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SYSTEMIC RISK IMPLICATIONS OF
THE HUNGARIAN INTERBANK MARKET

Ph.D. THESIS

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“In the wild periods of alarm, one failure makes many, and the best way to prevent the derivative failures is to arrest the primary failure which causes them.”

(Bagehot [1873], chapter II, paragraph 41.)
Systemic risk composes of many different phenomena and by no way is limited to economics or the financial system. One of the most natural illustrations of the concept of systemic risk can be found in the area of epidemic diseases. Just consider the pestilence epidemic in Europe in the 14th century or the SARS disease in South-East Asia in the recent past. By means of epidemics it can be easily demonstrated how a virus can spread over and wipe out a significant portion of a population.

In the last two decades systemic risk became one of the key concepts of financial stability as concerns about the vulnerability of national and international financial systems have been raised. Series of books and academic papers were published in this field, however no generally accepted definition of systemic risk was elaborated. The wide range of definitions can be explained by the complexity and diversity of systemic risk. As a consequence of the study of Danielsson and Shin [2002] dealing with endogenous risk the concept of systemic risk is strongly related to the story of the opening of the Millennium Bridge in London. In the afternoon of the 10th of June 2000 the Queen opened the Millennium Bridge over the river Thames. Many thousands of people turned up on the opening day and crowded on to the bridge. However, within moments of the bridge’s opening, it began to wobble violently. In order to fully investigate and resolve this phenomenon the decision was taken to close the bridge down for over 18 months. Hundreds of engineers started to analyze the static features of the bridge. The result of investigation was astonishing. The research indicated that the movement was caused by the sideways loads we generate when walking. The sideways movement when we walk need not matter if one person’s sway to the left is cancelled out by another person’s sway to the right. It is only when many people, in the case of Millennium Bridge 156 people, walked in step that the sideways force would be a problem. What is the probability that event? It is tempting to say close to zero, or negligible. However, that is what happened on the 10th of June 2000, most probably as consequence of stronger gust of wind. In the case of systemic risk we are up against a similar phenomenon. The probability of the event occurring is low, however once happens, the impact is truly severe.

In the Ph.D. thesis one aspect of systemic risk, that is, the domino effect in the banking system is captured. Chapter I introduces basic definitions related to contagion and provides a comprehensive list of factors influencing contagion. Contagion refers to a phenomenon when as a consequence of a narrow, either idiosyncratic or limited systematic shock at least one institution fails. In relation with financial fragility of banks, in order to be able to enhance financial stability, it is an important question how shocks propagate form one institution to the other. The information channel is related to the asymmetric information and expectations, meanwhile the fundamental channel can be linked to direct and indirect interbank exposures. As a consequence of the complex web of linkages between banks in the interbank funding market, derivative markets, through off balance sheet items and the payment and settlement systems a couple of initial bank failures could trigger the collapse of the whole financial system. The severity and probability of contagion depend on several institutional features. At the interbank market level the structure of the interbank market is playing an important role. The link between contagion and structure of the interbank market can be analysed along various dimensions. Two most important dimensions of the structure of the interbank market are the concentration of exposures and the network topology of the interbank market, that is, the structural features of interbank linkages. However regulatory authorities can play an important role in assuring financial stability by taking measures to prevent or ex post reduce the risk of contagion. According to the widely spread international practice central banks can enhance financial stability by means of macro prudential regulation, meanwhile supervisory
Authorities are responsible for micro prudential surveillance. The severity of contagion is also influenced by the architecture of the payment and settlement systems, by the application of risk mitigation techniques, like collateralized loan and deposit transactions, repurchase agreements, netting agreements and by the effectiveness of internal limit systems. Mutual monitoring of banks, market discipline and transparency represent factors that also influence the scope of contagion.

Endogenous risk represented by number of contagious bank failures varies from country to country. The severity and probability of contagion depend on several, in most cases hardly quantifiable factors. However, the research question that still emerges is how could we measure the risk of contagion? Chapter II introduces empirical models dealing with contagion through the interbank market. The empirical models supplementing the standard stress testing methodology can be divided into three groups. The first group of empirical models concentrates exclusively on the impact of contagion. By means of simulation the models solely handle the effect of an idiosyncratic failure. The research question is whether due to the network of interbank exposures the failure of one bank can spread to the rest of the banking system. Models in this group indicate one basic type of interbank stress tests, the so called pure interbank stress tests. Solely direct lending is captured, that is, effect of non-repayment of interbank credits on the capital of creditor banks. The second group of empirical models dealing with contagion puts emphasis on different kind of macroeconomic shocks. In these integrated interbank stress tests simulated macro shocks are grossed up to the point where they trigger the failure of the weakest bank in system, which, in turn can trigger additional failures through interbank exposures. The third and the latest group of empirical models analyses the systemic risk implication of financial interlinkages by applying the newest findings from network theory.

As many national banks, the Hungarian National Bank also captures systemic risk implications of the financial sector. In the Report on Financial Stability of February 2001 the methodology of the Hungarian stress test is presented. (Stress test… [2001].) The aim of the stress testing carried out by the Hungarian National Bank is to capture the ability of the banking sector to absorb different kind of shocks. However, stress tests in Hungary are not able to handle spill over and liquidity effects induced by the initial shock. Among the Closing remarks of the Report we could read, that “it may occur that the system-level credit and/or market risk is relatively moderate but, when the loss is concentrated among banks which are characterised by extensive interbank relations, then significant ripple-over effects may multiply the magnitude of the risk. Hence the mapping of interbank exposures would significantly enrich our knowledge of system-level risks.” (Stress test… [2001], p. 65.) In my opinion, the above cited last sentence of Closing remarks of the Report highlights the systemic risk importance of interbank linkages of the Hungarian banking system.

Chapter III aims to map interbank linkages among Hungarian banks based on data of uncollateralized interbank loans and deposits denominated in Hungarian forints. The analysis begins with the review of turnover and volume data. It is shown that the monthly turnover of the Hungarian interbank money market demonstrates an upward trend. The special year-end-liquidity management of banks and the payment obligations of value added and consumption taxes of companies lead to the cyclicality of the turnover. Concerning the maturity of the interbank loan and deposit contracts overnight transactions dominate the market. In this sense the Hungarian interbank market can be truly seen as a tool of liquidity management. The average volume of uncollateralized interbank assets was 208.7 billion forints in 2003, which accounted for 1.71% of total assets and 19.69% of tier 1 capital of the banking sector. Interbank transactions are dominated by overnight transaction, but the amount of transactions
with original maturity of one week, two weeks, one month, three months and six months are also important.

In Chapter III, as a result of the explicit link between the severity and probability of contagion and the structure of the interbank market the key dimensions of the structure of the Hungarian interbank market is brought into focus. It is shown that based on the Herfindahl-Hirschman index the Hungarian interbank market is moderately concentrated. Concerning the market share of the most significant banks, both in the asset and liability side the three most significant institutions cover 45% of the market, meanwhile the ten most significant banks own about 80% of the market. The structure of the interbank market is similar to a multiple money centre structure, where the role of money centres is played by ten-fifteen big Hungarian banks. The multiple money centre structure of the Hungarian interbank market coincides with the experience of treasurers. In the opinion of financial experts in the interbank market there is a friendly, informal relationship among ten-fifteen banks. The hypothesis of the multiple money centre structure is also supported by the fact, that 60% of interbank transactions are settled among the 15 largest banks, while in 95% of transactions at least one of the partners is among those 15 banks. A new approach applied in the thesis is the network representation of banks. The network topology and the graphs of the interbank market also refer to a multiple money centre structure, where ten-fifteen banks are situated in the centre.

After the analysis of the structure of the Hungarian interbank market it is still an open question how the above mentioned multiple money centre structure influences the probability and the severity of contagion. In Chapter IV the domino effect through the Hungarian interbank market is quantified by means of simulations. The model follows the way marked out by first group of empirical studies dealing with contagion through the interbank market which will be presented in subsection 2.1. The empirical research solely focuses on the domino effect. By means of pure interbank stress tests the consequence of a financial crisis induced by an idiosyncratic failure of a bank is assessed. The most important value added findings of the thesis are related to the analysis of the effect of the non-repayment of interbank exposures on the capital of creditor banks. The research question consists of whether an idiosyncratic failure of a Hungarian bank can lead to further failures of other banks not directly affected by the initial shock. In the worst case how many banks could go bankrupt as a result of the initial failure? What percentage of total banking assets is represented by defaulting banks? What can we say about the weakening of the banking sector measured by the tier 1 capital losses? Can it happen that the initial failure of a bank affects the whole financial system and in this way distresses also the real side of the economy?

On the basis of uncollateralized interbank loan and deposit transactions denominated in Hungarian forints we will see that contagion is fairly limited in Hungary even under unrealistic assumptions. By assuming a 100% loss given default rate and defining default as the total depletion of tier 1 capital contagion occurs only in 11 cases, that is, 0.55% of the scenarios. All first round contagious failures are due to the failure of a head institution of a banking group, which causes the failure of its subsidiary. In the worst case scenario the banking system loses 3.53% of its tier 1 capital. During the examined 50 days, the banking sector loses 0.53% of its modified tier 1 capital on average.

In the next scenario a modified default definition is used which based on the current Hungarian regulation. In this case contagious failure occurs if there existed at least one bank whose capital adequacy ratio fall below 4%. At the majority of the banks the capital available for losses decreases, at the level of the banking sector by 30%. Given a 100% loss given default first round contagion occurs in 51 out of 1950 cases, that is, in 2.62% of the scenarios. Second round contagion never occurs. 43 out of the 51 first round contagious failures are due
to the failure of a head institution of a banking group, which causes the failure of its subsidiary. On average the banking system loses 0.80% of its capital maximum available for losses. Concerning those days, when contagion happens, the maximal loss is 8.33%.

In reality the failure of a bank is not a sudden, unexpected event, it is rather a result of a process. As a consequence, other banks can limit or even partly withdraw their interbank claims. By building market expectation into the model, it is assumed that the initially failed bank could not obtain interbank credit in the recent past. That is, the failing bank does have any interbank obligations with original maturity less, than one week. After building market expectations into the model contagion occurs only in 9 cases from the 51, mostly due to short term, 14-day claims. All of the contagious failures are related to the failure of the subsidiary. This means, that previously each contagious failures were a consequence of interbank exposures with original maturity less than one week.

In further scenarios instead of the effect of an idiosyncratic failure the effect of multiple bank failures with same risk profile are captured. Scenarios of joint failures are based on exposures stemming from concentrated credit portfolios, just like extended real estate project financing credits, agricultural credits and credits to financial enterprises. In the following scenario those banks are identified that in the case of an exchange rate shock could lose a significant part of their tier 1 capital. The identification is carried out on the basis of the outcome of stress tests carried out by the Hungarian National Bank. By assuming the joint failure of banks exposed to a foreign exchange shock, the systemic risk implications of the interbank linkages are quantified. In all of the scenarios assuming joint failures contagion proves to be limited regardless whether the severity of contagion is captured by the number of defaulting banks or by the mean and maximum losses measured in the tier 1 capital of the banking system. Second round contagion never occurs. The capital loss distributions of the surviving banks are similar to the previously observed.

The analysis of the regulatory and policy consequences of contagion is also of crucial importance. Especially as a result of previous analysis the Hungarian regulatory authorities could feel comfortable, the domino effect has a limited impact on the banking sector. By means of further simulations questions like the critical volume and concentration of exposure, at which the authorities responsible for financial stability should probably take measures are addressed. The main goal of the analysis is to look for circumstances under which the systemic risk implications of the interbank market increase significantly. We will see, that by tripling the interbank exposure of Hungarian banks there are scenarios when the idiosyncratic failure of a bank generates serious stability problems. At the same time this never happens in the case of duplication of exposures. It will be also demonstrated that in the case of a 25% increment in the market concentration measured by the Herfindahl-Hirschman index banks suffering contagious defaults solely affect a small part of the total assets of the banking system.

As several researchers prepared country case studies using the same simulation methodology international comparison of the severity of domino effect through the interbank markets can be carried out. Comparing the Hungarian outcomes and the results of previous studies made in other European counties we will see that nearly all of the foreign studies quantifying the danger of contagion finds that for low loss given defaults systemic risk implications of the interbank linkages are limited. However for higher loss given defaults, in fairly extreme scenarios the severity of contagion can be very high. In foreign countries the contagion can be seen as a low probability – high impact event, that is, the probability of contagion through the interbank market is low, however once happens, the consequences can be fatal. In contrast, in Hungary even under unrealistic assumptions the domino effect is fairly limited. Not only the
probability of contagious banks defaults is low, but the severity of contagion is also limited. The contagion in Hungary can be considered as a low probability – low impact event.

One of the most important findings of the thesis is that by assuming the dispersity of interbank exposures the probability of contagion is lower than the contagion experienced next to the real matrix of interbank assets and liabilities. In previous empirical literature the exact volumes of interbank assets and liabilities were not given on a bilateral basis. In the absence of bilateral data the authors estimated the matrix of interbank exposures by assuming the maximal dispersion of exposures. In contrast, in Hungary the proper volume of bilateral interbank positions is known. As we will see, in foreign countries due to the applied matrix estimation procedure – maximizing the entropy of the matrix – the probability of contagion is significantly underestimated.

Despite the several drawbacks of the empirical model by means of simulations the system perspective can uncover exposures to aggregate risk that are invisible for banking supervision relying on the assessment of single institutions only. Secondly the data used is available at central banks. The model itself is simple and instead of building a complicated model it is trying to read between the lines of the existing data. Thirdly „what happens if”-type questions can be relatively easily asked and answered. Additionally, consistent use of the methodology with different time-series of data would allow estimating the evolution of contagion risk over time.

The last part of the Ph.D. thesis covers the concluding remarks and defines the area for future research going beyond the scope of the thesis. Systemic risk implications of the Hungarian interbank market even under unrealistic assumptions are fairly limited both in absolute and relative terms. This can be explained with the low volume of interbank exposures measured by total assets or tier 1 capital of the banking sector. Differences in the ratio of interbank exposures over total assets among countries – Belgium vs. Hungary – are only surprising for the first sight. After filtering the data the differences are not that significant any more. However by comparing the ratio of interbank liabilities over tier 1 capital the difference between Hungary and other European countries becomes noteworthy. In Hungary a bank with a higher interbank exposure than its tier 1 capital is rather exceptional. In contrast, in Germany 85% of banks have a higher interbank exposure than banks’ tier 1 capital, which is basically the necessary condition for contagion to occur. (Upper and Worms [2000].) In Holland the ratio of interbank claims over tier 1 capital is also slightly above 1. (Lelyveld and Liedorp [2004].) Next to the volume of interbank exposures, the structure of the interbank market – moderately concentrated money centre structure of exposures – is also playing an important role in influencing the severity of contagion. As a result of low interbank exposures and moderately concentrated structure of interbank claims and liabilities, the limited risk of the contagion in Hungary is not surprising any more.
1. CONTAGION

The Ph.D. thesis begins with the introduction to systemic risk and contagion. The complexity and diversity of systemic risk was accompanied with a wide range of definitions on systemic risk. The terminology of De Bandt and Hartmann [2000] is applied to set systemic risk events in order. Afterwards systemic risk and contagion are defined. Contagion refers to a phenomenon when as a consequence of a narrow, either idiosyncratic or limited systematic shock at least one financial institution fails.

Subsection 1.2. of the thesis deals with the reasoning behind the fragility of banks. In this context two channels of contagion is distinguished. The information channel is related to the asymmetric information and expectations, meanwhile the fundamental channel can be linked to interbank exposures.

Subsection 1.3. systematizes the theoretical models dealing with contagion. The goal of the brief review of the theoretical literature is to designate the research area properly. In subsection 1.4. models finding empirical evidence on contagion are reviewed. As the results indicate contagion can jeopardize systemic stability even nowadays. In subsection 1.5. – by focusing on models of contagion through interbank linkages – the link between contagion and the structure of interbank market is explored. It is well known from the literature that the structure of interbank market influences the severity and probability of contagion. The structure of interbank market can be best captured by the concentration of exposures and by the network topology of the interbank market.

In subsections 1.6. and 1.7. the importance of regulatory authorities and the role of the architecture of payment and settlement systems in reducing the severity and likelihood of contagion are emphasised. Finally, in subsection 1.8. all other factors, like risk mitigation techniques, monitoring and market transparency influencing the scope of contagion are presented.

1. 1. Systemic risk and contagion

According to Tarafás [2001] among economists there exist two opposite theoretical explanations about the stability of the financial system. In the opinion of the post-Keynesians the financial system is inherently instable. In the case of upward economic trend the actors can be described by excessive indebtedness, and when the boom culminates the financial crisis becomes inevitable. According to the post-Keynesians theory the crisis is preventable or at least can be alleviated. In contrast, economists committed to monetarism argue that the financial system is fundamentally stable. Only the bank panic can be regarded as a financial distress, a situation in which the confidence in banks trembles. In the theory of monetarists bank panics with appropriate institutions and their proper functioning can be avoided or restrained.

In the financial literature the studies dealing with contagion are coherently related to the phenomenon of systemic risk. The precise meaning of systemic risk is ambiguous; it means different things to different people. However, definitions of systemic risk all refer to the fragility and instability of financial systems. According to Bartholomew and Whalen systemic denotes an event having effects on the entire banking, financial, or economic system, rather than just one or a few institutions. (Bartholomew and Whalen [1995], p. 7.) Schwartz reckons financial crisis as the collapse of payment and settlement systems. (Schwartz [1995], p. 20.)
Mishkin defines systemic risk as the likelihood of a sudden, usually unexpected event that disrupts information in financial markets, making them unable to effectively channel funds to those parties with the most productive investment opportunities. (Mishkin [1995], p. 32.) The definition of Kaufman focuses on potential spill over to others, systemic risk is the probability that cumulative losses will accrue from an event that sets in motion a series of successive losses along a chain of institutions or markets comprising a system. Putting it other way, systemic risk is the risk of a chain reaction of falling interconnected dominos. (Kaufman [1999], p. 17.) The definition the Bank for International Settlements regards systemic risk as the risk that the failure of a participant to meet its contractual obligations may in turn cause other participants to default with a chain reaction leading to broader financial difficulties. (Kaufman [1999], p. 17-18.) The book entitled Money, Banking and Financial Markets of Kohn defines systemic risk in relation to the payment system as a failure of one bank that generates further failures. (Kohn [1994], p. 561.) According to Boss et al. [2003] systemic risk is the risk of a large scale breakdown of financial intermediation due to domino effects of insolvency. Summer [2002] denotes systemic risk as joint failure of several banks. In this case a weaker correlation among institutions can be sufficient, the focus is much more on macroeconomic-type shocks.

