of the simulation and how each sector contribute to further shock propagation.

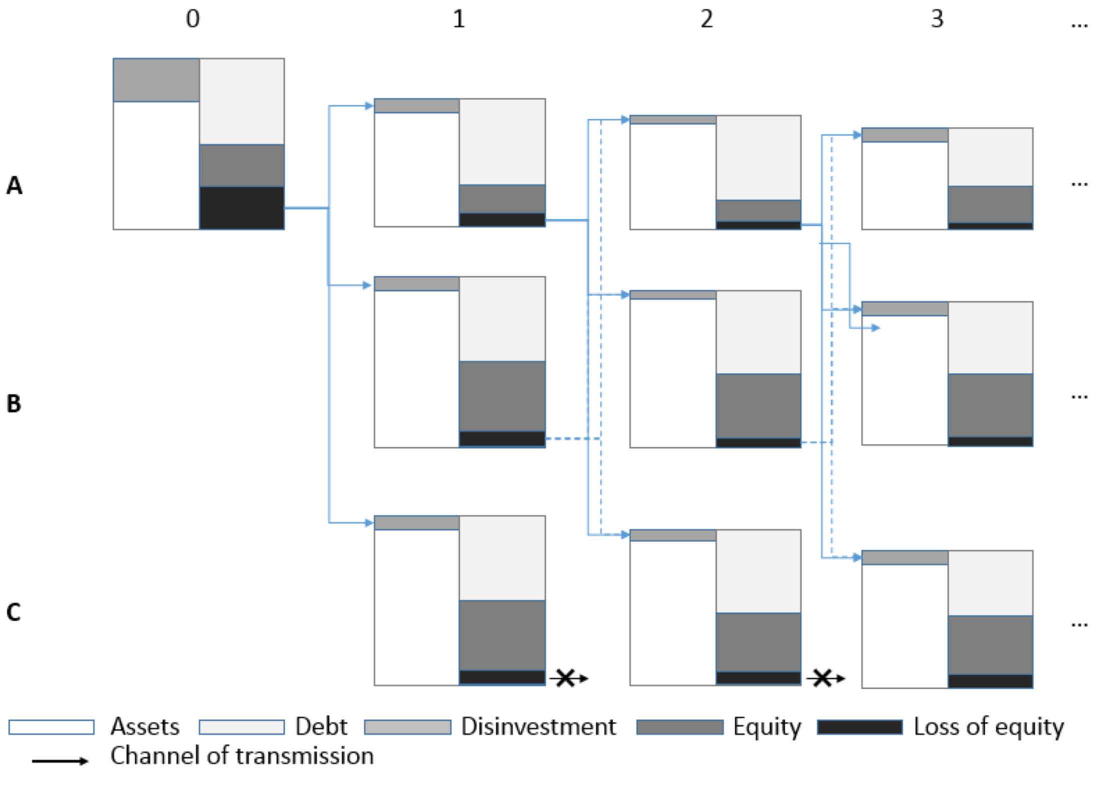
5.1 Transmission mechanism of a shock

Basic mechanism that allows for a transmission of shocks is through mutual exposures between economic agents' balance sheets. These exposures are in form of financial assets, where each of these assets acts also as a liability of the counterparty. In order to transmission mechanism to take place, balance sheet items have to be evaluated using mark-to-market accounting. Consequently losses caused by the shock will show up directly in accounts via its profit-and-loss account, affecting market price of shares. This form of the shock propagation is referred as *equity channel* of the shock transmission. Beside the equity channel, the shock can be propagated because of a market valuation of debt financing which can drive down value of the debt due to positive probability of default. This is called *risk channel*.

5.1.1 Equity channel

This mechanism of the equity channel is illustrated to more detail on Figure 5.1. Let us assume three sectors, denoted A, B and C. For illustrative purposes let us assume that both sectors A and B finance their assets partly by issued equity and that this equity is held by both remaining sectors and the issuing sector itself. This setup is possible if we consider each sector as an aggregation of individual economic agents who can interact one with each other. Regarding the sector C we assume that instead of equity he uses *net worth* to finance part of its assets. It implies that any losses recorded by the sector C are not passed to other sectors. As mentioned above we assume mark-to-market accounting implying that each sector has to deduct its losses through P&L account. Let us assume that a shock in form of an asset price decrease hits the sector A. This immediately leads via P&L account to a decrease in equity value of the sector A. Losses are realized by sectors B and C, leading to a decrease in the value of their assets because of their exposure to sector A. This leads immediately to decrease in value of their equity and the process goes to the next iteration. Note that magnitude of recorded losses diminish over time due to absorption of losses by the sector C. If we have assumed the sector C to issue equity instead of using its net worth the shock would stay in the system, losses would not diminish and the whole system would eventually collapse. Other possibility of the shock absorption is that some sectors may report earnings that would offset incurred losses. Although it would be probably meaningful to model such option we do not consider it in this model.