The above mentioned examples reflect the diversity of systemic risk definitions. In every study there is a different definition. Further hundreds of definitions could be listed, the enumeration would not be even complete and all definitions could highlight a further aspect of systemic risk. The paper of De Bandt and Hartmann [2000] provides a framework for the economic analysis of systemic risk by proposing a specific terminology, clarifying some important elements of the concept of systemic risk and leading to a general working definition of it. The authors define systemic event in the narrow sense as an event, where the release of bad news about a financial institution, or even its failure, or the crash of a financial market leads in a sequential fashion to considerable adverse effects on one or several other financial institutions or markets, for example their failure or crash. Essential is the domino effect from one institution to the other or from one market to the other emanating from an idiosyncratic or a limited systematic shock. Systemic events in the broad sense include not only the events described above but also simultaneous adverse effects on a large number of institutions or markets as a consequence of severe and widespread systematic shocks.

Besides, a systemic event can be week or strong, which is shown in the second and fourth, and third and fifth columns of Table 1 respectively. If the external effect is less than a failure or a crash, financial institutions/markets simultaneously affected by the shock do not actually fail or crash, the systemic event is denoted as weak. A systemic event in the narrow sense is strong, if the institutions affected in the second round or later actually fail as a consequence of the initial shock, although they have been fundamentally solvent ex ante, or if the markets affected in later rounds also crash and would not have done so without the initial shock.

Another dimension of the concept of systemic risk could be the geographical reach of systemic risk, which can be regional, national or international. At the same time according to the impact of systemic events occurring in the financial sector one may distinguish a horizontal view on the concept of systemic risk from a vertical view on systemic risk. (De Bandt and Hartmann [2000].) A systemic risk is horizontal if the shock is limited to events in the financial sector alone, meanwhile a systemic event is vertical, if the impact of a systemic event on output is taken to gauge the severity of such an event. In my opinion to draw a distinction between the horizontal and vertical dimensions of systemic events has only sense on theoretical level, as a consequence of the strong interconnection of the financial and real

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1 For grouping of systemic events with examples see Lublóy [2003].
side of the economy a pure horizontal event is non-existent. Exact categories and isolated events are hard to determine in reality, as in a financial crisis micro and macro level interweave. For example as a result of unfavourable macroeconomic conditions financial institutions lose some part of their capital by absorbing the shock, which makes the institutions more vulnerable to idiosyncratic shocks by increasing the probability of default and the likelihood of contagion.

Table 1: Systemic events in the financial system

<table>
<thead>
<tr>
<th>Type of initial shock</th>
<th>Single systemic events (affect only one institution or one market in the second round effect)</th>
<th>Wide systemic events (affect many institutions or markets in the second round effect)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weak (no failure or crash)</td>
<td>Weak (no failure or crash)</td>
</tr>
<tr>
<td>Narrow shock that propagates:</td>
<td></td>
<td>Strong (failure of one institution or crash of one market)</td>
</tr>
<tr>
<td>- Idiosyncratic shock</td>
<td></td>
<td><strong>Contagion</strong></td>
</tr>
<tr>
<td>- Limited systematic shock</td>
<td></td>
<td><strong>Contagion leading to systemic crisis</strong></td>
</tr>
<tr>
<td>Wide systematic shock</td>
<td>Ø</td>
<td><strong>Systemic crisis</strong></td>
</tr>
</tbody>
</table>

Source: De Bandt and Hartmann [2000], p. 12.

De Bandt and Hartmann define systemic risk both in the narrow and broad sense as the risk of experiencing systemic events in the strong sense. It is worth mentioning that strong systemic events, in particular systemic crises, are low probability events. However, once a crisis strikes the consequences could be very severe. Systemic crisis both in the narrow and broad sense was regarded as a systemic event that affects a considerable number of financial institutions or markets in a strong sense, thereby severely impairing the general well-functioning of an important part of the financial system. The well-functioning of the financial system relates to the effectiveness and efficiency with which savings are channelled into the real investments promising the highest returns.

According to De Bandt and Hartmann contagion occurs, if strong instances of systemic events eventuated in the narrow sense. If the initial shock generates the bankruptcy of single institution unique systemic event happened. If the initial shock triggers several insolvencies, it is about contagion leading to systemic crisis.

In the focus of the Ph.D. thesis stands contagion, one part of systemic risk. Systemic risk, by accepting the definition of De Bandt and Hartmann, is defined as the risk of experiencing systemic events in the strong sense. However in the thesis only those systemic events are
dealt with, where the initial shock consisted of a narrow idiosyncratic or limited systematic shock. Systemic risk in the broad sense, that is, wide systematic shocks are not handled. Contagion refers to a phenomenon when as a consequence of a narrow, either idiosyncratic or limited systematic shock at least one institution fails. In relation with the above mentioned terminologies two important consequences should be highlighted. First of all, the term contagion and the term domino effect are used as synonyms. Secondly, as systemic events in the broad sense are not handled, the examined systemic events are all accompanied with contagion. In this sense systemic risk and risk of contagion also can be seen as synonym terminologies.

1.2. Channels of contagion

Systemic risk, in particular potential contagion effects, is of special concern in the financial system. Financial fragility of banks can be explained by several special features of the banking business. Firstly, according to De Bandt and Hartmann [2000] financial fragility of banks is related to the structure of balance sheet of banks. Traditionally, commercial banks take fixed-value deposits that can be withdrawn unconditionally and at fixed value at very short notice and lend long term to industrial companies. Besides when the law of large numbers applies, only a small fraction of assets needs to be held in liquid reserves to meet deposit withdrawals. This fractional reserve holding can lead to illiquidity and even default, when exceptionally high withdrawals occur and long term loans cannot be liquidated, although the bank might be fundamentally solvent in the long run. Kaufman [1996] argues that financial fragility hypothesis is supported by the high leverage of banks, which leads to lower shock absorbing capacity. Additionally, under certain circumstances high fraction of short term liabilities that are deposits can result in bank runs and bank panics. Finally, Hellwig [1995] pointed out that the banking system can bring significant maturity transformation into effect. Negligible maturity transformation and insignificant interest rate risk of individual institutions are subject to significant interest rate risk at the level of the banking system.

Another feature of financial systems that can provide a basis for the financial fragility hypothesis is the interconnection of banks through direct exposures. As a consequence of mutual interbank credit agreements the failure of a couple of institutions can result in the collapse of the whole system. In the literature this phenomenon is called contagion or domino effect. The goal of the empirical research carried out in later sections of the thesis will be to quantify the domino effect related to interbank linkages. If an insolvent or an illiquid bank is not able to fulfil its interbank payment obligations for whatever reason, it could happen that as a consequence of the initial non-repayment of the exposure another bank also defaults on its obligation. The initial non-repayment of interbank obligations can spread across the system, just like a domino-line collapses, when one of the dominos is fallen over. Whether the whole domino-line collapses, depends on the structure and the distance of the dominos, that is, how far the dominos from each other are. Similarly, the stability of the banking sector depends on the interlinkages of the banks, that is, on the structure of the interbank market. Next to the exposures of interbank market cross holding of shares, financial interlinkages through derivative positions, and payment and settlement systems also contribute to systemic risk.

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2 In contrast with the study of De Bandt and Hartmann unique systemic events and contagion leading to systemic crisis are not distinguished.

3 Domino effect can also occur among corporations, however the cost of this kind of contagion is much lower than the cost associated with the collapse or weakening of the banking sector.
Finally, *information intensity of financial contracts and related credibility problems* – due diligence – also contribute to the financial fragility of banks. Financial decisions aim at the intertemporal allocation of purchasing power for consumption and are, therefore, based on expectations on what the value of the respective asset is going to be in the future or whether the future cash flows promised in a financial contract are going to be met. Hence, when uncertainty increases or the credibility of a financial commitment starts to be questioned, market expectations may shift substantially and individually rationally in short periods of time and so may investment and disinvestment decisions. As a consequence large asset price fluctuations can happen. (De Bandt and Hartmann [2000].)

In relation with financial fragility hypothesis of banks one can distinguish **two main channels** through which *contagion in banking markets* can work. According to Schoenmaker [1996] contagion can spread through the real or exposure channel and through the informational channel. In principle, these two fundamental channels can work in conjunction as well as quite independently. The *information channel* relates to contagious withdrawals when depositors are imperfectly informed about the type of shocks hitting banks and about their physical exposures to each other. *Expectations* are strongly related to the information channel. When one group of depositors experience that other group of depositors withdraw their deposits from a given bank, they also withdraw. Depositors withdraw their deposits as first-come-first-served rule applies, and if they arrive late, they would end up unsatisfied claim. Basically, deposit contracts are vulnerable to asymmetric information. In many cases contagion through the information channel is not based on fundamental information but rather on noisy signals. General uncertainty and agents’ awareness of potential asymmetries of information highlight the role that expectations can play for the occurrence or not of systemic events. Role of expectations is of major importance, bank runs based on non-fundamental signals can be self-fulfilling and lead to default of healthy banks. (Diamond and Dybvig [1983].)

De Bandt and Hartmann [2000] distinguish **three potential causes of narrow systemic events related to asymmetric information and expectations**. These are, first, the full revelation of new information about the health of financial institutions to the public; second, the release of a noisy signal about the health of financial institutions to the public; and, finally, the occurrence of a signal which co-ordinates the expectations of the public without being actually related to the health of financial institutions. In the literature these later signals are called sunspot.\(^4\)

The effect of the *full revelation of new information* can be best captured by the following example. (De Bandt and Hartmann [2000].) Suppose that, hidden from depositors, a bank has made a number of loans that turn bad, so that it is basically insolvent but continues to survive for some time since it can roll over debts in the interbank market. Suppose further that other banks having neglected to monitor their counterparties properly develop substantial exposures to it. If the information about these facts were then released in full, it would be individually rational for depositors to withdraw their funds and force those banks into liquidation. Ceteris paribus such an outcome, which can be denoted as a fully revealing equilibrium, would also be efficient, as opposed to a scenario where the bank continues to accumulate losses. Systemic event in this case was based on fundamentals.

To understand the *impact of a noisy signal* about the health of financial institutions to the public, given the example above, suppose that the information about bad loans and interbank exposures is not revealed in full but that depositors only receive imperfect information, a noisy signal from some outside source, which from their point of view increases the

\(^4\) The terminology of sunspot was introduced by Cass and Shell [1983]. Sunspots are defined as extrinsic events, which do not have an effect on fundamentals, however brings suddenness into the resource allocation.
likelihood for those facts. In such a situation it might still be rational for them to try and withdraw their funds early and thereby force the default of those banks. Whether the signal has been right or wrong would determine, ceteris paribus, whether this outcome is efficient or not. As it is triggered by imperfect information on fundamentals, this type of contagion could be denoted as information-based.

As the above mentioned example shows, one important feature of bank runs that there is no unique equilibrium. (Diamond and Dybvig [1983].) Depending on the behaviour of other depositors it can also be rational that a given depositor runs the bank (if other depositors do the same), and it can also be rational that the given depositor do not withdraw its money (if other depositors also do not withdraw it). What is however interesting is that bank runs can be independent of the performance of the bank. The actual performance of the bank and the probability of a bank run are only stochastically related. Depositors can lay siege to an impeccable bank and can leave operating a badly managed bank. However, the better a bank is managed, the lower probability of a bank run. If we investigate the two possible equilibria (there is a bank run/there is no bank run) in the function of bank performance, there are only two efficient outcomes out of four, as shown in Table 2. As systemic events driven by expectations might be individually rational but not socially optimal, the role of regulation and supervision is of major importance.

Table 2: Equilibrium as a function of bank performance

<table>
<thead>
<tr>
<th>Occurring event</th>
<th>Performance of bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank run</td>
<td>Bad performing bank</td>
</tr>
<tr>
<td></td>
<td>Well performing bank</td>
</tr>
<tr>
<td>No run</td>
<td>Inefficient</td>
</tr>
</tbody>
</table>

Source: Kiss Hubert [2003].

Finally, in order to illustrate how sunspots work, suppose that the level of deposit withdrawals in itself provides an imperfect signal for all depositors about the health of their own banks and the respective banks’ interbank counterparties. In these circumstances, even if all the banks have been healthy ex ante, any event that co-ordinates depositors’ expectations about other depositors’ withdrawals might induce them to rush to withdraw even from different banks and force those banks into liquidation. The related systemic event might still have been individually rational ex ante, while the outcome in the form of a self-fulfilling panic is inefficient, since depositors lose the benefits from financial intermediation and might also incur capital losses if the liquidation leads to asset values declining below the normal, non-crisis market levels. According to sunspot explanations financial system is inherently instable, unexpected shocks without any fundamental underlying problem can also result in bank panics. (Cass and Shell [1983].) The difference between models focusing on sunspots and on other information related contagion is that the latter type of models consider the behaviour of economic actors as a rational, thus withdrawal is also reckoned as a rational action. In contrast, models in the first group explain economic behaviour from psychological point of view, assuming for example herding effect.

In relation with the information channel, Aharony and Swary [1983] make a distinction between pure or industry specific contagion and noisy or firm specific contagion. Pure
contagion occurs when negative information, such as fraud or losses on specific risky investments about one bank adversely affects all other banks, including those that have nothing in common with the first bank. Noisy or firm specific contagion arises when the failure of one bank reveals a bad, but noisy signal regarding other banks with common characteristics. If one bank fails, then other banks with a similar asset and liability structure and therefore vulnerable to the same economic shocks and may also face a run. Thus, bank run is triggered by a failure of a bank, however only those depositors run their banks which have common characteristics with the initially failing bank.

Credit or fundamental channel of contagion is related to the complex web of linkages between banks in the interbank funding market, derivatives markets, through off balance sheet items and the payment and settlement systems. The size of interbank credit lines is exempt from large exposure rules and is usually related to the size of the borrowing bank and not of the lending bank. Surviving banks can thus have substantial claims on the failing bank and may subsequently fail. The failure of Continental Illinois in 1984 can be mentioned as one of the most well known episode. Continental acted as correspondent bank for nearly 1100 banks at the time. 66 banks had uninsured deposits exceeding 100% of their capital, and another 113 banks had deposits between 50 and 100% of their capital. (Schoenmaker [1996].) Moreover, as there is a lack of timely data on interbank exposures, contagion through the credit channel can be enhanced. Market participants know that interbank positions may be very large, but the size of particular bilateral positions is not known. In the event of a bank failure, market participants do not know which banks have unsatisfied claims against the failing bank. This in turn may generate a general loss of confidence in the interbank market. Additionally, as proper volume of realized losses and the date of recovery are also not known at the time of default, it could happen that banks with large interbank exposures should also face bank run. Especially, if depositors are not protected by a deposit insurance system.

De Vries [2004] relates syndicated loans of bank to the credit channel of contagion. De Vries argues that similarity in exposures carries the potential for systemic breakdowns. Failure by a large company reneging on its syndicated loan immediately affects a sizable part of the banking sector and can be a source of systemic risk.

The theoretical model of Aghion, Bolton and Dewatripont [2000] can also be related to the credit channel. The authors focus on the trade off related to interbank lending, namely that the advantage of insurance against liquidity shocks from the interbank market resulting in fewer individual failures comes at the price of systemic risk, that is, contagious character of bank failures increases. In the model banks invest in partly illiquid projects and are subject to uncertain depositor withdrawals in first, second and third periods. If withdrawals exceed the liquid project returns, then banks can either liquidate the remaining project at a discount or enter the interbank market. If the overall available liquid funds are sufficient, then no failure occurs since interbank loans by other banks save the ones with a liquidity shortage, who can then serve their depositors. However, if one bank cannot acquire the liquidity from the interbank market and fails, then contagious runs can occur, because other depositors interpret the failure of an institution as a signal of general lack of liquidity in the banking system. In this fashion one bank failure can result in the closure of the entire banking system.

Information and credit channels of contagion can enhance each others effect or can also exist quite independently. In the following parts of the Ph.D. thesis contagion related to the information channel is only partly captured. Contagion through the credit channel, that is, financial linkages of banks in the interbank market is brought into focus. As Aghion, Bolton

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5 Current Hungarian regulation will be discussed in subsection 1.6. in relation with the impact of regulation on contagion.
and Dewatripont [2000] have showed, interbank lending, providing insurance against liquidity shocks increases the probability of contagious defaults. One could ask with good reason, what are the factors influencing the probability of contagion. However before reviewing the components determining the severity and probability of contagion in detail, empirical models of contagion (subsection 1.3.) and empirical evidence on contagion (subsection 1.4.) are reviewed.

1.3. Theoretical models of contagion

In the last couple of years significant concerns about the stability of national and international financial systems have been raised worldwide. These concerns are reflected in a series of reports, private initiatives and academic papers, empirical and theoretical studies on systemic risk of the banking sector, justification of contagion and modelling of functioning and quantitative assessment of spillover effects. The grouping of theoretical studies on contagion can be followed in Table 3. In this subsection the forms that systemic risk may take is considered in greater detail, distinguishing between contagion in the banking sector, in financial and capital markets and in payment and settlement systems. Groups of theoretical models are reviewed briefly, as based on this framework the research area of the thesis can be defined more properly.

Table 3: Theoretical papers dealing with contagion

<table>
<thead>
<tr>
<th>Contagion in the banking sector</th>
<th>Contagion in financial and capital markets</th>
<th>Contagion in payment and settlement systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bank runs, bank panics</td>
<td>• Contagion across securities markets</td>
<td>• Interbank settlement systems</td>
</tr>
<tr>
<td>• Interbank market</td>
<td>• Currency crisis</td>
<td>• Foreign exchange and security settlement systems</td>
</tr>
<tr>
<td>• Macroeconomic fluctuations, aggregate shocks and lending booms</td>
<td>• Shocks to financial institutions</td>
<td></td>
</tr>
</tbody>
</table>

Source: Based on the survey of De Bandt and Hartmann [2000].

First column of Table 3 groups models dealing with contagion in the banking sector. The first generation (or classical) bank run models (Diamond and Dybvig [1983], Postlewaite and Vives [1987]) were designed to address the issue of the instability of single banks with fractional reserve holdings due to the risk of deposit withdrawal. In the models banks transform short term deposits into long term investments. Long term investments are assumed to be risk free, but illiquid. Depositors face a pay-off externality due to a sequential service constraint. When depositors withdraw their deposits, a first-come-first-served rule applies and banks have to liquidate their long term investments as in the models there is no market for investments or bank shares. A fraction of bank customers experience a liquidity shock and wish to withdraw their deposits early. As I have mentioned on page 15, in the Diamond-Dybvig model there are two equilibria, one of them is the bank run. If a depositor is convinced that other bank customers wish to withdraw, the depositor will also withdraw its
deposit. The motive behind the withdrawal is the fear that the loss of the asset liquidation of the bank will be pushed to the depositor. The crucial element is the fear of early withdrawals by a too large number of depositors may trigger a run on the bank. That is, bank runs are generated by the shifts in expectations. Expectations should not necessarily be based on fundamental information, it can be induced by all kinds of sunspot phenomenon. In this case bank runs take a form of a self-fulfilling prophecy.

Second generation bank run models (Gorton [1985], Chari and Jagannathan [1988]) take next to the risk of deposit withdrawal the risk of investments also into account. In this second class of models depositor runs are caused by the release of new information about the viability of bank investments and quality of credit portfolio. One of the key elements of the model is the information asymmetry between the bank and depositors concerning the proper value of credits. Based on fundamental information Gorton [1985] shows how, under complete information, rational and efficient depositor runs can occur. Under incomplete information the noisy signal can sometimes trigger rational but inefficient, information based runs. Concerning the withdrawal of other depositors the own deposit withdrawal is also rational, but it is inefficient, as could happen that as a consequence a sound bank fails. As indicated by the Chari-Jagannathan model, agents can only identify the real performance of a bank \textit{ex post}. In the model, some agents receive information about the performance of the bank’s assets. Although the other agents can observe the length of the queue at the bank’s door. As those agents are not informed about the actual proportion of informed withdrawers, having received a negative signal about the bank’s assets, as compared to agents simply experiencing a liquidity shock. The related signal-extraction problem can lead to uninformed depositors running the bank when the queue is too long, even if informed depositors had not received any negative signal. This information based bank run was caused by the fear from the insolvency of the bank. However a bank run could occur in the absence of bad news as well. The classical bank run models were \textit{extended} by several authors. De Bandt [1995] extends the model to a multiple banking system and considers how an aggregate and an idiosyncratic shock affect the return on banks’ assets. Chen [1999] presents a rich model combining an extension of the bank run models to a multiple banking system with the literature on rational herding. Chen examines bank runs, as a rational reaction of depositors by assuming a multiple banking system, partly well informed depositors, uncertain long term investments and speculative short term projects. In his model, similarly to the model of Temzelides [1995] agents adjust their choices over time through learning from past experience with the banking system. One of the two Nash equilibria of panic/no panic is selected and learning introduces some state-persistence. At the start of period 1 depositors at a subset of banks learn simultaneously about liquidity shocks and about their banks, exact long term investment outcome and they decide whether to withdraw or not. As a result a subset of these banks might be run and fail. Then depositors of the remaining banks learn how many of these banks failed, update their expectations about the likelihood that investment projects succeed in general and decide whether to withdraw or not.

Models focusing on \textit{macroeconomic fluctuations, aggregate shocks and lending booms} are based on the observation that many banking crises have occurred in conjunction with cyclical downturns or other aggregate shocks, such as interest rate increases, stock market crashes or exchange rate devaluations. (Gorton [1988], Lindgren, Garcia, and Saal [1996].) De Vries [2004] argue that banks are not only directly, but also indirectly linked as they are exposed to the same macro risk drivers, as banks are engaged in similar activities like mortgages concentrated in specific areas or loans to specific sectors of the economy. Moreover, through proprietary trades banks are exposed to the same market risks. On the liability side deposit contracts all move in similar directions since they all respond to the same interest rate.
movements. All these imply that the asset and liability sides of different banks balance sheets hold the same risks or risk factors, albeit in different proportions. As result of a shock, the value of bank’s assets can decrease dramatically, which can lead to huge capital losses. In the Hungarian literature the impact of stabilization by mean of exchange rate on the financial sector is emphasised by Tarafás [1999]. Mérő [2004] highlights the relation of the procyclical nature of banking and financial crisis.

The role of financial and capital markets is perhaps the most difficult element in the analysis of systemic risk. The theoretical literature is limited to two branches, one dealing with contagion between securities markets from a microeconomic perspective and the other dealing with contagious and joint currency crises using rather macroeconomic approaches. In the former case, like in the study of King and Wadhwani [1990] or Kodres and Pritsker [2002] contagion is based on the information channel, that is, on noisy signals under asymmetric information, or on credit channel, that is, on direct trade exposures, like the study of Lagunoff and Schreft [2001]. There are numerous studies dealing with currency crisis form a macroeconomic point of view, most interestingly by currency attacks by speculators on central banks’ foreign exchange reserves in response to unsustainable, conflicting macroeconomic policies and by crisis resulting in joint collapse of several markets of the financial sector. Besides, large general price fluctuations or liquidity crises are themselves shocks to financial institutions and other agents. Extreme events in any of the major financial markets, like stock market, government bond market affect a large number of agents at the same time and are therefore often of a systematic nature. Such systemic shocks from the markets will be even more widespread if they are contagious across markets.

By providing the technical infrastructure through which banking and securities market transactions are settled, interbank payment and settlement systems determine to an important extent the physical exposures among financial institutions. Depending on the internal organisation they also determine how shocks may propagate through the financial system, in particular how severe contagion can be. In multilateral net settlement systems payments among members are collected over a certain period of time, and at the settlement time the gross payments between members are netted against each other, so that only the net balances have to be settled with finality. Net settlement systems involve relatively low costs, because actual settlement is relatively rare and thus liquidity costs are low. However, without additional provisions, net settlement systems are still comparatively vulnerable to systemic risk, since gross exposures accumulating between settlement times can become very large. In contrast, real-time gross settlement systems are comparatively costly for member banks, as heavy charges for intra-day liquidity management is in place. However, as payment finality is virtually immediate for every transaction, so that the systemic risk from unsettled claims appears to be very limited. Angelini [1998] modelled profit-maximising banks’ behaviour in real time gross settlement system where intraday liquidity was available from the central bank against a fee proportional to the size of the overdraft. Schoenmaker [1995] compared multilateral net settlement systems and collateralised real time gross settlement systems both theoretically and through the simulation of average costs with real transactions and historical bank default data. Settlement delays and collateral requirements are also captured. In a more elaborate model, Freixas and Parigi [1998] introduced geographical consumption preferences in a Diamond-Dybvig-type model, which lead to interbank payments between two regions. In contrast to national interbank payments, foreign exchange and securities transactions involve the settlement of two „legs”. Foreign exchange transactions involve the opposite payment of

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6 As the stability and functioning of the interbank payment and settlement systems are preconditions of the stability of the whole financial system, subsection 1.7. of the thesis deals separately with the technical architecture of the Hungarian payment and settlement system.
the same principal amount in each of the two currencies, and securities transactions involve
the delivery of the security in one direction and the payment of funds in the other.

The Ph.D. thesis concentrates on contagion in the banking sector, more precisely on
contagion through the interbank market, which can be seen in the first column of Table 3.
Systemic risk in financial and capital markets, risks stemming from payment and settlement
systems are not captured. As subsection 1.6. dealing with regulation shows, regulatory
intervention such as suspension of convertibility or deposit insurance may alleviate or even
eliminate the problem of bank runs and banking panics. In countries with improved financial
systems regulatory policies and deposit insurance systems bank failures generated by bank
runs could be seen as improbable events. In these countries regulatory authorities can
presumably handle bank runs and bank panics in an efficient way. As a result, despite of the
challenging research area provided by the bank run literature, contagion induced by bank runs
or bank panics are not handled in the Ph.D. thesis. Models of contagion resulting from
macroeconomic fluctuations, aggregate shocks and lending booms are only captured, if
contagion through the interbank market is also incorporated into the model.

1.4. Empirical evidence of contagion

Before reviewing the literature on factors influencing the severity and probability of
contagion, models finding empirical evidence on contagion by means of analysing historical
events and data are delineated.

The empirical literature that developed around the contagion in the banking system can be
separated in several groups. One group of papers tries to link bank failures with subsequent
other bank failures directly by measuring autocorrelation. A second approach measures the
systemic risk of the banking sector by the physical exposures among operating banks or
between those and banks which have been bailed out by the government, to evaluate whether
a default would render other banks insolvent. A third and probably the most popular approach
is to estimate the relationship between bank failures or news and other banks’ stock market
values. Finally there exist studies, which analyse the effect of news or failures on the
probability of other banks’ defaults, as perceived by market participants and reflected in risk
premiums in interbank lending or test whether the survival time of banks decreases during
historically identified episodes of panics or through failures of other banks. The review is
proceeding in successive order.

The common ground of the first branch of the bank contagion literature focusing on
intertemporal correlation of bank failures is a test for autocorrelation in bank failures.
Basically, the rate of bank failures in a period $t$ is regressed on the rate in the previous period
$t-1$ and a number of macrometric control variables. Provided that all macrometric
shocks are effectively covered by the control variables a positive and significant
autocorrelation coefficient indicates that bank failures and periods of tranquillity cluster over
time, which is consistent with the contagion hypothesis.

In order to find evidence on contagion Schoenmaker [1996] applied an autoregressive Poisson
model to the number of bank failures. The study covered a data set of monthly bank failures.

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7 However, in my opinion, the achieved efficiency and the applied methodology is truly country specific. In
February 1997, when Postabank, a big Hungarian state bank at that time, suffered a bank run the regulatory
authorities had to bolster up the bank by all means and convince the depositors, that the Postabank is solvent
(when it was in fact insolvent). The bank panic passed away in a couple of days, however the depositors
withdrew 70 billion Hungarian forints, that is, one sixth of the liabilities of the bank. (Várhegyi [2002].)
under the US National Banking System from 1880 till 1936. To deal explicitly with the count nature of bank failure data – bank failure time series consist of count data, that are non-negative integers – an autoregressive Poisson regression model was developed. The reasoning behind the examined period was, that in contrast to several, mainly US studies, period was needed in which the central bank did not play an active role as lender of last resort to prevent contagious bank failures. By examining possible contagion effects after the establishment of the Federal Reserve System, the lack of evidence of contagion from such periods does not disprove the possibility of bank contagion. It could happen, that the lack of contagion is „only” the result of efficient measures of the FED, which tend to prevent that a single bank failure can lead to effective failures of competitors.

According to Schoenmaker there is contagion risk in banking, if after controlling for macroeconomic influences and taking multicollinearity into account bank failures are not independent. In the model the macro-economic variables included the growth of real output, the index of stock prices, the price level and the short term interest rate. By using monthly data Schoenmaker found a strong form of dependency in the bank failure data. In the period of 1880 and 1919 a combined impact of a 1% increase in the number of bank in each of the three preceding months was a 0.40% rise in the current number of failures. The results for another period of 1920-1936 indicated a higher, 0.83% elasticity of the current number of bank failures. To summarize, Schoenmaker found evidence on the risk of contagion, that is, an initial failure could generate further failures without intervention by the authorities. As a result, the author concluded that there may be a role for the central bank as lender of last resort to assist failing banks, whose failure is expected to have a systemic impact.\(^8\)

In contrast to Schoenmaker Grossman [1993] used ordinary least squares regressions to analyse bank failures. By analysing quarterly data on bank failures from 1875 to 1914 in the United States, Grossman found, that current number of failures will rise by 0.26% in response to a 1% increase in the number of failures in the previous quarter.\(^9\) However Schoenmaker [1996] argues the higher frequency of the data – monthly vs. quarterly – made it possible to identify more clearly the contagion effect. In addition, according to Schoenmaker, given the predominance of zeroes and small values and the discrete nature of bank failure data the use of ordinary least squares regressions to analyse discrete data may lead to mis-specifications. Hasan and Dwyer [1994] applied a probit analysis to data from the US Free Banking Era, 1837 through 1863. The authors found evidence of bank contagion, however concluded that the results are dependent on the crisis considered in this interval and the respective region. The impact of contagion was found to be less severe. In sum, the approach of testing for autocorrelation in bank failures seems to have been relatively successful in making the case in favour of the contagion hypothesis. However, the main disadvantages of this approach are that the negligence of macroeconomic factors exhibiting autocorrelation themselves would cloud any evidence of contagion. Multicollinearity need to be handled and the limited number of macroeconomic variables should be taken into consideration. Second, it can only detect intertemporal contagion at the frequencies – monthly, quarterly – of macroeconomic data and not at shorter time intervals. Finally, lack of evidence of contagion from periods when the safety net was at least partly established does not disprove the possibility of bank contagion.

The paper of Gropp and Vesala [2004] analysed contagion in a sample of European banks during 1996-2003 by means of a two stage model. In the first stage, in a Poisson model the number of banks experiencing a large shock was explained with a set of macro and sectoral

\(^8\) Regarding the regulation of the Hungarian interbank market, the lender of last resort role of the Hungarian National Bank will be elaborated in subsection 1.6.

\(^9\) In contrast, for the 1878-1914 period Schoenmaker [1996] estimated, that the current number of failures will rise by 0.38% in response to a 1% increase in the number of failures in each of the three preceding months.
risk exposure variables. The number of banks reflected the number of banks in the tail of the distribution of the percentage change in the distance to default. Gropp and Vesala estimated the distance to default by means of the KMV model\textsuperscript{10} based on monthly averages of the equity market capitalisation. The measure of distance to default took the leverage of the bank, the volatility of the bank’s assets, equity returns and abnormal returns also into account. The inclusion of the sector risk exposure variables into the model improved the fit of the model dramatically. In the second stage the residuals of the regression was used to estimate the probability of an individual bank being in the tail by means of a logit model. More properly, the authors estimated the probability that a bank in a given week experiences a large enough shock, such that its percentage change in the distance to default becomes part of the tail of the distribution of the change in the distance to default over all banks. Basically the probability of a large shock was explained by sectoral shocks and macro variables and by the number of banks in the tail. This latter measure was linked to contagion, to a phenomenon, when a shock to one bank appears in the distance to default of other banks. By means of this two-stage model the authors could answer the question how a shock to an individual bank influences the distance to default of other banks. The approach was intended to generate a contagion variable that is orthogonal to common shocks affecting more than one bank simultaneously. Gropp and Vesala found significant domestic and cross-border contagion. No evidence was found for cross-border contagion from the smaller banks in the sample. However, explained by asymmetric information there was significant contagion from small banks within countries. It was showed, that the introduction of the euro reduced domestic contagion, while no increase in cross-border contagion was found.

The study of Gropp and Moerman \textsuperscript{[2004]} is similar to the paper of Gropp and Vesala from several points of view. In order to test within country and across country contagion among large EU banks Gropp and Moerman examined the co-incidence of extreme shocks to banks’ risk. Banks’ risk was measured by the first difference of weekly distances to default and abnormal returns. Using Monte Carlo simulations, the paper examined whether the observed frequency of large shocks experienced by two or more banks simultaneously is consistent with the assumption of a multivariate normal or a student $t$ distribution. The authors found that in general, within countries and across countries multivariate normality and student $t$ assumptions can be rejected, which implies that there are non-linearities in the tails of the distribution. In particular, it suggests that the distribution of the first difference in the distance to default of each individual bank not only exhibits fat tails, but that the probability of one bank being in the tail is conditional on other banks being in the tail. However the number of banks in the tail, either means that large common shocks are more highly correlated across banks than small common shocks or that idiosyncratic shocks affecting one bank are transmitted to other banks. Gropp and Moerman distinguished common shocks affecting two or more banks from contagion by the help of a non-parametric approach, by defining net-contagious influence. Net contagious influence represents the difference in the conditional probabilities of being in the tail between two banks adjusted for differences in the probabilities of being hit by an idiosyncratic shock. By means of this relatively simple metric the contagion from one bank to another could be identified and systemically important banks in the EU could be determined.

By reviewing briefly papers dealing with intertemporal correlation of bank failures it is inevitable to mention copulas.\textsuperscript{11} Several authors have shown (see for example De Servigny

\textsuperscript{10} The KMV model is a model developed by Moody’s, which serves to evaluate risky credits. (http://www.moodyskmv.com/)

\textsuperscript{11} Putting it simple, a copula is a multivariate distribution function on the $n$ dimensional unit cube with uniform marginal distributions, which allows separating the effect of dependence from the effects of the marginal
and Renault [2002], Das et al. [2005]) that the correlation of probability of defaults of different companies, just like banks, are not constant over time, during crisis periods the correlations increase significantly. The higher correlations in periods of distress can be seen as a signal of contagion.

From the point of view of the Ph.D. thesis studies belonging to the second group and measuring whether effective interbank exposures to certain potentially or effectively failing banks are larger than the capital are of major importance. Instead of analysing historical systemic events the focus is on systemic risk implications of potential systemic events. In general, as a consequence of prudential rules limiting large exposures, banks can only lend a small share of their capital to a single borrower. However large exposures can occur in the correspondent banking networks. Additionally, the size of interbank credit lines can be exempted from large exposure rules, just like in Hungary. The story of Continental Illinois serves again as a good example for correspondent banking networks. As I have mentioned in relation with the credit channel, when Continental Illinois failed in 1984, the bank acted as correspondent bank for nearly 1000 banks at the time. At a loss rate of 100%, 66 banks would become legally insolvent, as these banks had uninsured deposits exceeding 100% of their capital. According to a study prepared by the Congress, if Continental’s losses would have been 60%, then 27 banks would have been legally insolvent and 56 banks would have suffered losses above 50% of their capital. (Kaufman [1994].)

Blåvag and Nimander [2002] analyses the severity and probability of contagion by taking the interbank exposures of the four major Swedish banks into account. The authors used the quarterly reported data of the four big banks. The reporting requirements covered the fifteen largest individual exposures. The assets of the four banks covered 80% of the total assets. The examined period started in September 1999 and ended in September 2001. The 15 largest uncollateralized credit exposures that give rise to the size ranking were uncollateralized lending, holdings of securities issued by counterparties and the credit element of derivative exposures. The 15 largest outstanding foreign exchange settlement exposures were also included – separately – in the reporting. Under direct contagion Blåvag and Nimander considered a situation, in which the exposed bank’s tier 1 capital ratio falls below the statutory 4% level if one of the other Swedish banks defaulted. There have been 16 cases where the exposed bank’s capital fell below the statutory 4%. These 16 cases out of 108 occurred by assuming a full loss of the total exposed amount. If the authors assumed that the losses at default are only 75% of the exposed amounts, the number of cases where the tier 1 capital ratio falls below 4 per cent decreased to 4 cases. If one of the largest foreign counterparties of the four major banks defaulted, there were no instances when the capital ratio fell below the statutory 4% level. That is, the effects on the system from foreign counterparties seem to be smaller than from the domestic counterparties. The risk of direct contagion in foreign exchange settlement is however significant. In the case of default of a large counterparty, a Swedish bank, a Nordic bank, a large Swedish non-financial company or a foreign financial company defaulted. After losing the largest foreign exchange exposures there were no fewer than 12 cases out of 108 in which the capital ratios fall below the 4% threshold, assuming no recoveries. Assuming 25% loss given default on the foreign exchange exposures the number of cases where the capital ratio falls below the statutory level was limited to 6. However the size of the effects of defaults surely has diminished after the introduction of the payment versus payment mechanisms.

distributions. The literature of copulas is pretty diversified, even a brief introduction to copulas is beyond the scope of this Ph.D. thesis. About copulas applied in the financial sector a detailed review can be read in Cherubini et al. [2004].
In the last couple of years several studies were published on the home pages of central banks dealing with contagion. The studies can be classified in the second group of literature aiming to find empirical evidence on contagion by examining financial interlinkages of banks. Empirical papers estimating the proper interbank exposures and addressing by means of simulations the severity and probability of contagion are presented in chapter II of the thesis.