Figure 5.1: Equity channel of shock transmission mechanism

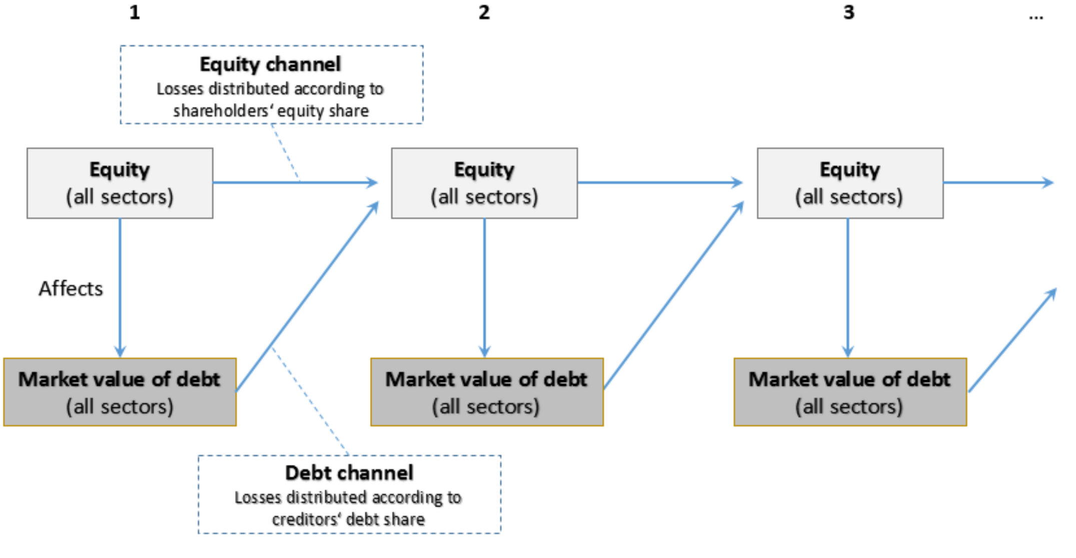


Source: Author based on Castrén and Kavonius (2009)

5.1.2 Risk channel

When a shock A resulting in a decrease of value of equity hits sector, probability of default of this sector increases. It is because the equity serves as a buffer against possible future changes in the asset value and the sector is therefore less likely to serve its obligations in case of future shocks. Assuming market pricing of the debt which it a cornerstone of the CCA model, any increase in probability of distress leads to a decrease in market value of the debt. Because any creditor sector needs to reflect the decrease in debt value in its balance sheet, value of bond holdings has to be decreased accordingly in the following period. As the value of bonds drops, equity value drops too, driving the market value of debt down according to the same principle. This process continues until the shock is not absorbed in similar way as in case of equity channel. Logic behind the risk channel is shown on Figure 5.2

Figure 5.2: Risk channel of the shock transmission mechanism



Source: Author based on Silva et al (2011)

In order to perform the simulations several more adjustments of the model have to be done. Until now the model has assumed two variables to be endogenous, A and σ_A, and several variables exogenous, determined outside the model, notably σ_J, J, B and r. This setup will be somewhat changed for the purpose of forward-looking simulations as σ_J will be endogenous. Also, fixed interest rate r will be assumed. Therefore only J and B will be exhibited to possible exogenous shocks.

For shocks to the *B*, these transmit directly to the balance sheet of the creditor. A possibility of shocks to *B* is not straightforward however. The reason is that if we take into consideration a single isolated economic subject, then as long as the value of assets is higher than the value of the debt, all obligations are fulfilled to the full extent. Otherwise the subject goes bankrupt because there is no possibility of not paying part of own obligations without going bankrupt. Nevertheless, possibility of a decrease in debt is given by sector aggregation and by assuming that a part of the aggregated subjects does not repay its debt and goes bankrupt while the other part stays unaffected.

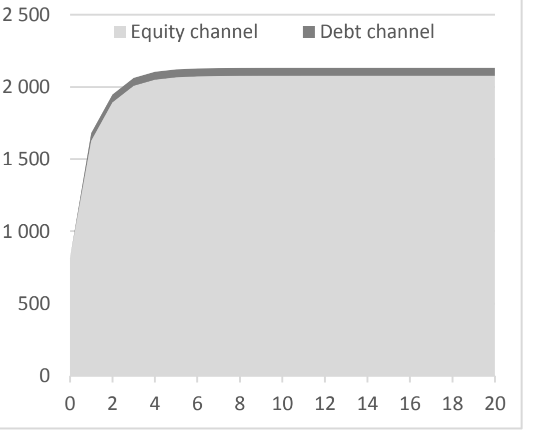
As mentioned in Section 5.1.1 there have to be some sectors which do not issue equity in order to make the shock diminish over time. This is achieved by the HOU, the GOV and the NPI sectors. Also, in line with Plašil and Kubicová (2012) we assume that only 1/5 of losses caused to the ROW return back to the system. It is because non-residents exposed to the domestic economy are different from those who are debtors of the economy. The value is chosen to correspond to the ratio of residents' shares abroad to non-residents' shares in the Czech economy.

Selection of shocks in our analysis is based on the previous literature. Castrén and Kavonius (2010) performs simulation of two shocks. The firs one assumes 20% drop in equity of non-financial corporation while the other one assumes 15% impairment of the loans extended to the households sectors resulting to losses to household sector's creditors. Silva (2010) considers somewhat stronger shock to the NFC and therefore assumes 30% decrease in their shares prices. This value corresponds to the 10^{th} percentile of normally distributed annual returns of the PSI-20 Portuguese stock index during a period from 1993 to 2010. Also Plašil and Kubicová (2012) simulate problems in the households sector.