The third, and probably the most popular approach to test for contagion effects turned out to be event studies of bank stock price reactions in response to „bad news.” Bad news can be related to banking business, like the announcement of an unexpected increase in loan-loss reserves or the failure of a commercial bank or can be related to macroeconomic events, like worsening of the rating of a country. The presence of contagion is usually tested by comparing the normal return of a bank stock, as predicted by a standard capital market equilibrium model, such as the CAPM estimated with historical data, to the actually observed returns at the announcement date or during a window around this date. Bad news for a bank A leading to significantly negative abnormal returns of another bank B is interpreted as evidence in favour of contagion.

The forerunners in applying this approach were Aharony and Swary [1983] who studied the effects of the three largest bank failures in the United States, and Peavy and Hempel [1988], who analysed the consequences of the Penn Square Bank failure of Oklahoma in 1982. Swary [1986] applied the same approach to the Continental Illinois National Bank failure in 1983-84 and examined the spill over effect to American banks. At the same time Jayanti and Whyte [1996] looked for changes in stock market values of British and Canadian bank as a consequence of the Continental failure. All above mentioned studies considered bad news as a failure of a bank and the severity of contagion induced by the initial failure was measured by the negative abnormal returns experienced by the stockholders of the surviving banks. By analysing stock market data around the announcement day the authors found in not all, but in most of the cases significant negative abnormal returns, which reflect contagion.

Madura, Mc Daniel and Whyte [1991] analysed the effect of the 3 billion-dollar loan-loss reserve announcement of Citicorp in 1987 on the stock prices of the 13 UK banks. Docking, Hirschey and Jones [1997] studied also the impact of loan-loss reserve announcements on stock prices. The authors covered the effects of 188 announcements by nine leading money-centre banks and 390 announcements by 102 regional banks in the United States from 1985 to 1990. It turned out that there was little impact of money-centre bank announcements on other money-centre banks’ stock prices, but regional banks’ announcements could have detrimental effects on other regional or money-centre banks.12

The study of Slovin, Sushka and Polonchek [1999] could also be mentioned as an example of another event study of bank stock-price reactions in response to bad news, but the conditioning events are taken to be 62 dividend reduction announcements and 61 regulatory enforcement action announcements in a sample of US money-centre and regional banks between 1975 and 1992. The analysis by Brewer and Jackson [2002] is also a prominent example of event studies. However the authors focused on inter-industry contagion effects induced by adverse information about commercial real estate portfolios.

Most of the event studies came to the – not surprising – conclusion, that bad news result in a downfall of stock prices, but generally do not imply failures of financial institutions. Thus, the results reflect firm specific contagion mentioned in relation with the information channel of contagion, as the initial failure did not generated further failures, but bad signals about the banks facing problems also affected negatively other banks with common characteristics. By

12 Basically these results are compatible with the hypothesis that investors better anticipate unfavourable announcements from the large and more transparent money-centre banks than from smaller regional banks.
using the terminology of De Bandt and Hartmann (see page 10) the event studies addressed week systemic events, decrease in stock prices does not necessarily mean bank failures. Besides, another drawback of the model, that it is hard to disentangle news affecting stock prices from each other. At the same time various information can be built into the stock prices, next to the stressed bad news effects of several other news should be studied. Furthermore, by using event time study occasionally, it is also not clear whether the effects measured originate in an aggregate shock or are a reflection of a sequential propagation. Additionally, Gropp, Vesala and Vulpes [2002] have pointed out that cumulative abnormal returns can not be applied to measure all kind of shocks, just like the volatility of profits or growth of leverage. Finally, most of the results of the event studies were found for US data. An interesting question to ask is whether they carry over to other financial systems.

Finally, the last group of studies connect the change of bank debt risk premiums with contagion. These studies examine whether contagion effects can be detected in the market prices of bank debt instruments and whether the announcement of bad news resulted in higher cost of capital as a consequence of higher spreads. These studies (see for example Saunders [1986], [1987], Karafiath, Mynatt and Smith [1991], Cooperman, Lee and Wolfe [1992], Jayanti and Whyte [1996]) build exclusively on American data and using again the terminology of De Bandt and Hartmann (see page 10) usually cannot show the occurrence of systemic events in the strong sense. Last but not least it is worth mentioning the study of Calomiris and Mason [2000], which provides the first comprehensive econometric analysis of the causes of bank distress during the Great Depression. They constructed a model of bank survival duration using fundamental determinants of bank failure as predictors, and investigated the adequacy of fundamentals for explaining bank failures during alleged episodes of nationwide or regional banking panics. Calomiris and Mason found, that county-level, state-level, and national-level economic fundamentals explain most, but not every of the incidence of bank failures. Again, evidence on contagion was found, however only in selected regions of the United States.

13 An exception is the study of Gay, Timme and Yung [1991] in which effects of bank failures in Hong Kong during the 1980s are examined.
1.5. Contagion and the structure of interbank market

The severity and probability of contagion depends on several institutional features. At the interbank market level one important factor determining the degree of contagion is the structure of interbank linkages. The structure of the interbank market can be analysed along various dimensions.

One important dimension of the structure of the interbank market is the concentration of exposures. Banking market concentration is measured by the market share of the most significant banks and by the Herfindahl-Hirschman index.\textsuperscript{14} Several papers deal with the question of the impact of increasing concentration in banking markets on the stability of interbank markets. However the economic theory does not provide an unambiguous response to the relationship between the concentration of the interbank market and the stability of the market.

The study of Boss et al. [2004] showed, that market share in the interbank market alone is not a good predictor of the relevance of a bank for the banking system in terms of contagion risk. Carletti, Hartmann and Spagnolo [2003] examined the effects of bank mergers on reserve management and on interbank market liquidity. They argue that the stability measured by the probability and severity of the banking system experiencing a liquidity shortage following a merger hinges on several factors. The stability is influenced by the structure of the post-merger liquidity shocks to banks, by the cost of refinancing on the interbank market relative to the cost of raising deposits and by the new market shares after the merger. Allen and Gale [2004] address in the article about Competition and Financial Stability from the point of view of welfare economics, the relevant question of what are the efficient levels of competition and financial stability. The authors considered a variety of different models of competition and financial stability, including general equilibrium models of financial intermediaries and markets, agency models, models of spatial competition, Schumpeterian competition and contagion. By using a variety of models, the authors found that different models provide different answers, the relationship between competition and stability is more complex and multi-faceted than a simple trade off. Sometimes competition decreases stability. In addition, in a second-best world, concentration may be socially preferable to perfect competition and perfect stability may be socially undesirable.

According to Degryse and Nguyen [2004] higher degree of concentration results per se in higher risk of contagion. Moreover, concentration increases the probability of a too-big-to-fail type of intervention in a crisis, which may stimulate ex ante risk-taking behaviour on the part of large banks and increase the impact of a crisis.\textsuperscript{15} By taking 25 banks from Chile as a basis of the study Cifuentes [2003] explored the impact of banking concentration on systemic risk and arrived to a similar conclusion. The concentration of banks in Chile was approximated by the distribution of tier 1 capital among banks and by the number of interbank linkages. The banking market was more concentrated if share of total loans of the largest five, ten, fifteen banks and the Herfindahl–Hirschman index was higher. By means of simulations Cifuentes explored the impact of different structures of interconnections. In particular, the impact of

\textsuperscript{14} The Herfindahl-Hirschman index (HHI) shows the sum of the squares of the individual banks’ market share expressed in a percentage form. Accordingly, the maximum of the index is 10 000, if this case one market participant owns 100% of the market. According to the Horizontal Merger Guidelines of the United States the market is highly concentrated if the Herfindahl-index is above 1800. The market is moderately concentrated if its HHI is between 1000 and 1800 and the market is not concentrated if its HHI is under 1000. (1997 Merger… [1997].)

\textsuperscript{15} It is pretty hard to test empirically the relationship between concentration and contagion as in reality the impact of concentration can not be separated from other impacts.
varying the number of counterparties with which banks interact was studied. In a given scenario the number of counterparties were supposed to be the same for all banks and ranged from three to twenty both on the borrowing and lending side. After simulating bilateral interbank positions and individual bank failures Cifuentes concluded, that the risk of idiosyncratic shocks spreading through the system are substantially higher in concentrated systems than in decentralized ones. In concentrated banking market measured by the differences in capital structures and by the number of interbank linkages the incidence and severity of contagion increased significantly.

A second important dimension of the structure of the interbank market is the **network topology** of the connections, that is, the structural features of interbank linkages. In the article of *Financial Contagion* of Allen and Gale [2000] two main network topologies was distinguished. As shown in Figure 1 interbank market can be complete and incomplete. In a complete interbank market all banks are connected to all other banks, and before the decision of the customers the size of the interbank deposits is the same. In an incomplete interbank market in the base case (Figure 1, case A) banks have a direct claim only on the neighbouring banks. Thus, in a banking system of four banks, bank A deposited its surplus funds at bank B, bank B at bank C, bank C at bank D, and finally bank D at bank A.

Figure 1: Complete and incomplete interbank market structure

![Complete and Incomplete interbank market structure](image)

Source: Allen and Gale [2000].

A special case of the incomplete interbank market, when banks belong to not one, but two closed systems, see Figure 1, case B. Again, in banking system of four banks, banks A and B transact with each other in the interbank market, and banks C and D deposit their surplus funds to each other reciprocally. In this case banks belong to one of the closed systems, inside the closed system there exist interbank linkages, however the separate systems are not linked. Incomplete markets can came into existence due to several reasons, one possible explanation emphasize the role of transaction costs and information asymmetry.

In the article of Allen and Gale [2000] – based on the model of Diamond and Dybvig [1983] – there exist four regions, and in each region operates one representative bank. In the model consumers deposit their endowments in the banks and on behalf of the depositors banks invest in short term and long term assets. The provision of insurance against a liquidity shock is organized through the deposits of interbank market. The economy was divided into four ex

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16 One of the newness of the model is the introduction of the term region. Allen and Gale suppose that the economy consists of a number of regions and that the number of early and late consumers in each region
ante identical regions, however different regions received different liquidity shocks. Each region contained a continuum of ex ante identical consumers. Banks exchange deposits at the first date before they observe the liquidity shocks, the randomly fluctuating number of early and late consumers in each region. At the first date the consumers meet their decision, with a given probability they are early consumers and only value consumption at the first date, or they are late consumers and only value consumption at the second date. As a consequence representative bank at the first date has to face the possibility that the fraction of early consumers in its region may be above average, in which case it will need more liquid assets to satisfy the demands of the early consumers. At the second date – depending on the decision of the consumers – the representative bank either withdraws its interbank deposits or leaves it unchanged. In regions suffering a negative liquidity shock banks can meet the demand of depositors by liquidating short term investments held to maturity, withdrawing interbank deposits and it could happen that the only way to provide more consumption is to liquidate the long asset. However liquidating long assets is very costly, so banks try to avoid doing this whenever possible. If banks are allowed to exchange deposits at the first date, the costly liquidation of long assets can be avoided, as interbank deposits are perfect substitutes. Regions with high demand for liquidity liquidate all of its deposits in other regions, meanwhile regions with low demand for liquidity retain interbank deposits in the other regions until the final date. At the second date the opposite happens, regions in which late consumers are dominant withdraw there interbank deposits from regions where early consumers prevailed. Interbank liabilities are paid back fully, and all long term investments mature. Ex ante each region has the same probability of having a high liquidity preference shock. At the beginning banks are aware of the possible realizations and probabilities of the liquidity preference shocks, however they can not observe which consumer’s type will be dominant in that corresponding region. This can only be observed at the first date. As the aggregate demand for liquidity is constant, inter-regional insurance is in place as regions with liquidity surpluses provide liquidity for regions with liquidity shortages. In this case, banks regardless of the structure of the interbank market can mitigate liquidity risk and avoid bank failure.

In the model of Allen and Gale [2000] the contagion is related to the insufficient aggregate liquidity which spread through the credit channel. Interbank market plays a role in allocating liquidity, in the case of insufficient aggregate liquidity banks are not able to provide additional liquidity to the system. The aggregate demand for liquidity can be greater than the system's ability to supply liquidity due to several reasons. In this case the demand for liquidity in one region is somewhat higher and as a result, the average demand for liquidity across four regions is slightly higher than in normal states. In the model it is assumed that late consumers will always withdraw their deposits in the final stage if it is at least weakly optimal for them to do so. That is, they vote for a solution which gives them the larger amount of consumption. By assuming complete information this means, late consumers only run the bank at the first date, if after the complete liquidation of interbank deposits and short term investments banks have started liquidating its long assets. And long assets were liquidated at such a huge loss, that late consumers would be worse off at the final date. If the liquidity shock is high enough, then the liquidity preference shock in one region can spread by contagion throughout the

fluctuates randomly. The term region should be understood in a transferred sense, and refers to the situation that banks operating in an economy differ along certain criteria. For example some banks have easy access to funds, meanwhile others are good at providing credits. Additionally, banks can differ in the number and group of interbank counterparties. The relevance of the regions defined by Allen and Gale is supported by the fact, that it is suitable for the current Hungarian banking business. In Hungary a couple of banks have easy access to retail funds, others are specialized in corporate customers. There are groups of banks focusing on project financing, agricultural credits or on financing financial corporations, and so on.
economy. When one region suffers a bank crisis, the other regions suffer a loss because their claims on the troubled region fall in value. If this spill over effect is strong enough, it can cause a crisis in the adjacent regions. In extreme cases, the crisis passes from region to region and becomes a contagion. The severity of contagion depends mostly on the volume of liquid assets in distressed regions and in the rest of the regions. This latter one can decrease dramatically as a consequence of interbank deposit withdrawals. Contagion is spread in the system by means of reduction in the value of interbank liabilities of the failing banks which is proportional to the reduction in the asset value. Depending on the severity of the liquidity shock, this reduction can lead to the failure of the whole banking system. Besides, contagion depends on the loss realized at the liquidation of long assets, on the volume of interbank deposits, and on the structure of the interbank market. However the capital endowment of the banks does not influence the severity of contagion, the role of capital in absorbing shock is neglected in the model. In the study of Allen and Gale a bank is said to be bankrupt if it cannot meet the demands of its depositors by liquidating all its assets as a consequence of high liquidation cost of long term investments.

Allen and Gale showed that in the case of aggregate liquidity shocks if the interbank market is complete, that is, each region is connected to all the other regions, the initial impact of a financial crisis in one region may be attenuated. If the interbank market is complete the probability and severity of contagion is lower than in the case of incomplete market. In spite of the fact that the article of Allen and Gale is full of equitation, the idea behind it is simple. If the market is complete, as losses resulting from a liquidity shock affect several banks. If every region takes a small hit, that is, liquidates a small amount of the long asset there may be no need for a global crisis. This is what happens with complete markets. Banks in the troubled region have direct claims on banks in every other region and there is no way to avoid paying one's share. On the other hand, if the interbank market is incomplete and, as a result, each region is connected with a small number of other regions, the initial impact of the financial crisis may be felt very strongly in those neighbouring regions, with the result that they too succumb to a crisis. As each region is affected by the crisis, it prompts premature liquidation of long assets, with a consequent loss of value, so that previously unaffected regions find that they too are affected because their claims on the region in crisis have fallen in value. That is, with incomplete markets, banks in the troubled region have a direct claim only on the banks in adjacent regions. The banks in other regions maximize their own interests and refuse to liquidate the long asset until they find themselves on the front line of the contagion. In the case of incomplete interbank market the probability of contagion also depends on the connectedness of the banks. Figure 1, case A reflected a market with high level of connectedness. The level of connectedness would be low, if the interbank market structure would reflect the network topology shown in Figure 1, in case B. In incomplete markets if the level of connectedness is high the probability of contagion is also higher, meanwhile if the level of connectedness is lower, the probability of contagion is also lower. Allen and Gale also distinguished an alternative market structure, the so called partially incomplete market structure, which compound elements of the complete and incomplete interbank market. If the market is partially incomplete, this means that looking at Figure 1, case A the arrows go back and forth, that is, for example bank C have deposited surplus funds both in bank B and bank

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17 More precisely, by assuming same parameter values in the case of complete market there exists an equilibrium in which no bank run happens, meanwhile in the case of incomplete market no such equilibrium exists.

18 If the market is complete, the level of connectedness can only be high as all banks are linked to all other banks in the system. If the market is complete and banks are strongly connected the probability of contagion is low, as there exists an equilibrium in which no contagion is experienced.
In this case the probability of contagion is higher than in the case of complete market, but lower than in the case incomplete market with high connectedness.\textsuperscript{19}

The paper of Sáez and Shi [2004] re-evaluates the model of Allen-Gale [2000] analysis of interbank deposits to explain financial contagion. The authors showed that under certain circumstances the pecking order of liquidation – liquid assets, interbank deposits and investments – can be violated, but such a violation avoids financial contagion. If the excess liquidity demand is not too high, however the cost of liquidation interbank deposits is significant, the bank facing problems has an incentive to liquidate long assets before withdrawing interbank deposits. Whenever a bank is hit by excessive liquidity demand and becomes bankrupt another bank could have the incentive to violate the liquidation order and liquidate its long assets to help the bank in trouble. The authors call this phenomenon as a selfless sacrifice. By undertaking such a course of action, the bank also saves itself from bankruptcy. Under these exceptional circumstances the probability of contagion is reduced regardless of the interbank market structure.

In the model of Elsinger, Lehar and Summer [2003] the authors compared the number of contagious defaults based on different interbank market structures. The first interbank matrix exploited the structural information about the multi-tier architecture of the Austrian banking system. 72% of the interbank matrix was known, missing cells were estimated by means of entropy optimization.\textsuperscript{20} The second interbank market structure reflected a complete structure, that is, a network topology of the interbank market where all banks were connected with each other by claims or liabilities. The theoretical findings of Allen and Gale [2000] could not be justified empirically. The complete market structure lead to an increase in scenarios with contagious defaults by roughly three percentage points, form 1.35% to 4.2%. As a consequence, Elsinger, Lehar and Summer concluded, that more diversification, putting it other way, less concentration in the interbank market does not necessarily reduce the risk of contagion. The classification into complete and incomplete structures does not give the whole story when the role played by the network topology of interbank linkages for financial fragility of a banking system was investigated.

Allen and Gale [2000] assumed constant bank portfolios over time. Under the assumption of 0% loss given default the findings of Cifuentes, Ferrucci and Shin [2004] was consistent with that of Allen and Gale [2000], even when institutions marked their assets to market. However, by incorporating the possibility of marking to market of asset book and the possibility of falling asset prices if the loss given default is higher than 0% the results of Allen and Gale can be disproved. Cifuentes, Ferrucci and Shin showed that if balance-sheet adjustments take place by selling liquid assets it is possible, that the fall in the price of the illiquid asset may be higher in the case of more interconnections. If the price fall is larger, adjustments to comply with capital requirements by other banks will also be higher. This implies that the endogenous process of price reduction that is being unleashed can be of wider magnitude in the case of a higher number of counterparts. By increasing the number of counterparts and getting more near to complete interbank market structure the chain of asset sales is longer, the fall in asset prices is more drastic and the number of contagious defaults is higher. That is, more interconnected systems can lead to more systemic risk also in a world without price contagion, as in Allen and Gale, if shocks are large enough. However, an unrealistically high loss given default – 400% – should be assumed. This non-linear response to a shock with

\textsuperscript{19} One of the most important drawbacks of the model, that it does not handle the fact that central banks can easily overcome shocks resulting from insufficient aggregate liquidity. However by means of the analytical framework developed by Allen and Gale the link between the structure of the interbank market and the contagion can be captured.

\textsuperscript{20} The method of entropy optimalization and the reasoning behind it will be explained in subsection 2.1.2.1.
respect to the number of interconnections was one important finding of the simulation exercise of Cifuentes, Ferrucci and Shin. Under certain circumstances more intense interbank relations could mean higher risk of contagion.

Next to the two main structures of Allen and Gale [2000] Freixas, Parigi and Rochet [2000] have distinguished a new interbank market structure, namely interbank market with money centre. The money centre is symmetrically linked to other banks of the system, but those other banks are only linked together through the money centre.

In the study of Freixas, Parigi and Rochet banks face liquidity needs as consumers are uncertain about where they need to consume. Interbank credit lines allow coping with these liquidity shocks while reducing the cost of maintaining reserves. At time 0, consumers deposit their endowment in the bank of their location. The authors considered an economy with \( N \) locations with exactly one bank in each location. The bank either stores or invests the deposit of customers for future consumption. In the model a spatial dimension was introduced, a fraction of the late consumers, the so called travellers need the good at date \( t = 2 \), must consume in other locations. The remaining depositors consume at \( t = 2 \) in the home location. To consume at \( t = 2 \) at another location the travellers can withdraw at \( t = 1 \) and carry the cash by themselves or can have their deposits transferred. In order to avoid liquidating long term investments and minimizing the value of foregone investment returns banks offer credit lines to each other. The credit line granted by a bank \( A \) to bank \( B \) gives the depositors of bank \( A \) going to bank \( B \) the right to have their deposits transferred to location \( A \) and obtain their consumption at \( t = 2 \) as a share of the assets at bank \( B \) at date \( t = 2 \). The interbank network established through credit lines disappears at \( t = 2 \) as banks compensate their claims and transfer the corresponding amount of the good across space. A two period model is adopted, the bank is liquidated anyway, either at \( t = 1 \), or at \( t = 2 \) and customers also withdraw all of their deposits, latest at \( t = 2 \). If all banks are solvent and liquidity shock occurs only as a consequence of geographical preferences there are at least two pure strategy equilibria. In the credit line equilibrium interbank market based on interbank credit is efficient, banks fulfil all of their obligations and no contagious run happens. In gridlock equilibrium, in the presence of illiquid investments, interbank relations expose the system to the possibility that a coordination failure arise even if all banks are solvent. If consumers wishing to consume in other locations believe that there will not be enough good left for their consumption at the location of destination, their best response is to liquidate early their investment at the home location, which by backward induction, makes it optimal for consumers in other locations to do the same. In this case all the banks’ assets are liquidated. Basically in speculative gridlock equilibrium it is not the banks that do not honour the credit lines, rather are the depositors that, by forcing the liquidation of the investment, reduce the amount of resources available at \( t = 2 \).

According to Freixas, Parigi and Rochet poor return of its investment leads one bank to insolvency. The authors investigate contagion in function of number of banks, turnover of the interbank market, that is, the proportion of depositors consuming in another location and structure of interbank market. Regardless of the interbank market structure, as the number of banks or proportion of travellers increases, the system becomes less exposed to market discipline. As it is intuitive, when the number of banks increases, the insolvency of one bank has a lower impact on the value of the deposits in the other banks. Similarly, an increase in the fraction of travellers spreads on the other banks a larger fraction of the loss due to the insolvency of one bank. Freixas, Parigi and Rochet tackled the issue of the impact of the insolvency of one bank on the rest of the system by analysing three possible interbank market structures established through credit lines. The structure of the payment flows implied by credit chain interbank funding is similar to the perpetual, incomplete market structure of Allen
and Gale [2000]. With credit chain interbank funding it is convenient to think that the consumers are located around a circle. All travellers go from their location to the clockwise adjacent location, where they must consume at $t = 2$. The payments structure implied by this travel pattern generates that credit flows in the direction opposite to travel. With diversified lending every bank gives credit lines uniformly to all other banks. This market structure is similar to the complete market structure of Allen and Gale. In the case of interbank market structure with money centre there is one bank with a key position in the interbank market. The other two banks have peripheral locations which are only linked to the money centre. Bank at periphery are not directly linked to each other. In the model Freixas, Parigi and Rochet showed that in case of the insolvency of one bank, the system is more exposed to market contagious defaults under diversified lending than under credit chains. Intuitively, in a diversified lending there is more diversification so that solvent banks exchange a larger fraction of their claims. As a consequence in a diversified lending the insolvent bank is able to pass over to the solvent banks a smaller fraction of its losses. The authors have also proved, that the liquidation of the money centre bank can trigger the liquidation of all other banks. However the liquidation of banks at periphery does not trigger the liquidation of any of the other two banks.

In Hungary the savings co-operative sector can be described as a structure with money centre. The role of the money centre is played by the Magyar Takarékszövetkezeti Bank (Bank of Hungarian Savings Co-operatives Ltd., henceforward Takarékbank). The Takarékbank which was established in 1989 by the savings co-operatives plays a very special role in the co-operative sector. According to an agreement signed in October 1993 159 savings co-operative institutions belonging to the National Institutional Insurance Fund of Savings Co-operatives (OTIVA) have to manage their banking account at the Takarékbank. (Katz [2003].) That is, Takarékbank is a special bank acting both as a central bank and as a commercial bank. As the central bank of the Hungarian savings co-operative sector, the bank provides products and services to the savings co-operatives. At the same time as a commercial bank by accepting the principle of subsidiarity Takarékbank provides services to key customer groups.²¹

One special case of interbank market structure with money centre which reflects the reality better when there is not one, but multiple money centres, just like in Belgium. (Degryse and Nguyen [2004].)

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Figure 2: Interbank market structure with money centres

![Interbank market structure with money centres](image)

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²¹ As a consequence of the special role played by the Takarékbank in the savings co-operative sector, in the empirical part of the Ph.D. thesis it would be interesting to investigate what would happen with the 176 savings co-operatives if Takarékbank would default. However this kind of research can not be carried out, not only the...
If there are multiple money centres in the banking system we can distinguish between two different interbank market structures depending on the linkages of banks at periphery. In both cases money centres transact with each other regularly. However in the first case banks at periphery are only linked to one money centre, meanwhile in the second case at periphery banks are linked to most or all of the money centres. That is, banks at periphery are directly not linked to each other. They are only connected indirectly, through the money centres. The different types of interbank market structure with money centres are shown in Figure 2. Of course, in reality, as we will see in subsection 2.3. apropos of the review of network theoretical models, the interbank market structure can be truly complex reflecting a complicated combination of the above mentioned interbank market structures.

Thurner et al. [2003] combined the findings of network theory with an iterative risk-trading game between several agents who build their trading strategies based on a general utility setting. The game is studied numerically for different network topologies. The authors introduced measures which characterize the performance of different network topologies with respect to overall fairness and stability of the network, individual safety, that is, survival probability, the efficiency of reducing exogenous, externally enforced risk and consequences of regulation. In the iterative dynamical model agents, that is, banks can choose between different trading strategies, depending on their need to reduce individual risk. Banks are equipped with a von Neumann-Morgenstern utility function with a given risk aversion. The essence of the model is that this risk can be traded away, if the bank is able to find a neighbour bank, which is willing to enter a betting contract which serves to reduce this risk. Thurner et al. came to the conclusion, that by increasing the average number of interbank linkages, the probability of a systemic event decreases. Additionally the authors have proved that in a highly regulated banking system the topology effect is small, in the unregulated world, however, a large connectivity has a mayor impact on reducing the number of defaults. Thurner et al. experienced that the denser the interbank network is, the higher the mean first-default-times is. It is worth mentioning that by increasing the number of cycles composed of three links the systemic risk became higher. This result implies that in regulated regimes banking systems with risk-sharing co-operations have higher global risk than systems with lower cyclicality.

By artificially removing a single large, wealthy bank from the network at a given simulation time-step Thurner et al. concluded that the spread of the crisis depends heavily on the network topology, and ranges from small, locally bounded events to the total collapse of the network. In these sets of simulations contagion meant that the default of a given bank significantly increased the default probability of its neighbours. However as the authors found these results hard to visualize over the course of time, and they did not present them.

1.6. Contagion and regulatory authorities

According to Tarafáš [1999] the function of the regulatory authorities is to limit risks accumulated in the banking sector that can threaten the stability and the functioning of the system. The role of regulatory authorities responsible for financial stability is crucial in data at disposal are limited, but the Act XLVI of 1993 on Statistics related to disclosure should also be taken into account.
preventing and managing systemic risk events and contagious defaults. Strong systemic events may involve external effects; that is, in the case of contagious failures the private costs of the initial failure can be lower than the social costs. As a consequence, individually rational bank may operate with higher risk than would be socially optimal. Thus, bank management may lead to a higher level of systemic risk than the desired level. Basically this is one, may be even the fundamental rationale for the regulation and supervision of banks; a pre-emptive policy to avoid the emergence of systemic problems, in contrast to ex post policies, like crisis management. It is worth mentioning that in this sense, the socially optimal probability of bank failures is not zero, the failure of a badly managed bank can be desired.

According to the widely spread international practice central banks are responsible for macro prudential regulation by means of their role as a crisis manager. In the focus of the central banks stands the ability of financial institutions to absorb shocks, the consideration and management of exogenous and endogenous risk factors are of major importance. In the case of many central banks, just like the Hungarian National Bank the promotion of the stability of the financial system and the development and smooth conduct of policies related to the prudential supervision of the financial system is defined as one of the basic tasks. (Act LVIII of 2001 on … [2001], 4. § (7).) The operative tasks of the central bank related to the stability of the financial system include the analysis of systemic stability from macro prudential point of view, monitoring of systemic risk, occasional intervention, participation in the regulatory process, and modernization and improvement of regulation. The most important tools of the central banks cover central banks inspections, conduction of restrained on-site inspections from non prudential point of view, crisis prevention through analysis and communication, that is, „conversation” with market participants, so called moral influence.

Central banks take the role of lender of last resort and provide emergency liquidity assistance to individual banks. By means of this potential policy response to individual failures, the likelihood of causing contagion can be diminished or eliminated. Emergency loans can be provided in distressed situations. The lender of last resort role of the Hungarian National Bank is declared in article 14. of the Central Bank Act. „In the event that circumstances arise which jeopardise the stability of the financial system due to the operation of a credit institution, the Hungarian National Bank may extend an emergency loan to the credit institution.” (Act LVIII of 2001 on… [2001], 14. §.) The discretionary character of the regulation aims to diminish the risk of moral hazard. The importance of emergency loans extended by central banks can be best captured by the story of the Bank of Credit and Commerce International. In June 1991, an incident that has been described as the biggest bank fraud in history came to a head when regulators in seven countries raided and took control of branch offices of the Bank of Credit and Commerce International. In addition to legitimate banking activities BCCI was involved in dubious lending, fraudulent record-keeping, rogue trading, flouting of bank ownership regulations and money laundering. Following the closure of BCCI several individual and local governments transferred their deposits from a

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22 In order to support and promote financial stability it is inevitable that market participants are informed about the state and tendencies of the financial system and about the economy in which it operates. As a consequence, since August 2000 the Hungarian National Bank publishes its Report on Financial Stability every half a year. The Hungarian National Bank undertakes a regular and comprehensive analysis of the macroeconomic environment, the operation of the financial markets, domestic financial intermediaries and the financial infrastructure, reviewing risks which pose a threat to financial stability and identifying the components and trends which increase the vulnerability of the financial system. The primary objective of the report is to inform stakeholders on the topical issues related to financial stability, and thereby raise the risk awareness of those concerned as well as maintain and strengthen confidence in the financial system.

23 The story of BCCI can be read in detail on the webpage of ERisk. Go to: http://www.erkisk.com/Learning/CaseStudies/ref_case_bcci.asp.
smaller bank to a larger bank. However the aggregate liquidity supply remained unchanged, the closure was an important factor behind major financial firms being less willing to lend to small UK banks. As small banks suffered from insufficient liquidity supply, the Bank of England had to intervene. (Michael [1998].)

The lender of last resort role of the central bank is strongly related to the „too-big-to-fail” doctrine. From systemic risk point of view this unwritten doctrine means that regulatory authorities could not allow large, systematically relevant banks to fail. The unwritten and discretionary character of the doctrine can be related to the fact that now it is widely recognised that public safety nets, whichever form they take apart from the beneficial stabilisation effects bear the risk of creating moral hazard. Why should not take banks excessive risk, if central banks bail them out anyway? (Bernard and Bisignano [2000].) The explicit awareness of „too-big-to-fail” or „to sophisticated to fail” can be accompanied with the reduction of monitoring by investors.

In connection with the lender of last resort function of the central banks, Freixas, Parigi and Rochet [2000] emphasize the central banks’ role as a ”crisis manager.” By guaranteeing the credit lines of all banks, the central bank can eliminate any incentive for early liquidation. Contagious failures can be prevented as depositors have no more incentive for speculative gridlocks. If the banking system as a whole is solvent the costs of the coordination role of the central bank are negligible and its distortion effects may stem only from moral hazard issues. However if one bank is insolvent, as the closure of insolvent banks may cause systemic repercussions, the central bank faces a much more complex trade off between efficiency and stability. In this case, according to Freixas, Parigi and Rochet, two courses of actions are available. The central bank should orderly close or bail out the insolvent banks. Given the interbank links, the closure of an insolvent bank must be accompanied by the provision of central bank liquidity to the counterparts of the closed bank. Similar course of actions are suggested by Rochet and Tirole [1996], and Sáez and Shi [2004]. The authors argue that systemic risk can be best minimized by means of centralized liquidity management. Under this kind of liquidity management Rochet and Tirole meant a payment system in which central bank acted as counterparty and guaranteed the finality of payments. As in this case the central bank bears the credit risk if one of the sending banks defaults, so the central bank should ask for collaterals in order to scope with this kind of risk. One of the most important drawbacks of centralized liquidity management is that the advantages of a flexible interbank market would disappear. Sáez and Shi [2004] suggested the establishment of a liquidity pool that can both achieve risk sharing and greatly reduce the chance of financial contagion. The authors showed that as a consequence of a liquidity pool the probability of contagion was reduced both in the case of complete and incomplete interbank markets defined by Allen and Gale [2000]. The „fund manager” of the liquidity pool is able to isolate the failing bank form the others and thus prevent contagious failures.

Supervisory authorities being responsible for prudential surveillance play also an important role in assuring financial stability.24 Efficient prudential supervision limits the

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24 In most of the countries the basic task of the supervisory authorities is the micro prudential surveillance of banks. Thus, the authorities are not responsible for managing systemic events, as it does not have sufficient tools to intervene in cases when macro prudential tools would be required. The basic tasks of the Hungarian Financial Supervisory Authority (HFSA) include the regulation of the market and micro prudential analysis and surveillance. In the focus of the HFSA are the individual institutions and related exogenous risks, the aim of the actions is to prevent crisis. According to the CXXIV Act of 1999 on the Hungarian Financial Supervisory Authority, the aim of the Supervision's activities shall be to promote and monitor the undisturbed and effective operation of the money and capital market, the protection of the interests of financial organisations' clients, the transparency of market conditions, the strengthening of confidence in financial markets, and in order to maintain fair market competition, to promote and monitor the prudent and efficient operation of organisations (…) and the
danger of contagion ex ante in a number of ways, mostly by means of prudential regulation and regular on-site inspection. By forcing or encouraging banks to behave more prudently banking supervision aims at reducing the incidence of individual failures and thus the probability of contagion.

Prudential regulations of banks related to the capital endowment of the institutions are of major importance. Banks with high capital adequacy ratio are able to absorb larger shocks more easily. Banks with high capital adequacy ratio, even when assets are marked to market and banks have extended interbank relations are less prone to generate systemic events.

As a result of actions taken by the supervisory authority not only the probability of default, but also the loss given default, that is, the severity of contagion can be reduced. One possible measure consists of the quick liquidation of the failing bank, which result in higher recovery rate, that is, lower loss given default rate. Kaufman [1994] argues, that if banks in trouble are liquidated as soon as possible, the major part of uncollateralized claims will recover, as the value of total assets of a bank will not fail to zero from one day to the other. Elsinger, Lehar and Summer [2003] have proved empirically, low bankruptcy costs and an efficient crisis resolution policy are crucial to limit the system wide impact of contagious default events. The relation between contagious defaults and bankruptcy costs is nonlinear, once bankruptcy costs exceed a certain threshold, the number of contagious defaults increases quite dramatically. The authors experienced little contagion for low bankruptcy costs and very high contagion for levels above 30%. The jump in the maximum number of contagious defaults clearly showed that financial stability can be enhanced when bankruptcy costs are kept low.

Banking regulation may limit the exposures of banks to any single debtor or group of debtors, which in turn reduces the scope for contagion. By limiting the volume of interbank assets and liabilities the supervisory authority can basically hinder the existence of large interbank positions. However, as I have mentioned in relation with the credit channel, interbank exposures are mostly exempted from large exposure regulations. According to the current Hungarian regulation in the several times amended Act CXII of 1996 on Credit Institutions and Financial Enterprises in the part related to large exposures it is stated, that „aggregate volume of net exposures taken by a credit institution to any single debtor or group of debtor should not exceed 25% of the regulatory capital of the institution” (79. § (2).) and that „overall volume of large exposures taken by a credit institution should not exceed 800% of the regulatory capital of the institution.” (79. § (3)) However, as stated in annex 2 of the corresponding Act in relation with III. Other determinations, part 10.2. d) under 79. §. exposures should not be considered as large exposures if „exposures are taken to a credit institution residing in a country of zone A and the maturity of the exposure is less than one year, unless the exposure is part of the regulatory capital of the credit institution.” This regulation means that for interbank exposures with short term maturity no large exposure limit should be applied. However it is worth mentioning that the internal limit system of banks also cover counterparty limits against credit institutions, that is, self-regulation of banks make up an effective limit.