5.2 Simulation of a shock to the non-financial corporations

We performed a simulation assuming a shock into the NFC sector in form 20% decrease in value of its equity. Such shock can take place as a result of a deterioration of a growth outlook and resulting decrease in valuation of the NFC's equity by the market. Despite some differences between the methodology used here and in other literature, notably the disaggregation of the OMFI sector, our result do not differ much from the previous literature. When running the simulation we took the equity and the debt from the last period of our dataset (i.e. 2Q 2012) as initial values. Beside the decrease in value of the NFC's equity, an important component of the simulated shock is a surge in the volatility of equity. Value of the volatility in 1Q 2009 was taken and increased by 10% to simulate a major tension in the system. Moreover, all the volatilities were scaled up to the largest one by a coefficient equal to $coef_i = (\sigma_{max}/\sigma_i)^{0.5},\ i = 1,2 \dots (number\ of\ sectors)$ due to rather low volatility for some sectors at that, particularly HOU and GOV.

Figure 5.3: Accumulated losses in the system after the NFC shock



(in CZK billions)
Source: Author's calculations

Accumulated losses in the system in time are shown in Figure 5.3. Total losses are disaggregated into the two channels described above, i.e. the equity channel and the risk channel. Vast majority of the total losses is attributable to the equity channel which constitutes around 97.5% of total accumulated losses after the convergence of the system. Such dominance of the equity channel is given by the fact that none of the sectors did get enough close to the distress barrier to record significant losses due to the risk channel. In fact, Table 5.3 shows a certain drop in the DD, but losses resulting from this drop are not high enough to ignite further accumulation of risk in the system.

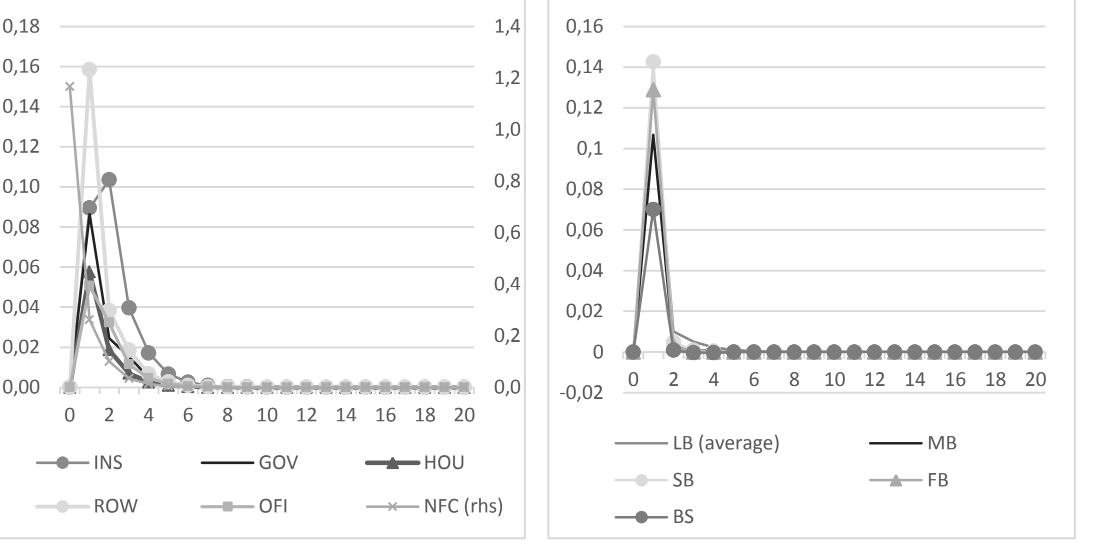
Table 5.1: Selected CCA indicators and their change during the NFC shock simulation

	Beginning		End		% change	
	DD	Assets	DD	Assets	DD	Assets
NFC	3.9	3 055	3.7	2 756	-5.9%	-9.8%
LB (avg)	2.3	582	2.3	575	-2.7%	-1.3%
MB	2.3	809	2.3	800	-2.9%	-1.2%
SB	2.3	87	2.2	86	-2.4%	-1.2%
FB	2.3	494	2.2	488	-2.6%	-1.2%
BS	2.7	419	2.6	417	-1.1%	-0.4%
CU	17.5	53	16.9	53	-3.3%	-1.0%
OFI	3.6	560	3.3	530	-8.5%	-5.4%
INS	2.4	692	2.3	679	-3.1%	-1.9%
GOV	15.8	3 378	15.3	3 177	-2.9%	-6.0%
HOU	20.1	3 560	19.5	3 318	-3.0%	-6.8%
ROW	4.8	4 278	4.5	3 789	-7.8%	-11.4%

(in CZK billions, in standard deviations)
Source: Author's calculations

Major losses are recorded by those sectors that hold the highest part of the NFC's equity, notably ROW, NFC itself, HOU and GOV (ordered from the highest to the lowest share of equity). Figure 5.4 displays these losses for selected sectors in each period of the simulation as a percentage of initial junior claims. The disaggregated OMFI sector is shown on the right panel. A peak recorded in the second period is related to write-offs of a risky debt and only a negligible part is related to the equity channel. It is caused by a structure of equity holdings between sectors; only a tiny fraction of NFC's equity is held by the financial system. Transmission of the shock is therefore possible only via other sectors. We can therefore state that the financial sector does neither strengthen the shock nor absorbs it (the non-absorption is given by the fact that no net worth is present in the OMFI's balance sheet).

Figure 5.4: Sector's losses in different iterations during the NFC shock

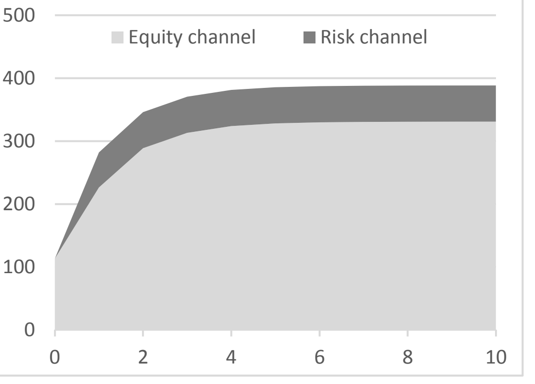


(in % of initial junior claims)
Source: Author's calculations

5.3 Simulation of a shock to the households sector

The second scenario we simulate is based on a situation when households get to problems with repayment of their debt. The form of the shock is again similar to the previous literature (Silva, 2010, Plašil and Kubicová, 2012), however our goal is to enrich the analysis of the shock transmission through the disaggregation of the OMFI sector. Assumptions used here are the same as in the NFC shock simulation with an exception of the shock itself. We do not assume an equity of a particular sector to be hit but instead problems originate in the households sector which record an unrecoverable loss of 10% of all loans granted to it. The shock is integrated into the model by writing-off this amount from the equity of the creditor sectors, notably the large banks (LB, 55.2% of volume of the shock), medium banks (MB, 17.9%) and building societies (BS, 12.2 %).

Figure 5.5: Accumulated losses in the system after the HOU shock



(in CZK billions)
Source: Author's calculations

Total accumulated losses in the system are shown in Figure 5.5. Compared to the effect of the NFC shock (Figure 5.3) losses from the debt channel constitute significantly larger part here, namely 14.8% (compared to 2.6%). The impact of the debt channel is larger even in absolute terms even though the size of the initial shock is only 13.9% of the NFC shock. There are two reasons behind such difference. The first is that major part of the losses from the debt channel arises purely from the non-zero probability of default at the initial state of the system and therefore it would be reported even if there have been no shock (this property is identical in for the NFC shock). The second reason is connected to a structure of the mutual exposures between the sectors which results in a transmission of the shock to sectors that lie closer to the distress barrier and are therefore prone to report losses when their equity tightens.

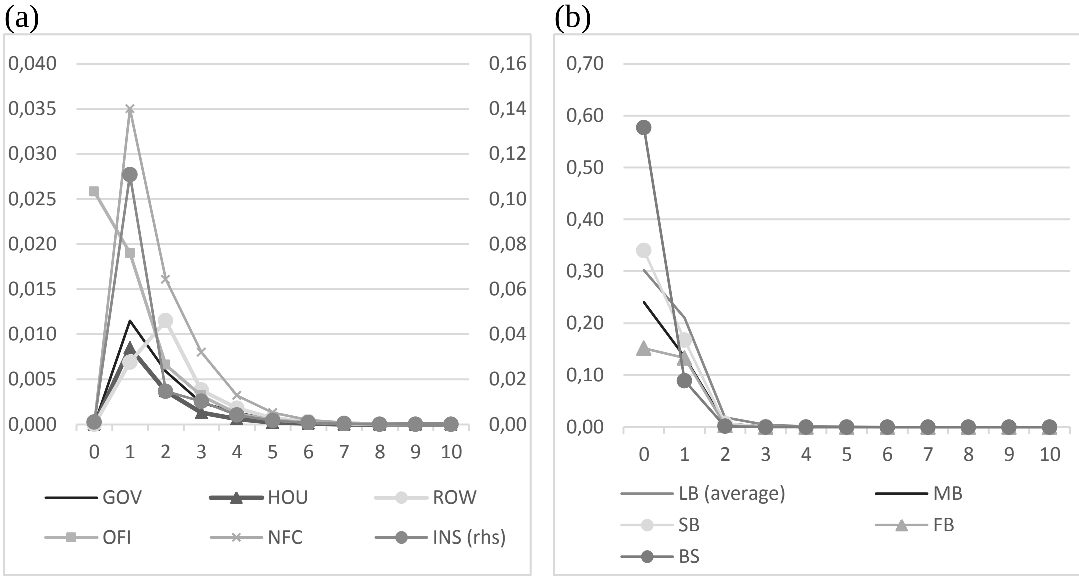
Table 5.2: Selected CCA indicators and their change during the NFC shock simulation

	Beginning		End		% change	
	DD	Assets	DD	Assets	DD	Assets
NFC	3.9	3 055	3.8	3 003	-2.6%	-1.7%
LB (avg)	2.3	582	2.2	555	-3.8%	-4.7%
MB	2.3	809	2.2	777	-3.8%	-3.9%
SB	2.3	87	2.2	83	-3.4%	-4.2%
FB	2.3	494	2.2	481	-3.0%	-2.6%
BS	2.7	419	2.6	403	-2.3%	-3.8%
CU	17.5	53	16.7	48	-4.4%	-10.7%
OFI	3.6	560	3.3	550	-7.2%	-1.7%
INS	2.4	692	2.3	687	-2.7%	-0.7%
GOV	15.8	3 378	15.7	3 342	-0.7%	-1.1%
HOU	20.1	3 560	19.9	3 498	-1.0%	-1.7%
ROW	4.8	4 278	4.7	4 217	-3.8%	-1.4%

(in CZK billions, in standard deviations)
Source: Author's calculations

Figure 5.6 shows how the shock is distributed between the individual sectors (period 0) and how the sectors are affected in subsequent rounds of the simulation. Equity channel in the subsequent rounds affects mainly sectors from on left panel of the figure. An interesting pattern is revealed in case of ROW sector which records the highest losses in the second iteration due to its exposure mainly to the NFC sector (which in turn records losses not earlier than in the first iteration).