Deposit insurance system is able get over contagion through the information channel. For example Freixas, Parigi and Rochet [2000] hold a brief for deposit insurance, as by guaranteeing the value of deposits at the consumption locations deposit insurance eliminates any incentive for the depositors to protect themselves by liquidating the investment, thus careful exercising of rights by the owners.” (Act CXXIV of 1999 on … [1999], 2. §.) The most important tools of the HFSA include participation in the elaboration of financial laws, on-site and off-site inspections, taking sanctions, like penalties, suspensions, withdrawing operational permission, and communication, that is, informing and cooperating with market participants.
making it optimal for banks to extend credit to each other. Diamond and Dybvig [1983] have pointed out in their study that by means of government deposit insurance unconstrained optimum as a unique Nash equilibrium can be achieved, if the government imposes a certain amount of tax on all wealth. The key social benefit of government deposit insurance relies on the fact that banks can follow a desirable, profit maximising asset liquidation policy, which can be separated from the cash flow constraint imposed directly by withdrawals. Deposit insurance prevents run, because for all anticipated withdrawal policies of agents, it never pays to participate in a run. The magnitude of the tax imposed is not indifferent, too high taxes can result in higher cost of capital and distort resource allocation, which can turn out to be more costly than the absence of deposit insurance. On the other side, too low taxes make the implementation of deposit insurance impossible.

Deposit insurance is part of the banking system in market economies. The National Deposit Insurance Fund of Hungary was established in 1993. The aim of the Fund is to maintain people's trust in credit institutions through deposit insurance and to protect small depositors. Deposit insurance can not be seen as a preventive crisis management tool, the goal of the regulation is to minimize the impact and the cost of a failure of a specific financial institution on the national economy. Deposit insurance is strongly related to the importance of a given institution in the economy, as the institution is a trustee of the confidence of depositors. In Hungary all credit institutions must join the National Deposit Insurance Fund, hereinafter the NDIF. The NDIF is responsible for taking action to prevent the freezing of deposits and for paying depositors an indemnity should the deposits placed with a credit institution that is a Fund member be frozen. In the light of the regulation the NDIF has to consider on the basis of the principle of smallest possible cost the possible ways to avoid freezing of deposits. The Fund can even assume other commitments to facilitate the beneficial effects of special measures, as well as to avoid the freezing of deposits. (Act CXII of 1996 on...[1996], Section IV.)

Next to deposit insurance regulatory authorities can handle bank runs and bank panics related to the information channel of contagion effectively by means of suspension of convertibility contracts. Diamond and Dybvig [1983], and Gorton [1985] urge the suspension of the withdrawal. They argued that under incomplete information the noisy signal could sometimes trigger rational but inefficient runs. The author showed that this problem can be resolved by adding a suspension of the withdrawal possibility to the deposit contract, so that banks can signal the mutually beneficial continuation of investments and thereby approximate the complete information world. If by means of signals the bank can demonstrate the high quality of its assets and the solvency of the institution the run stops. If the bank is not able to send positive signals about the state of the institution, the bank run was justifiable as fundamentals of the bank confirm the decision of the depositors. One drawback of the suspension, is that it can also be used unprovoked, which result in an ex post inefficient situation.

Finally, it is worth mentioning that in spite of the fact that regulation aims to assure prudential operation of financial institutions, under certain circumstances regulation can lead to undesirable contagion and can be a source of systemic risk. As an example the one-period model of Eichberger and Summer [2004] can be mentioned, in which the authors analyse the impact of capital adequacy regulation on probability of bank defaults and systemic stability. In the model systemic risk is related to correlated portfolio positions of the banking system.

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25 One of the main dangers of the institutionalized deposit insurance schemes is the appearance of moral hazard, as deposit insurance can lead to a rise in the risk taking appetite of both banks and depositors.

26 The principle of smallest possible costs mean the course of action that bears the least amount of longterm loss for depositors, credit institutions and the central budget alike.
and domino effects appear as a consequence of interbank exposures resulting from liquidity management. The authors assumed interlinked heterogeneous banks and modelled the impact of bank activities on the real economy, as well. Eichberger and Summer show that the impact of capital adequacy on systemic stability is ambiguous, as systemic risk might actually increase as a consequence of imposing capital constraints on banks. By taking indirect consequences of capital adequacy regulation also into account the capital endowment of individual banks tend to increases, however as a consequence of the higher volume of interbank exposures which have lower risk weight the risk of contagious default increases. Additionally, systemic risk is further enhanced by falling interbank rates which decreases refinancing costs for the unconstrained banks and boosts credit in these firm groups.

Several authors have showed that regulation increases systemic risk by generating vicious feedback loops. Danielsson and Shin [2002] mention the functioning of VaR models. VaR models were recently accepted by the Basle committee to measure the riskiness of a portfolio. Basically VaR models estimate how much a portfolio could lose in a single bad day. If assuming 99% probability that amount gets too large, the VAR model signals that the bank should sell. The trouble is that lots of banks have similar investments and similar VAR models. In periods when markets everywhere decline, the models can tell everybody to sell the same things at the same time. The liquidation of risky positions at the same time makes market conditions much worse. In effect, VaR models can, and often do, create a vicious feedback loop. In the model of Cifuentes, Ferrucci and Shin [2004] an initial shock reduced the market value of a firm’s balance sheet will, which elicited the disposal of assets or of trading positions. The authors showed that if the market’s demand is less than perfectly elastic, such disposals will result in a short run change in market prices. When assets are marked to market at the new prices, the externally imposed solvency constraints, or the internally imposed risk controls may dictate further disposals. In turn, such disposals will have a further impact on market prices. In this way, the combination of mark-to-market accounting and solvency constraints has the potential to induce an endogenous response that far outweighs the initial shock.

1.7. Contagion related to payment and settlement systems

The stable and safe functioning of interbank payment systems is crucial for the financial stability of the whole system. This is also reflected in the Central Bank Act of Hungary, in which the development of the payment and settlement systems and monitoring their activities in order to achieve sound and efficient operation and smooth money circulation are listed as basic tasks of the Hungarian National Bank. (Act LVIII of 2001 on … [2001], 4. § (5).) The reasoning behind the subsection devoted only to payment and settlement systems is the fact, that the payment system serves as an intermediate and under certain circumstances can transmit problems from one institution to other institutions. In this way insolvent or illiquid banks can jeopardize the stability of the payment system, and so the stability of the financial system.

In Hungary two interbank settlement systems operates side by side. The VIBER (Valós Idejű Bruttó Elszámolási Rendszer) is a real time gross settlement system. The essence of the real time gross settlement system is that the moments of clearing and settlement are not separated in time, booking is managed item by item continuously and in real time. In Hungary the VIBER was designed to handle the payment and settlement of high value, urgent interbank
transactions, which occur in small numbers.\textsuperscript{27} The gross system is based on the central bank’s account management service. In VIBER the processing of payment orders and their final settlement takes place continuously, while notifying participants concerned in real time. Each settlement takes place by examining whether the bank provided sufficient coverage. Payment transactions are settled immediately by the Hungarian National Bank provided that there is coverage. The liquidity of a direct VIBER participant consists of the positive balance available on the accounts of VIBER participants and of the intraday credit line that is the limit of domestic credit institutions. The limit is an intraday roll-over credit line on the bank account. Of the portfolio deposited at KÉLER Rt. with the MNB as beneficiary, those securities can be used as collateral for the intraday credit line. During the business day the VIBER participant can have a debit balance in the amount of the credit line. If the debit balance of a domestic credit institution still prevails when the current account is closed, the Hungarian National Bank provides automatically a one-day credit against securities collateral in accordance with the provisions of „Business terms and conditions of HUF and FX market transactions of the central bank.” If one order in not covered by collateral, the order is queued and the sender bank is notified. If the bank provides the collateral for the transaction by the end of the day the settlement will take place with finality. The provision of collateral can be effectuated also in form of credit granted by the central bank. Central bank credits are granted the initiation of credit institution during VIBER operating hours. The Hungarian National Bank books the amount of credit on the VIBER account of the credit institution. The Hungarian National Bank reserves the right to grant credit on the current account as well. If the bank did not provide sufficient collateral at the end of the day, the Hungarian National Bank deletes the items in the queue notifying the sender and obligor accordingly. (VIBER System … [2005].)

As the VIBER is real time gross settlement system and as orders are settled subject to cover check in both the account manager system and VIBER, banks do not have open positions against each other resulting form payment and settlement. The system of VIBER, as a consequence of its architecture is a safe system, credit risk and systemic risk is totally eliminated. However as a consequence of the profit maximizing policy of commercial banks liquidity risk emerges. In developed countries during a business day commercial banks settle transactions exceeding multiple (even more hundred) times their average balance of current account. Next to high turnover/balance ratio it could happen that a bank is not able to provide funds for its transactions for a little while as it has exhausted its current account. This situation can easily eventuate, if one of the counterparties has lagged the agreed the money transfer upon which amount the bank counted. The liquidity risk of the real time systems is reduced by the credit line provided in return for collateral in form of securities and by automatic resolution of gridlocks. The frequency of intraday queuing and the value of transactions queued in VIBER have both been rising recently. In 2002, the total value of transactions queued (first items in queues) reached HUF 32.3 trillion in 2002. Nevertheless, all presented transactions were settled in VIBER by the end of the day; the system did not delete items in queue due to lack of funds. (Operations of and Risks… [2003].)

In contrast to gross settlement systems net settlement systems involve relatively low costs, because actual settlement is relatively rare, normally occurring only once at the end of the day and thus liquidity costs are low. Until mid 90s in countries with developed financial systems

\textsuperscript{27} VIBER and the Interbank Clearing System complement each other harmoniously. The Interbank Clearing System specialises in handling and clearing large volumes of low value commercial and private payment orders. There is no mandatory value limit or other criterion for channelling turnover between VIBER and the Interbank Clearing System. However the pricing policy is developed to encourage the declared aim of the payment and settlement systems.
the large value interbank payment and settlement systems based on multilateral netting. Payments among members were collected over a certain period of time and at the settlement time the gross payments between members are netted against each other, so that only the net balances have to be settled with finality. In multilateral net settlement systems debit and credit positions were accumulated vis-à-vis a central counterparty until they were offset at the settlement time. However if a member bank to become insolvent during a business day there was significant risk to the other clearing banks, especially as banking practice has been to allow customers to treat incoming payment messages as good funds immediately, that is, before they had been received with finality at the end of the day. The timing of intraday payment flows could be such that some banks, had they been declared insolvent during a working day, would have left others with exposures equivalent to their entire capital base, given that funds would have been advanced to customers on the basis of payment instructions from the insolvent bank which it was then unable to match with actual funds. This risk has now been addressed through the establishment of real-time gross settlement systems for large value transactions. (Michael [1998].) The popularity of real time gross settlement systems among regulators can be explained by the fact that in net settlement systems there exists credit risk and so systemic risk. It could happen that the central bank should intervene in its function as lender of last resort in order to safeguard financial stability. Namely, if at the end of the business day a debtor bank is unable to fulfil its payment obligations direct or indirect creditors of the bank could also become insolvent.

The interbank clearing system, run by the Elszámlálásforgalmi Rt., is the Giro Clearing System, called also Interbank Clearing System. The system handles transfers gross, although it does not dispatch transfers promptly when receiving an order, they are cleared on the day in question at a specified point in time. Transfers are cleared after the business day, in the period of 17 p.m. and 02 a.m. The system only accepts batched orders provided that coverage of the transaction was ensured in advance. This coverage, similar to VIBER, composes of the balance available on the accounts of the participants and the intraday credit line of domestic credit institutions. The credit line, the so called limit is calculated on the bases of securities deposited at KELER Rt. with the Hungarian National Bank as beneficiary. If the limit turns out to be insufficient in order to settle the transaction the order is queued. If the payment orders of one or more VIBER participants cannot be settled during Giro night processing due to lack of funds, processing may take place in the morning. Any intention of processing in the morning must be reported to the MNB in the morning no later than 8 o’clock. In 2002, participants did not provide funds enough for overnight settlement in the Giro on 21 settlement days out of the total 251. As a result, a total amount of HUF 14.6 billion was settled the next morning. Four of the queuing banks do not take advantage of the intraday credit facility at all. (Operations of and Risks… [2003].) If sufficient funds are not available for an item of a financial institution for any reason the bank may either release additional liquidity of its own (with inter-bank deals, with a limit increase with cash deposits) to resolve the queue. It has various instruments (credit facilities) available to obtain additional liquidity from the central bank. Until the funds are provided, none of the other items of the VIBER participant will be settled. If the VIBER participant is unable to provide funds for the Giro morning processing by 09.30 a.m. either, the Hungarian National Bank shall delete the transfer between accounts for blocking the collateral. In the Giro Settlement System the clearing takes place on a gross basis, meanwhile payment is effectuated on net basis. Net balances are comprised in the IBI (Interbank Indebtedness) matrix, which is booked after the night processing on the current accounts of banks.

As in the Giro System all transactions are settled if sufficient coverage is provided, the system is not a real time one, but a gross one, so credit risk is again totally eliminated. To summarize,
in Hungary neither VIBER nor Giro bears systemic risk. However liquidity risk is present in
the systems. At the same time in the case of insufficient liquidity a bank can obtain additional
liquidity from the central bank provided collaterals are ensured. According to 7.§ a) of the
Central Bank Act the Hungarian National Bank „accepts deposits and lends based on
adequate collateral, within the scope of its account management.” Act LVIII of 2001 …
[2001] 7.§ a).) If a bank is not able to provide adequate collateral, the central bank can even
decide to provide emergency loan to the corresponding credit institution as the lender of last
resort in order to ensure financial stability.

In the system of VIBER and Giro, transactions denominated in Hungarian forints are settled.
Orders denominated in a foreign currency are mostly realized through nostro accounts held in
foreign banks. In this case risk is involved, as exposures that arise from nostro accounts are
generally not collateralised. (Michael [1998].)

1.8. Additional factors influencing contagion

The structure of interbank market, the legal and institutional framework developed by
regulatory authorities, the architecture of the payment and settlement system are factors which
influence the probability and severity of contagion. However there are several additional
factors which have an impact on the nature of contagion. At bank level risk mitigation
techniques should be mentioned. Among others the most important techniques include
collateralized loan and deposit transactions, repurchase agreements, netting agreements and
internal limit systems. Besides mutual monitoring, market discipline and transparency are also
of major importance.

In case of collateralized interbank transaction if one bank defaults and the bank’s payment
obligations are not or only party fulfilled the severity of contagion is lower compared to an
exposure without any coverage. If transactions are collateralized by means of a marketable
security, in case of necessity the securities can be sold and as a consequence the exposure will
at least party recover. Collaterals however only diminish the probability and severity of
contagion, but do not eliminate them. Under distressed market conditions it could happen that
the value of securities provided as collaterals drastically decreases and only a smaller part of
the interbank exposure recovers. As in relation with the introduction of the Hungarian
interbank market we will experience (see page 102), that in Hungary neither the turnover nor
the volume of collateralized interbank loan and deposit transactions are significant. In 2003
the daily average of collateralized interbank transaction – including also bail-type repurchase
transactions – accounted for 1.26% of the total volume of interbank exposures. In the broad
sense repo transactions called also repurchase agreements include sell/buy back transactions
and securities lending as well as classic repos (or sale and repurchase agreements). In
Hungary, in contrast to money markets of the euro zone the turnover of repo transactions is
low, in the second quarter of 2002 repo transaction accounted for solely 2.5% of all interbank
transactions. (Balogh and Gabriel [2003].)

Bilateral netting of interbank assets and liabilities reduces the exposures of banks against
each other and in this way decrease the risk of contagion. In most of the countries however
netting is not put in force automatically, on balance sheet netting should be documented.
Besides, usually netting is not recognised for all transactions. Normally on balance sheet
netting is a contractual agreement which becomes enforceable in case of default. By definition
loans can be netted against deposits. This principle is also followed by the new Basle Capital
Accord. According to the Basle Committee netting is allowed if banks have legally
enforceable netting arrangements for loans and deposits. (Basel II… [2004], 139. §. and 188. §.)

According to the current Hungarian regulation the Act CXX of 2001 on Capital Market only recognises the position closing netting. 28 Position closing netting agreements contracted in accordance with the prescription of the Hungarian Financial Supervisory Authority ensure that in the case of non-payment of one of the counterparties claims and liabilities can be netted against each other automatically and immediately. (Act CXX of 2001 … [2001], 173. § (2) d) 3.) Position closing netting agreements are accepted by the Authority if it was convinced on the basis of the netting contract that there is no legal obstacle in front of the automatic and immediate netting. Additionally, it is also specified in the regulation that legal conditions and enforceability of the agreement should be monitored continuously in accordance with the internal controlling and monitoring process. (Act CXX of 2001 … [2001], 173. § (4).) Thus position closing netting is also not automatic in Hungary, it requires contractual agreement and can be enforced only in case of certain transactions. One special case of position closing netting is on balance sheet netting, when loans can be netted against deposits. On balance sheet netting is a contractual agreement which declares that in case of default netting can be employed.

Internal limit systems of banks aim to restrain the risk of banks taken against each other. Limit systems of banks are fairly complex, even a brief introduction to limits is behind the scope of this Ph.D. thesis. In the light of systemic risk implications of interbank market most important limits include position limits, foreign exchange limits and counterparty limits.

Next to the above mentioned risk mitigation techniques Sheldon and Maurer [1998] emphasize the importance of the structure and diversity of bank portfolios. According to the authors if the asset portfolio of the financial institution is more concentrated, under distressed market conditions or idiosyncratic shocks the probability of default of the bank is higher which can easily generate domino effects. Especially, if the asset and liability portfolio of financial institutions showed structural similarities. In this case as a consequence of an initial macroeconomic shock all other institutions should have already absorbed smaller or larger losses. At bank level Goodhart, Sunirand and Tsomocos [2003] pointed out in a general equilibrium model the relationship between diversified bank portfolios and probability of default. The authors analyzed individual bank behaviour in crisis situations by assuming heterogeneous agents, multiple commodity, credit and deposit markets and inter-relationships between banks. Banks with diversified portfolios could better absorb exogenous shock without depressing credit and asset prices.

Among additional factors influencing the probability and severity of contagion the state of the real economy should also be mentioned. The probability of bank default is higher in recession, when not only the profit expectations of banks are worse, but the shock absorbing capacity is also lower.