Figure 5.6: Sector's losses in different iterations during the NFC shock



(in % of initial junior claims)
Source: Author's calculations

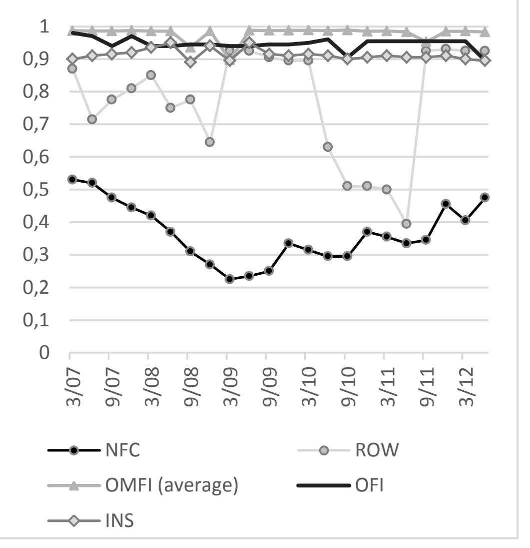
As mentioned, there is a significant impact on the highly leveraged OMFI sector during this simulation. Moreover, further simulations show that an increase of the initial unrecoverable loss originating from households by 1 percentage point would lead in the model to a distress situation of one of the banks. Although the model is very simplified reflection of the reality and it has certain limitations we would like to use this circumstance to stress a problem connected to aggregation of heterogeneous elements into a single group. The distress situations would not happen on such level of shock if the OMFI sector has been aggregated because the aggregation would lead to melt down of idiosyncratic risks and only characteristics common for the whole group would prevail. It is necessary to consider this feature when building a model that should capture such sector-specific (institution-specific) risks.

5.4 Stability frontier

The simulations performed above give an insight to how the economy looks like after it is hit by a shock. Prior assumptions are made about the shock, often based on empiric observations, and then a progress of the shock transmission and the final state of the economy is analyzed. As pointed by Silva et al. (2011) and implied by the model, while the marginal variation in total losses related to the equity channel decreases as the number of iterations increases, losses related to the risk channel do not behave in the same manner and non-monotonic behavior can take place. It is due to the fact that while the losses from the equity channel can either diminish with further iterations or stay constant if there is no sector that would absorb them, losses from the risk channel can suddenly start to grow as the risk accumulates and creditor sectors need to write-off debt considered as risky causing further losses and further write-offs in the system. Existence of such *tipping point* is shown for example by Allen and Gale (2000). Therefore when asking for robustness of the system, both the losses from the equity channel and possible accumulation of risk behind the tipping point need to be considered.

The *stability frontier* concept can be employed when looking for such size of a shock that would lead to a distress of at least one of the sectors or institutions (Silva et al. 2011). The stability frontier corresponds to a boundary that separates a subset of points in R_N characterizing shocks leading to a distress of at least one of the sectors from a subset of points characterizing shocks which do not lead to a distress in the system. Dimension N is a number of parameters defining the shock and it is not necessarily the number of sectors. For example, in a situation when the shock is defined by a certain decrease in the equity of one or more from total of K sectors and by certain volatility of junior claims for the same number of sectors, then $N = 2K$. Here we use the concept somewhat simplified and calculate an *individual stability frontier* for which $N=1$. In other words we are looking for such a shock resulting in a distress conditional on fixed value of other parameters. We consider two types of shock: the first one is the shock to the equity and the second one is the debt shock. Transmission mechanism of the debt shock into the balance sheets of other sectors is the same as described above in Section 5.3.

Figure 5.7: Individual stability frontiers implied by an equity shock



(in % of equity)
Source: author's calculations

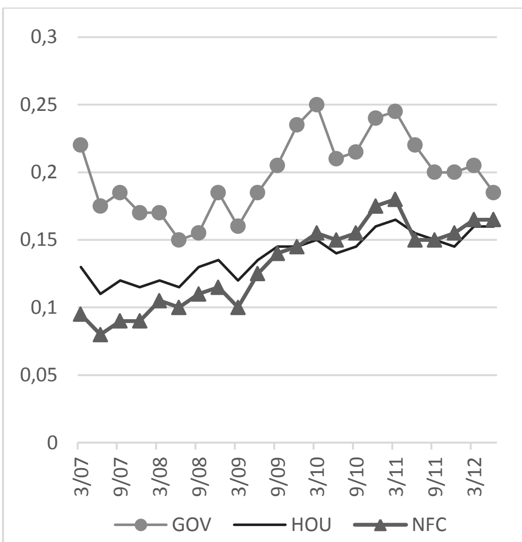
Development of the individual stability frontiers for selected sectors over time is shown in Figure 5.7. They are expressed as a percentage of each sector's equity. The lowest individual stability frontier is manifested by the NFC sector with a progress similar to the NFC's distance to distress. See Section 5.5 (discussion about different indicators) for a discussion about differences between the two indicators. Due structure of inter-sector relations the NFC sector is also the one that gets under distress. It is not a case of the ROW's individual stability frontier where different sectors at different moments of time indicate a distress situation when the stability frontier is crossed. Table 5.3 shows a sector that gets under distress first when the frontier is crossed. Contrary to rather volatile development in case of NFC and ROW, frontiers of INS, OFI and averaged subsectors belonging under OMFI are relatively high and stable and indicate only minor swings during turbulent periods.

Table 5.3: Overview of sectors that get under distress after the stability frontier is crossed

1Q 2007	INS
2Q 2007	INS
3Q 2007	INS
4Q 2007	INS
1Q 2008	INS
2Q 2008	INS
3Q 2008	INS
4Q 2008	FA
1Q 2009	ROW
2Q 2009	ROW
3Q 2009	FA
4Q 2009	FA
1Q 2010	FA
2Q 2010	FA
3Q 2010	FA
4Q 2010	FA
1Q 2011	FA
2Q 2011	FA
3Q 2011	ROW
4Q 2011	ROW
1Q 2012	ROW
2Q 2012	ROW

Figure 5.8 shows development of individual stability frontiers implied by debt shocks from selected sectors. The frontier is increasing over time for both the HOU and the NFC sectors indicating an increasing resilience of the system against shocks originating from debt non-repayment of these two sectors. In case of the government a decrease of the frontier can be observed after 2010.

Figure 5.8: Individual stability frontiers implied by a debt shock



(in % of debt)
Source: author's calculations

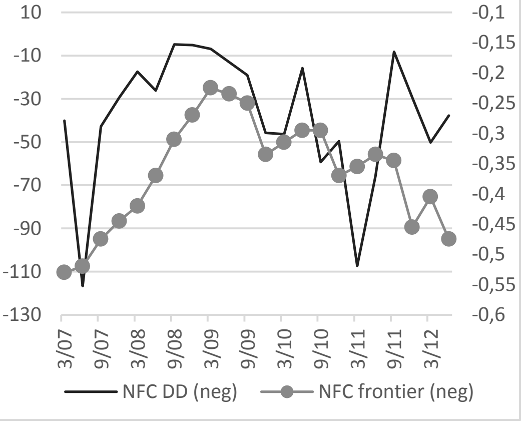
5.5 Systemic risk measurement, a comparison of indicators

As the CCA risk-based indicators obtained from the analysis can be used to assess the risk accumulated in the economy, it is meaningful to compare our results with others. Adam and Benecká (2013) develop a composite indicator of systemic stress (CISS) base on the information from five segments of the financial system—the money market, the bond market, the stock market, financial intermediaries, and the foreign exchange market. Each of these segments constitute a single sub-index and these are them mixed into the CISS. Metrics reflected in the indicator include volatilities of returns, spreads between two financial instruments, measures of potential loss (maximum cumulative loss) and idiosyncratic risk of an instrument. Systemic dimension of risk is captured by a method the indicator is constructed as its value is dependent on cross-correlations between individual ingredients of the index.

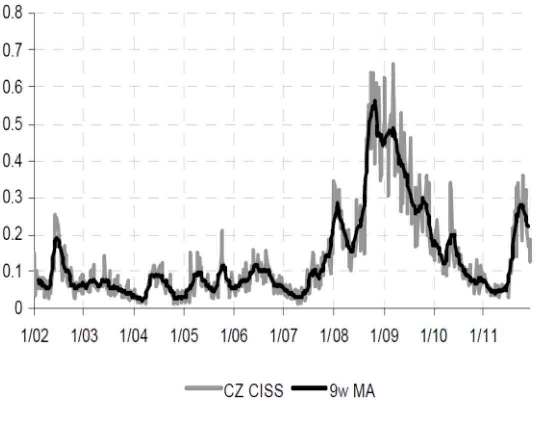
Figure 5.9 captures negative value of both the DD and individual stability frontier for the NFC (left panel) and also the CISS indicator (right panel). Whereas the CISS indicator reflects stress in the financial system, the (negative) DD reflect rather risks of default of a single sector due to deterioration of its balance sheet situation and an increase in its equity volatility and other exogenous variables of the model. (Negative) NFC's individual stability frontier is more systemic oriented as it reflects situation in the individual sector conditional on a situation in other sectors, as described in Section 5.4.

Figure 5.9: Comparison of indicators for systemic risk measurement

(a)



(b)



(in standard deviations; in negative % of equity; arbitrary units)
Source: Author's calculations, Adam and Benecká (2013)

Right half of the CISS indicator chart, i.e. after 1/2007, covers the period of our analysis. An increase can be observed for each of the indicators although a rough visual analysis hare has its limitations. Each of the three indicators uses its own metrics which can lead to disproportionalities of changes in indicators' levels and a potential correlation analysis should bear that in mind. Increase in the (negative) DD is due to an increase in shares volatility and due to an increase in leverage because of the drop of the asset prices. Rise in the CISS indicator is caused mainly by an increase in three of its components, namely the bond market sub-index, financial intermediaries sub-index and the foreign exchange market sub-index and cross-correlations between them. (Negative) NFC frontier captures some sources of complexity behind a hypothetical shock transmission. To conclude, various indicators can be used to capture the increase in systemic risk in relation to financial crisis and its spillovers in the Czech Republic.

6 Conclusion

In this work we analyze how sectors in the Czech economy are interconnected by mutual exposures and using the contingent claims analysis (CCA) model we attempted to quantify risks in the system that that are implied by the existence of these linkages.