Previously presented methods which aimed to prevent contagion (see subsection 1.6.) are all related somehow to the public sector and the state. Rochet and Tirole [1996] argue that one of

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28 “Position-closing netting is the transformation, based on an agreement between the parties and effected upon the non-fulfilment of the agreement or the onset of other events specified by the parties, into a single receivable or liability, as an accepted method of settlement on the market of the product in question, of debts and claims arising from prompt foreign exchange and securities transactions, derivative transactions, repo or reverse repo transactions, securities lending agreements, pledge agreements or other financial collateral agreements, as a result of which the debt or claim is confined to the net amount so determined.” (Act CXX of 2001 on… [2001], 5. §. 87.) Next to position closing netting settlement netting is also recognised, however this bears a relation to taking collaterals into account.
the most important drawbacks of insurances limiting the impact of contagion provided by the state is the absence of incentives for *mutual monitoring* and for the functioning of *market discipline*. In contrast, one of the most important advantages of the decentralized interbank market is the mutual monitoring. Rochet and Tirole have showed in their study that decentralized monitoring is a viable alternative or rather beneficial substitute of centralized regulation whenever central bank intervenes solely in emergency cases. By minimizing interventions of central planners the moral hazard can also be minimized.

In the theoretical model of Rochet and Tirole there are three periods and different investment possibilities. The invention of the model is related to the different level of mutual monitoring. If monitoring is intensive, than the probability of fulfilment of the credit obligation is higher. In contrast, if monitoring is superficial, the probability of fulfilment is lower. The disciplinarian role of monitoring is set off by rationing the credit that is in case of long term credits the next instalment is only granted provided previous ones were used circumspectly. However mutual monitoring is costly. Incentives for monitoring are created by the fact that the costs of monitoring are lower than the potential negative consequences of omission of the monitoring. Additionally, the authors pointed out that moral hazard, probability of negative returns and so contagion would be minimal provided creditors and depositors could monitor managers efficiently.

The importance of *market discipline and transparency* are also highlighted by the third pillar of the new Basle Capital Accord. (Basel II... [2004].) One of the key motives behind the third pillar was that market discipline should complement the first two pillars, namely minimum capital requirements and supervisory review process. The Committee aimed to encourage market discipline by developing a set of disclosure requirements which will allow market participants, amount others banks, to assess key pieces of information on capital, risk exposures, risk assessment processes, and hence the capital adequacy of the institution. The quantity, quality and efficient flow of information influences directly the probability and severity of contagion. As a result of the transparency, operation of counterparty banks becomes controllable, hence exposures to banks facing troubles can be withdrawn in the course of time and systemic risk stemming through this channel can be limited.
II. CONTAGION THROUGH THE INTERBANK MARKET

Cifuentes, Ferrucci and Shin [2004] consider a situation, in which financial institutions do not settle interbank loan and deposit agreements. In this case, on one hand the institutions do not have insurance against a liquidity shock. However, on the other hand, the banking system is more stable, as the credit exposure channel of contagion is simple non-existent. The insurance against a liquidity shock provided by the interbank market together with the diversification of bank portfolios, including the diversification of interbank linkages reduce the frequency of individual bank failures, a smaller shock can be easily absorbed by the system. A shock, which affected only one institution at the beginning, now affects several market participants, however in a smaller extent. However, as institutions are linked through the interbank market, a default of a bank can trigger domino effect not only because distressed institutions can depress the market prices of assets further, but also through the credit exposure channel. In this sense the systemic risk is higher. The systemic risk implication could be even more severe in a situation, where the emerging shock is not isolated. Several other authors (see for example Aghion, Bolton and Dewatripont [2000], Allen and Gale [2000] or de Vries [2004]) refer to this relation, that is, there is a trade off from being connected through a network. On the one hand, being connected smears out the risks over multiple institutions. Adverse movements which might have toppled a single bank, therefore have no effect since the multiple banks are now carrying this risk together. On the other hand, a network is more conducive to systemic risk than a number of banks operating in isolation. A very large shock may topple the entire system, since no bank is able to bear its share in the adverse movement.

In spite of the fact that several theoretical models handle the question of contagion in the banking system, studies dealing with the quantitative assessment of the probability and severity of contagion have recently emerged. In most of the cases the empirical models supplemented the standard stress testing methodology. The empirical models of contagion can be divided into three groups.

The first group of empirical models concentrates exclusively on the impact of contagion and ignore shocks driven by macroeconomic factors. According to Čihák [2003] these models indicate one basic type of interbank stress tests, the so called pure interbank stress tests. In this case the shock is the failure of one bank, triggered for example by fraud, and where the impact on other banks in the system is traced through the interbank exposures. The main research question of this first-type model is, whether due to the network of interbank exposures the failure of one bank can spread to other banks. Researchers focus on credit risk associated with interbank lending, which may lead to domino effect, that is, the failure of one bank results in failure of other banks not directly affected by the initial shock. Precise pattern of interbank linkages are also analysed, as recent works in economic theory suggest that risk of contagion depends on the structure of the interbank market. By means of simulation the models solely capture the direct lending, that is, the effect of non-repayment of interbank credits on the capital of creditor banks. Risks driven by the payment and settlement systems or cross holding of shares are ignored. Liquidity risk is also omitted. In most cases systematically relevant banks are identified and the weakening of the banking sector is quantified.

The second group of empirical models dealing with contagion puts emphasis on different kind of macroeconomic shocks. Čihák [2003] denotes these models as integrated interbank stress tests, where simulated macro shocks are grossed up to the point where they trigger the failure of the weakest bank in system, which, in turn can trigger additional failures through interbank exposures, exactly as in the pure interbank stress test. According to De Bandt and Hartmann
[2000] the studies in this group analyse systemic events in a broad sense. Authors assess the insolvency risk of banks for different scenarios of macroeconomic shocks, like interest rate shocks, exchange rate and stock market movements as well as shocks related to the business cycle. The key difference between the integrated and the pure test is that the aggregate, wide systematic shock will have weakened the other banks in the system, making them more vulnerable to the initial bank failure. As I have mentioned in the last paragraph of subsection 1.3, I will only deal with those models related to macroeconomic fluctuations and aggregate shocks, which also handle the domino effect through the interbank market. Models solely capturing systemic events in the broad sense are omitted.

The third group of empirical models analyses the systemic risk implication of financial interlinkages by applying the newest findings from network theory. In this case the analysis relies on the idea that an interbank market can be interpreted as a network where banks form nodes and claims and liabilities between them define edges of the network. By using different measures from the network theory the empirical network structure of the banking system and the systematic relevance of different banks can be investigated. The main question of these studies is how the structure affects the stability of the network, that is, the stability of the banking system with respect to the elimination of a node in the network, that is, a default of a single bank.

In the following subsections of the Ph.D. thesis the empirical models of contagion is reviewed according to the above mentioned grouping.

2.1. Contagion related to idiosyncratic bank failures

The first group of empirical models focuses solely on systemic risk implications of the domino effect. In order to be able to access the severity of the domino effect by means of simulations qualitatively, the contagion is isolated from all other shocks. The initial bank failure is an unexpected, idiosyncratic event. In subsections 2.1.1. – 2.1.3. the empirical models concentrating exclusively on the impact of contagion are reviewed in a chronological order. After a brief introduction to the papers in subsection 2.1.1, the data used in the models are summarized. Subsection 2.1.2. deals with the methodology of the empirical papers. The most important issues incorporate the entropy optimalization, the iteration procedure of the simulation, the necessary condition of a bankruptcy to occur and the value of loss given default. Subsection 2.1.3. reviews the drawbacks of the models. The main results related to the structure of the interbank market and to the probability and severity of contagion are presented in subsection 4.4. in comparison with the Hungarian results.

The BIS working paper of Furfine [1999a] was the first attempt to understand the likely magnitude of systemic bank failures and measured interbank exposures beyond what might arise in a payment system. The study of Furfine exploits payment flow data from the Federal Reserve’s large-value transfer system, Fedwire, to simulate the impact of various failure scenarios. The payment flow data captures only a smaller proportion of total interbank exposures. In the study of Furfine between February and March 1998 the failure of the most significant bank, the failure of the second most significant bank, the failure of the 10th most significant bank and the joint failure of the two most significant banks are simulated. In the function of the loss given default additional bank failures happened.

Upper and Worms [2002] used balance sheet information to test whether the breakdown of a single bank can lead to contagion. The analysis covered both short and long term, and both collateralized and uncollateralized exposures. The matrix estimation procedure of the
interbank exposures relied on the assumption of dispersed interbank assets and liabilities. Credit risk and contagion were captured by means of simulations. In the model every bank defaulted once as a consequence of an idiosyncratic failure, which could generate further failures depending on the proper value of the loss given default. The authors have also incorporated a couple of elements of the German safety net.

The study of Wells [2002] also focuses on interbank exposures of UK banks, as a possible source of direct contagion. Similar to previous authors Wells addressed the question whether an insolvency of a bank can induce further bankruptcies. The matrix of bilateral exposures is estimated under two sets of stylised assumptions about how banks distribute their aggregate interbank lending and borrowing across other individual banks, or groups of banks. The first set of estimates, similarly to Upper and Worms [2002], assumes that banks seek to spread their borrowing and lending as widely as possible across all other banks. The second model assumes that concentrations in the interbank market are reflected in the pattern of the large exposures data, which data detail the size and counterparty for each of the bank’s 20 largest exposures and any other exposures exceeding 10% of its tier 1 capital. The foreign banks, as possible sources of systemic risk are also incorporated into the model. In a later study of Wells [2004] a third matrix estimation procedure is presented. The major banks are assumed to act as a money centre for all other banks participating in the UK interbank market. Smaller banks and foreign banks in this system must carry out all interbank activity with the major banks. The major banks, on the other hand, are fully connected with all banks, and with each other.

Degryse and Nguyen [2004] investigated the systemic risk implications of the Belgian interbank market similar to Wells, on the basis of balance sheet and large exposure data sources. Bilateral interbank matrices are estimated in three different ways. The structure of the Belgian interbank market changed in the period of 1993-2002. There was a shift from a complete structure, where all banks had symmetric links towards a multiple money centre structure. Money centres are symmetrically linked to some banks, which are themselves not linked together. Additionally the banking market became more concentrated. In general the risk and impact of contagion decreased in Belgium during the last couple of years. According to the authors an increase in the proportion of cross-border interbank assets had lowered the risk and impact of local contagion. This reduction was probably accompanied by an increase in contagion risk generated by foreign banks. Although even in this case the contagion risk appears fairly limited. Sensitivity analysis were also performed to incorporate the effect of an implicit deposit insurance, that is, the doctrine of "too-big-to-fail" and potential anticipations by banks were also captured.

Lelyveld and Liedorp [2004] investigated interlinkages and contagion risks in the Dutch interbank market. The authors addressed the question whether the decreasing number of firms in the Dutch banking market, the higher concentration and more interlinked institutions had increased the severity of contagion. The severity of contagion was quantified on the basis of the structure of the interbank market, number of interbank exposures and volume of interbank exposures. By creating several scenarios Lelyveld and Liedorp showed that the national interbank market only seems to carry systemic risks if a large bank fails, although even in this extreme and unlikely event not all the remaining banks are affected. The contagion induced by smaller banks is limited. Additionally the authors highlight the fact that the volume of interbank liabilities is about two times higher than the volume of interbank assets. The Dutch banks hence borrow on the international interbank market and have a net debit position

29 The money centre structure was introduced by Freixas, Parigi and Rochet [2000], which was described in subsection 1.5.
relative to the rest of the world. This may render the Dutch banking system more likely to be the source of contagion rather than the “victim”.

2.1.1. Description of the sample

Furfine [1999a] exploited payment flow data from the Federal Reserve’s large-value transfer system. The data was used to uncover federal funds transactions on a bilateral basis. By means of a search algorithm Furfine identified all federal funds transactions between financial institutions that were conducted over Fedwire. Because such transactions are uncollateralized interbank loans, they represent a measure, calculable bilaterally, of interbank credit exposures. The above described set of federal funds transactions provided a conservative measure of interbank credit exposure. That is, interbank exposures arise from many other sources besides federal funds loans. Several other exposures are reported on bank call report forms in an aggregate amount. This means that the call report reveals a bank’s aggregate cash and balances due from other institutions, but does not report this exposure bilaterally. According to the estimation of Furfine the bilateral exposures which were settled through the Fedwire represents approximately 14% of the total interbank exposure. The sample of federal funds transactions contained the 719 commercial banks that traded funds using Fedwire at least once during the February–March 1998 period. These banks account for over 70% of total commercial banking assets. On the basis of the bilateral data Furfine found evidence that mean exposure increases with a bank’s ability to absorb losses, measured here by tier 1 capital. It was also shown that smaller banks generally have larger funds exposures relative to their capital level.

The study of Upper and Worms [2002] relied on balance sheet information reported monthly to the Bundesbank. The sample covered each 3246 German banks, which consisted of 331 commercial banks, 594 savings banks, 13 Landesbanken related to the savings sector, 2256 cooperative banks, 4 central banks of the cooperative sector and 48 other banks. As in Germany more than one half of the interbank assets and liabilities have a maturity of at least 4 years the authors argued, that for the assessment of the danger of contagion, it is therefore not sufficient to consider just these short run relationships, but it is necessary to take longer-term assets and liabilities into account. The balance sheet data of 31 December 1998 covered both collateralized and uncollateralized interbank assets and liabilities. The matrix of the interbank exposures was estimated through an entropy optimization procedure in two different ways. The first method was related to the submatrices of different banking groups, by adding up these matrices the total amount of interbank exposures could be obtained. As the data at disposal contained information on interbank lending and borrowing in each of five maturity categories in five types of relations 25 matrices of bilateral exposures were constructed. Since most banks borrow and lend only at specific maturities most of the elements of total interbank assets and liabilities for the different maturity categories were zero. These zero restrictions considerably reduced the number of possible counterparts for each bank. The second method of matrix estimation is solely based on aggregate balance sheet data. In this case the dispersal of interbank assets and liabilities was assumed. This latter matrix served as a benchmark that proxies the complete structure of claims.

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30 The five maturity categories consisted of exposures with original maturity of one day, exposures with maturity between one day and three months, between three months and one year, between one year and four years and above four years. The five types of relations covered deposits and loans from savings banks to regional giro institutions (Landesbanken), deposits and loans from regional giro institutions (Landesbanken) to savings banks, deposits and loans from cooperative banks to cooperative central banks, deposits and loans from cooperative central banks to cooperative banks and all interbank loans and deposits that do not belong to the above described.
The analysis of Wells [2002] is based on balance sheet data of UK-resident banks, that is, UK-owned banks and branches or subsidiaries of foreign banks located within the United Kingdom. The data is collected regularly by the Bank of England. The simulation is conducted using exposures of 31 December 2000. Wells handle the 24 UK-owned banks individually. The remaining UK-owned banks are grouped together since they account for less than 1% of assets held by the UK banking system. The UK-resident foreign banks are grouped into 8 groups according to domicile. A matrix of bilateral exposures between these groups is estimated under two sets of stylised assumptions about how banks distribute their aggregate interbank lending and borrowing across other individual banks, or groups of banks. The first set of estimates assumes that banks seek to spread their borrowing and lending as widely as possible across all other banks. The exposures in the estimated matrix reflect the relative importance of each institution in the interbank market via the size of its total borrowing and lending. This assumption basically rules out the possibility of relationship banking, that is, a bank preferring some counterparties to others. The second model assumes that concentrations in the interbank market are reflected in the pattern of the large exposures data, which data detail the size and counterparty for each of the bank’s 20 largest exposures and any other exposures exceeding 10% of its tier 1 capital. In this case Wells assumed the existence of relationship lending, which was reflected in the volume of the largest interbank exposures.

Degryse and Nguyen [2004] used data from a confidential database containing banks' balance-sheet statements and a set of financial information collected for prudential supervision purposes. At an aggregate level, each bank reports monthly its total interbank loans and deposits and provides breakdowns of these positions according to the type of loan or deposit, the geographical origin of the lender or the borrower, and the residual maturity of interbank loans or deposits. Additionally, at an individual bank level banks report their large exposures, exposures exceeding 10% of their own funds, to single obligors, including their interbank exposures. On a company basis, the Belgian banking system, at the end of 2002, comprised 65 banks. The banking system could be characterised by a high degree of concentration since the four largest banks account for 85% of total assets of Belgian banks. According to the study, more than 40% of interbank exposures are covered, probably nurtured by the monetary policy reform in Belgium in 1991 which fostered the use of repos between Belgian banks. Degryse and Nguyen estimated the bilateral interbank matrices in three different ways. Each matrix was based on different data on interbank exposures, that is, data at an aggregate level or at an individual bank level. The first one consisted of using the matrix of bilateral exposures based on large exposures only. The information at disposal allowed the authors to fill in several cells in the matrix of bilateral exposures but not to reconstruct the full matrix, since smaller exposures were omitted, which were probably less significant in terms of contagion risk. The large exposure data did not require any additional assumptions on the distribution of bilateral exposures, and included exposures to foreign banks. The second matrix based on the observed aggregate interbank assets and liabilities. In this case an assumption on the distribution of the individual interbank exposures was needed. The third estimation technique combined both approaches by incorporating large exposures in the matrix of bilateral exposures and by using the aggregate interbank exposures net of large exposures, to calculate the residual, unreported exposures. This method is basically equivalent to making an assumption on the distribution of smaller exposures only. Degryse and Nguyen

31 The eight categories included the following regions: emerging markets, France, Germany, other EU, Japan, Switzerland, United States of America and other developed countries.
32 Degryse and Nguyen made distinction between Belgium, one of the other European Union members or the rest of the world.
carried out the analysis between 31 December 1992 and 2002 every half a year, so the evolution of contagion over time could be accessed.

Lelyveld and Liedorp [2004] used several data sources for analytical purposes. Similarly to the study of Wells [2002], and Degryse and Nguyen [2004] the authors built upon the monthly reports which reflected the aggregate interbank assets and liabilities of a bank comparable to the Call report. This data was collected monthly by the central bank. In the large exposures data report, banks reported risks larger than 3% of actual own funds on bank counterparties and risks larger than 10% of their actual own funds on non-bank counterparties. To obtain complete information on some part of the interbank exposures, the top ten banks with respect to interbank assets were asked to report data on bilateral exposures. Using the above mentioned data, Lelyveld and Liedorp estimated the structure of the interbank market twice. In the first estimate only the large exposures data and the monthly report were used. The second estimate incorporated the reported data for the ten banks. The exposures on foreign banks have been divided into five geographical areas, namely Europe, North America, Turkey, Asia and Rest of World. Table 4 summarises the features of data used in above mentioned previous papers.