The contingent claims analysis is designed to calculate credit risk of a company with a certain capital structure. Such risk exists because the assets are assumed to be marked-to-market and in a situation when their price drops below value of debt the company might not be able to meet its obligation and default. Shifting this concept to sector level and connecting it with a suitable model of linkages in the economy allows us to model systemic risk, shock transmission and assessment of resiliency of both individual sectors and the system as whole. Identification of systemic risk accumulation is important both for policymakers to possibly act against this accumulation and also for economic agents to hedge against this type of risks.

We started by summarizing framework for financial stability by its general description and definition of its key concepts. Its relation to monetary policy was briefly described as well as some existing models capturing systemic risk.

Next, indicators for individual sectors were calculated using empirical data from 2007 to 2012. In line with previous results majority of sectors indicated decrease in solvency during the turmoil in 2008 and 2009 and also during following sovereign debt crisis. For some sectors, notably the government sector, increase in risk indicators was somewhat delayed which is again in line with the previous literature. However, one should be cautious when deducing implication from the model as further analyses show high sensitivity of results to values of model parameters.

In order to put the system under stress scenario we ran two simulation under which the non-financial corporations sector and the household sector were assumed to be hit by a shock. Results show that in case of the first shock the system accumulated relatively low losses related to *risk channel*, i.e. losses from write-offs of debt due to increased probability of counterparty default. In case of the second shock the losses connected with credit risk were much higher due to difference in sectors through which the shock passed. Higher losses we reported notably by sector of insurers and by some parts of the banking sector.

Finally, concept of stability frontier is used to assess size of an equity shock to each sector that would lead to a distress in the system. The stability frontier is assessed for each period of the dataset. While the value of the frontier is rather stable and high for some sectors, notably the banking sector, insurers and other financial intermediaries (meaning that a strong shock would be required to get the system under distress), stability frontier of the rest of the word is very volatile and potential shock would have various results.

There are many possible variations and extensions of the framework used in this work to capture more precisely interactions between sectors and institutions in the economy. Let us mention few of them. (i) An alternative way of modelling the equity volatility should be considered. Majority of the Czech banks is not publically traded on the stock exchange and use of foreign indices might bias the results. Possible way is to incorporate return on equity or other financial ratio deduced from publically available information. (ii) Further disaggregation of sectors might lead to better explanation of risks in the system. Idiosyncratic risks hidden under aggregated data might be detected. (iii) Incorporation of more shock transmission mechanisms can possibly better describe how shocks spread through the economy. On the other hand we might face a tradeoff due to an undesirable increase in complexity of the model.

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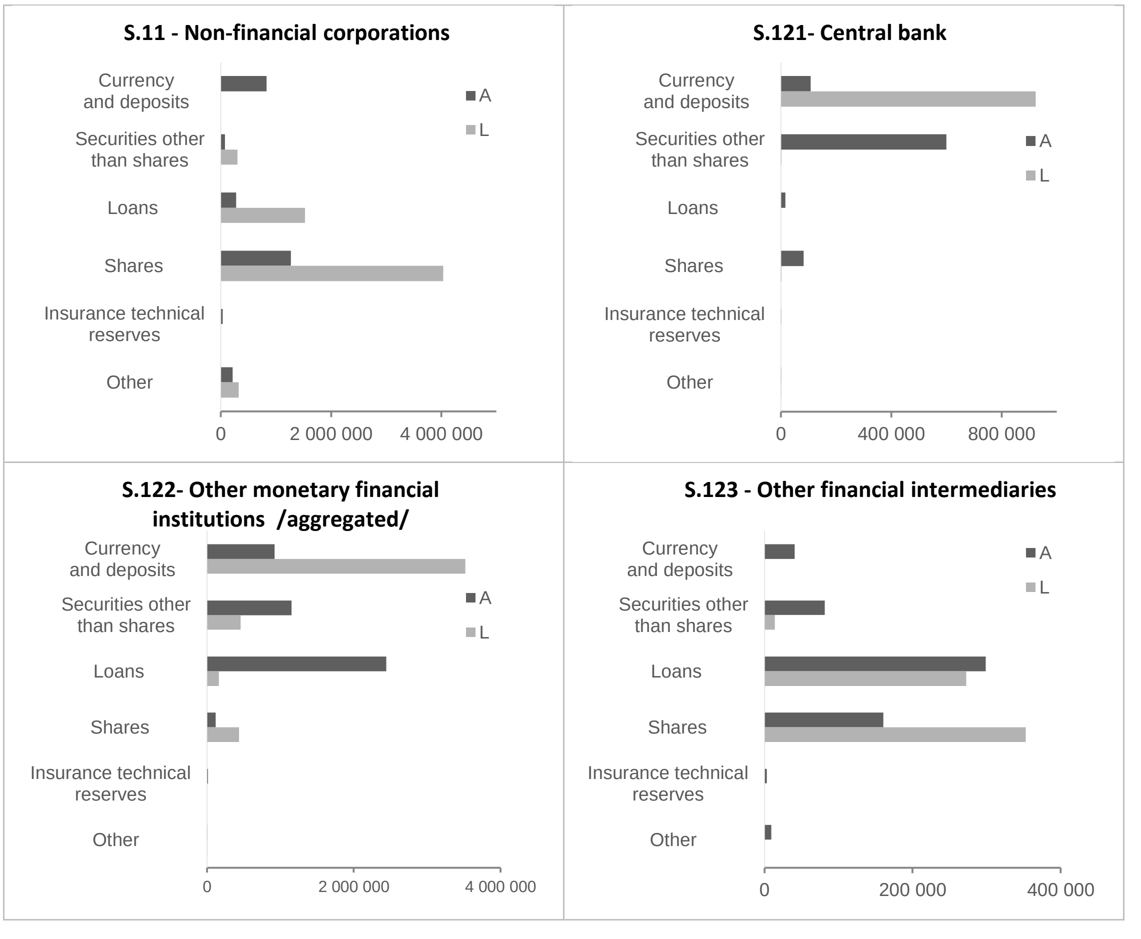
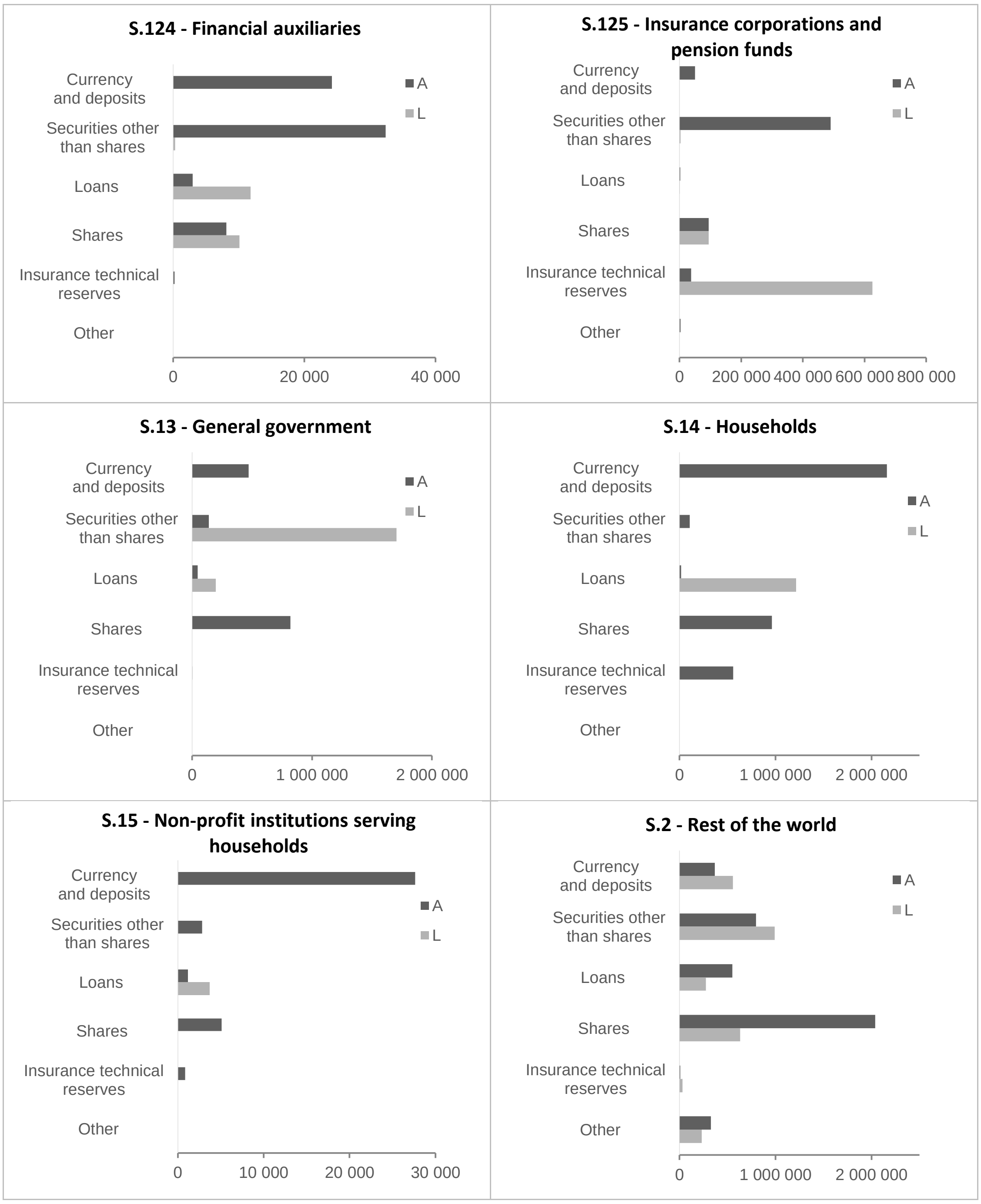
Appendix A: Balance sheets of selected sectors in the Czech economy

(Data for 2Q 2012, CZK million)

Source: Quarterly financial accounts




S.124 - Financial auxiliaries
Currency and deposits
Securities other than shares
Loans
Shares
Insurance technical reserves
Other
0
20 000
40 000
A
L
S.125 - Insurance corporations and pension funds
Currency and deposits
Securities other than shares
Loans
Shares
Insurance technical reserves
Other
0
200 000
400 000
600 000
800 000
A
L
S.13 - General government
Currency and deposits
Securities other than shares
Loans
Shares
Insurance technical reserves
Other
0
1 000 000
2 000 000
A
L
S.14 - Households
Currency and deposits
Securities other than shares
Loans
Shares
Insurance technical reserves
Other
0
1 000 000
2 000 000
A
L
S.15 - Non-profit institutions serving households
Currency and deposits
Securities other than shares
Loans
Shares
Insurance technical reserves
Other
0
10 000
20 000
30 000
A
L
S.2 - Rest of the world
Currency and deposits
Securities other than shares
Loans
Shares
Insurance technical reserves
Other
0
1 000 000
2 000 000
A
L