Table 4: Description of data used

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Institutions examined</th>
<th>Domestic vs. foreign banks</th>
<th>Sources of data used</th>
<th>Collateralised vs. uncollateralized transactions</th>
<th>Bilateral vs. aggregated data</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craig Furfine</td>
<td>719 commercial banks (70% of total assets)</td>
<td>domestic</td>
<td>Interbank transactions realised through Fedwire</td>
<td>Uncollateralized</td>
<td>Bilateral</td>
<td>Febr.-March 1998</td>
</tr>
<tr>
<td>Simon Wells</td>
<td>24 big banks, the others are grouped into one group</td>
<td>foreign as well (8 groups)</td>
<td>Data collected by the authority, large exposures statistic</td>
<td>Both</td>
<td>Partly aggregated</td>
<td>31. Dec. 2000</td>
</tr>
<tr>
<td>Hans Degryse, Grégory Nguyen</td>
<td>65 banks</td>
<td>foreign as well (2 groups)</td>
<td>Data collected by the authority, large exposures statistic</td>
<td>Both</td>
<td>Aggregated</td>
<td>31. Dec. 1992 -2002, (two times a year)</td>
</tr>
<tr>
<td>Iman van Lelyveld, Franka Liedorp,</td>
<td>88 banks</td>
<td>foreign as well (5 groups)</td>
<td>Data collected by the authority, large exposures statistic, questionnaire (10 banks)</td>
<td>Both (mostly uncollateralized)</td>
<td>Aggregated (partly bilateral)</td>
<td>31. Dec. 2002</td>
</tr>
</tbody>
</table>

Source: Furfine [1999a], Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004], Lelyveld and Liedorp [2004].

2.1.2. Methodology

2.1.2.1. Matrix of bilateral exposures

In order to be able to access the structure of interbank market and the severity of contagion the matrix of bilateral exposures should be constructed. In the previous empirical literature the study of Furfine [1999a] is the only one in which the exact volumes of uncollateralized interbank assets and liabilities are given on bilateral basis. However the study of Furfine relies on the ability to measure only partly the bilateral interbank credit exposures, around 14% of total bilateral exposures are covered.

The large exposures data report is not complete. First of all, not all risks are accounted for, in particular off-balance sheet risks are not included. Secondly not all certified banks are required to report their large exposures data. Finally, the mentioned amounts are not always outstandings, as reporting of risk limits is allowed as well.
If the lending relationships in the interbank market can not be observed, than the matrix of bilateral exposures should be estimated in some way. This can be done on the basis of observed aggregate interbank assets and liabilities reported to central banks or supervisory authorities. The bilaterally measured interbank assets and liabilities should be written in a matrix form, presented in Figure 3. In the case of $N$ domestic and $M$ foreign banks we arrive to a matrix of $(N + M) \times N$. The $x_{ij}$ element of matrix $X$ represents the gross exposure of a domestic bank $i$ to another domestic bank $j$, that is, outstanding loans made by bank $i$ to bank $j$.

Figure 3: Matrix of bilateral exposures

<table>
<thead>
<tr>
<th>X matrix</th>
<th>Domestic banks</th>
<th>Foreign banks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$a_i$, $y_{ij}$, $f_{ai}$</td>
<td>$l_j$</td>
</tr>
<tr>
<td>2</td>
<td>$x_{ij}$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$i$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sum_i^N x_{ij}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$l_j$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Based on Degryse and Nguyen [2004].

Summing across row $i$ gives the total value of the bank $i$’s interbank assets, that is, $a_i$ represents the domestic interbank assets of a domestic bank $i$. Summing down column $j$ gives bank $j$’s total liabilities, that is, $l_j$ represents the domestic interbank liabilities of a domestic bank $j$. The element $y_{ij}$ represents the gross exposure of a domestic bank $i$ to the foreign bank $j$. Finally, $f_{ai}$ represents the foreign interbank assets of bank $i$.

Without an assumption about the distribution of the bilateral exposures the matrix $X$ can not be identified. Based on the observed column and row sums of matrix $X$, that is, $a_i$ and $l_j$, let us suppose that banks seek to maximise the dispersion of their interbank activities. In this case, a bank’s choice of who to lend to is determined solely by the distribution of borrowing across banks. Similarly, the choice of who to borrow from is determined by the distribution of lending across banks. The source and destination of credits are independent, and interbank loans and deposits are as equally spread over banks as possible. In this case with the appropriate standardisation, this would be equivalent to assume that the elements of matrix $X$ can be obtained by multiplying $a_i$ and $l_j$. The assumption on the dispersity of bilateral exposures basically implies that banks hold claims on other banks in the economy, conditioned on the size of the interbank exposures of the banks. The proper value of $x_{ij}$ can be determined formally by the following expression:

$$x_{ij} = \frac{(a_i \times l_j)}{\sum_{ij}^{NN} x_{ij}}.$$
This simple solution does not make use of all available information. For example such a distribution would neglect an important feature of the interbank market which is that banks do not have interbank exposures to themselves, so we have to add the constraint that \( x_{ij} = 0 \) if \( i = j \). At the assumption of maximal dispersion of interbank exposures, it is straightforward to impose additional, altogether four, constraints on the interbank structure:

\[
\begin{align*}
(1) & \quad \sum_{j}^{N} x_{ij} = a_i \\
(2) & \quad \sum_{i}^{N} x_{ij} = l_j \\
(3) & \quad x_{ij} = 0, \text{ if } i = j \\
(4) & \quad x_{ij} \geq 0
\end{align*}
\]

The constrained matrix \( X^* \) of bilateral exposures should, however, stay as close as possible to the matrix subject to the row and column adding up constraints. A suitable measure of closeness is the cross-entropy between the two matrices. The cross-entropy of matrix \( X^* \) can be minimalized by finding the minimum of the expression \( \sum_{ij}^{NN} [x_{ij}^* \ln(x_{ij}^* / x_{ij})] \), with the conventions that \( x_{ij}^* = 0 \) if, and only if, \( x_{ij} = 0 \), and \( \ln(0/0) = 0 \). Problems of this type can be solved using a matrix balancing algorithm known as the RAS algorithm.

In order to obtain the matrix of bilateral exposures with the exception of Furfine [1999a] all of the previous empirical studies (Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004], Lelieveld and Liedorp [2004].) applied the above presented entropy optimization method. One of the biggest advantages of models applying entropy optimization is that the procedure is adaptable to include any new information that might get available in the process of future data collection. The method is able to include all kinds of constraints we might find out about the matrix \( X \) from different sources, just like the statistics of large exposures or partial aggregates. As more information becomes available the approximation can be improved. However there are many reasons to believe that the assumption on the dispersity of exposures is a rather poor description of reality. First of all, the relationship lending, that is, a bank preferring some counterparties to others is ruled out, which may be an important feature of the interbank market. Furthermore, by assuming dispersed interbank market structure we bias our test against the hypothesis of contagion. As a result of the dispersity assumption the probability and severity of contagion is probably underestimated. I will come back to the critique of the matrix estimation method in subsection 2.1.3, when the drawbacks of the models focusing solely on contagion are presented.

### 2.1.2.2. The procedure of contagion

The aim of the empirical models presented in the previous subsections is to capture the credit risk and domino effect of the interbank market related to mutual interbank credits. For this purpose simulation methodology was used. In the base cases of the simulations every bank goes bankrupt due to an idiosyncratic event, which means that the failed bank does not or only partly honours its obligation. One drawback of the model consists of the idiosyncratic nature of the initial failure. As pure idiosyncratic shocks occur rarely in reality, this presumption could seem unrealistic. However in the past we could have experienced a couple of idiosyncratic bank failures, just like the operational risk induced failure of Baring Brothers in 1995. Failures of financial institutions which originate in idiosyncratic, company-specific

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34 For a broader review on the literature of relationship lending see for example Boot [2000], or Degryse and Ongena [2004].

35 Nick Leason, the broker of Baring Brothers in its Asian securities branch, in Singapore violated intra-day volumes and product specific limits. As a consequence one single person lost all the capital of a 233-year old
factors are rare episodes, however potentially could eventuate in practice. As the initial shock is of exogen nature the models can not capture the probability of different scenarios. One of the most important drawbacks of the model is that it isolates contagion from all kind of other macroeconomic shocks.\textsuperscript{36} The research question is whether by assuming several recovery rates, failure of one bank would cause subsequent collapse of a large number of other banks.

If there is no bank, which fails as a result of the initial failure, there is no contagion and the iteration stops. If there is contagion, which means that at least one other bank failed as a result of the initial failure, the bank failed in the first round of contagion does not or only partly pays back its liabilities. If there is no further contagion, the procedure stops. If there is again a bank, whose unpaid interbank claim is higher than its tier 1 capital, a second round contagion occurs.

**Figure 4: The procedure of contagion**

- **Idiosyncratic failure of a bank.**
  - The failed bank does not or only partly pays back its interbank obligation. The other banks try to pay back their obligation fully.
  - No further bankruptcy occurs.
  - End.

- **There is at least one new insolvent bank, as a result of the loss realised on its interbank claims.**
  - The new insolvent bank does not or only partly pays back its obligation. The other banks try to pay back their obligation fully.
  - Further insolvency occurs.

*Source: own figure.*

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\textsuperscript{36} The model of Elsinger, Lehar and Summer [2002], which will be presented in subsection 2.2.2. in detail is the only one which handles both shocks originating from the real side of the economy and interbank contagion.

bank, specifically USD 1.4 billion. The historical financial institution was ruined and the Dutch ING Bank eventually purchased it for a symbolic price of one pound. Events leading to the failure and factors enabling the series of frauds are presented in Horváth and Szombati [2002] in detail.
As a consequence of the second round contagion, further – third, fourth, etc. round – contagion can occur. The iteration starts from the beginning again, and stops if in the next round there is no insolvent bank. The methodology of the simulation is shown in Figure 4.

The iteration procedure presented in Figure 4 was applied by Upper and Worms [2002], Wells [2002] Degryse and Nguyen [2004] and Lelyveld and Liedorp [2004]. In each model the effect of a failure of an individual institution is traced through the banking system. The simulation of Furfine [1999a] is slightly different form the sketched procedure, as in his study does not fail each bank.

2.1.2.3. The necessary condition

The necessary condition for contagion to occur is that the realised loss suffered by a bank must be higher than the bank’s capital. Formally this means, that the idiosyncratic failure of bank $i$ leads to contagion, if there exists any bank $j$, whose loss is higher than its $c_j$ capital. The loss of bank $j$ is equal to the product of $x_{ji}$ exposure and $\theta$ loss given default. Theoretically the loss given default can vary between 0-100%.

$$x_{ji} \times \theta \geq c_j$$


Let us suppose that bank $i$ fails due to its exposure to bank $j$. This will cause the breakdown of bank $k$ if its exposure to banks $i$ and $j$ multiplied by the loss rate exceeds its capital, that is,

$$(x_{ki} + x_{kj}) \times \theta \geq c_k$$

This line of argument also applies to higher orders. Generally, bank $i$ fails if

$$\sum_j^N x_{ji} \times \alpha_j \times \theta \geq c_i$$

where $\alpha_j$ is a dummy variable. $\alpha_j = 0$, if bank $j$ has not failed and $\alpha_j = 1$, if bank $j$ has failed.

2.1.2.4. Loss given default

Another question to investigate is the proper value of $\theta$, the loss given default. Based on previous studies Furfine [1999a] refers to two empirically observed loss given defaults. According to James [1991] in the middle of 1980s in the United States the average value of $\theta$ was 30% of the book value of the banks’ assets. An additional 10% covered the administrative and legal costs as well. That is, typical losses on assets of a failing bank including the cost of resolution are around 40%. However, the bank failures that James studies were not systemic events. Kaufman [1994] estimated a loss given default of 5% on the failure of Continental Illinois, that is, creditor banks recovered 95% of their exposure.

37 Thanks to Basle II in the literature the widely used abbreviation of LGD became popular for the loss given default. It is worth mentioning that the recovery rate equals 1 minus the loss given default.

38 In their study Upper and Worms [2002] do not describe in detail the composition of book capital.

39 The analysis was based on realized losses and loss estimates as of December 1988 for 412 bank failures occurring during 1985 through mid-year 1988. The mean value of total assets of the failing institutions was 32 575 thousands, meanwhile the median value of total assets totalled up to 25 680 thousand dollars.
Besides 40% loss given default of James and 5% loss given default of Kaufman, Upper and Worms [2002] mention two empirically measured loss given defaults. Referring to an article of Financial Times the authors mention, that creditors preliminary assumed a loss given default of 90%, when the BCCI went bankrupt in 1991. Finally they ended up recovering more than half of their deposits—albeit many years after the failure. According to an article of Frankfurter Allgemeine Zeitung several decades after the failure, creditors of Herstatt received 72% of their claims, with the liquidation of the bank continuing to drag on even a quarter of a century after its closure in 1974. Upper and Worms point out, that these examples show that it may not be the actual losses borne by the creditor banks that matter, but the expected losses at the moment of failure. Fundamentally the expected losses determine to which extent the exposure to the failing bank has to be written down, hence whether the creditor bank becomes technically insolvent. Even though a bank might be able to achieve a relatively high recovery rate over the long run, there will almost inevitably be uncertainty about eventual losses so that a bank with much of its capital at risk may be unable to continue to operate. As a consequence, Upper and Worms conclude that high values for loss given default can not be ruled out.

Wells [2002] mentioned one empirically observed loss given default in the United Kingdom by referring to the study of Jackson. Based on recoveries by the UK Deposit Protection Fund in the early 1990s Jackson [1996] suggested a median loss-given-default of 35% for failed UK banks. But the sample contained just 14 banks and individual values varied greatly, from 0% to 100%. Moreover, the sample included only small banks, and so the estimate may well not be suitable for large banks. Also, these recovery rates were not adjusted for the time taken to achieve them. As a result, Wells concluded that there is a need to consider the possibility of a higher loss-given-default rate.

As we can see the uncertainty about the proper value of the LGD could not be diminished significantly by examining historical loss given default. Furfine [1999a], Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004], and Lelyveld and Liedorp [2004] came to the conclusion that instead of a single loss given default it has more sense to present the simulation results for a range of loss given defaults. The authors tested for the possibility of contagion using a variety of values for LGD between the theoretical minimum of 0% and maximum of 100%. Each study assumed a constant loss given default common to all banks in a given scenario, the ratios did not vary from bank to bank or time to time.

### 2.1.3. Drawbacks of the model

Before looking through the drawbacks of the simulation methodology I would like to highlight the advantages of the model. First of all, the system perspective can uncover exposures to aggregate risk that are invisible for banking supervision relying on the assessment of single institutions only. Secondly the data used is available at central banks. Thirdly, the model itself is simple and instead of building a complicated model it is trying to read between the lines of the existing data. Finally „what happens if“-type questions can be relatively easily asked and answered.

One of the most important drawbacks of the model is that most financial crisis affects multiple institutions and an idiosyncratic failure of one bank is rather improbable.

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40 A forbearing supervisory authority can however overlook the phenomenon that banks do not write down their whole expected losses, even if it is sure enough that banks will not recover their claims. This situation happened basically in the case of American banks related to the Mexican debt moratorium of 1982 and in the case of Japanese banks in the 1990s.
Additionally, as the initial failure is idiosyncratic, the model cannot capture any kind of probability. As the models solely focus on contagion stemming from the interbank linkages, it does not give any idea how to disentangle the risk that comes from fundamental shocks and the risks that come from contagious bank failures. However, this might create a possibility to qualify the actual importance of contagion effects that have received so much attention in the theoretical debate. It could also be clarified whether future empirical research should concentrate more heavily on contagion or on shock originating from the macro side of the economy.

As nearly in every model this general contagion exercise presented in subsection 2.1.1. – 2.1.2. in detail also involve biases, some of which tend toward underestimation and others toward overestimation of contagion risk. The sources of over- and underestimation of systemic risk is presented in Table 5.

Table 5: Sources of over- and underestimation of risk of contagion

<table>
<thead>
<tr>
<th>Sources of overestimation of the risk of contagion</th>
<th>Sources of underestimation of the risk of contagion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neglecting the potential reactions of banks (withdrawal of interbank exposures, raising capital)</td>
<td>Neglecting the risk stemming from the payment and settlement systems</td>
</tr>
<tr>
<td>Neglecting the potential measures of supervisory authorities</td>
<td>Ignoring off-balance sheet items</td>
</tr>
<tr>
<td>Ignoring the reaction of the National Bank (to big to fail)</td>
<td>Ignoring repo positions</td>
</tr>
<tr>
<td>Ignoring the netting agreements</td>
<td>Ignoring systemic effect of cross-holding of shares</td>
</tr>
<tr>
<td>Non-consolidated data</td>
<td></td>
</tr>
<tr>
<td>Liquidity risk</td>
<td></td>
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<tr>
<td>Assumption of dispersed bilateral exposures</td>
<td></td>
</tr>
<tr>
<td>Ruling out contagion imported from abroad and contagion exported to abroad</td>
<td></td>
</tr>
<tr>
<td>Definition of default (tier 1 capital)</td>
<td></td>
</tr>
<tr>
<td>Using end year data</td>
<td></td>
</tr>
</tbody>
</table>

Source: own table.

In several points Wells [2002] and Degryse and Nguyen [2004] refer to the caveats of this type of model. In reality, the failure of a bank is not a sudden, unexpected event, it is rather a result of a process. As a consequence, other banks can limit or even partly withdraw their interbank claims. Additionally, the model is static in the sense that banks in trouble do not manage the source of the problem leading to bankruptcy or banks do not raise capital either. This leads to the overestimation of contagion. Especially in Hungary, where many banks are owned by big foreign banks.

Except the model of Elsinger, Lehar and Summer [2002] which will be presented in the following subsection, all of the models are static concerning the formation of loss given defaults. The loss given default in constant in one scenario and the same for each bank. This is surely far from reality.

Similarly to the banks supervisory authorities and central banks are passive institutions in the model, neither of them take any measures in order to prevent contagion. However, as we could see in subsection 1.6. the role of regulatory bodies is important in preventing the contagion
for example by means of limiting high exposures or stimulating the use of financial collaterals. Most of the models do not handle the stabilizing function of central banks, among others the systemic risk mitigation effect of lender of last resort. The authors do not even mention the possible measures taken by central banks and the role of emergency credits granted to credit institutions in the case of a crisis related to interbank credit linkages. Building lender of last-type of intervention into the model would have although at least two drawbacks. First of all, the lender of last resort function is a discretionary measure, which makes it difficult to add it to the model. 41 Secondly, on the level of individual banks making lender of last resort explicit could lead to moral hazard. By ignoring the potential reaction of the regulatory bodies, the risk of contagion is overestimated.

Additionally the ignorance of netting agreements also lead to the overestimation of contagion, as the model captures exposures which could be netted in the case of default. In contrast, netting is not automatic, in many countries legally enforceable agreements are needed. The ignorance of netting basically results in higher loss given defaults. However by simulating systemic risk implications of an initial default by means of a range of LGDs, the effect of netting is partly captured. In previous studies different levels of loss given defaults made it possible to handle besides netting other risk mitigation techniques, just like repos and collateralized interbank transactions.

It is also an important question whether the data at disposal are consolidated. The effect of non-consolidated data is twofold. On one side the risk of contagion is overestimated as we assume that interbank transactions are not within a banking group, but between two different banks. Basically in a subsidiary - mother bank relation no collateral is needed and no limits exist. On the other side it could happen that both the subsidiary and the mother bank borrowed funds from the same bank. In this case the potential default of the creditor bank depends on the joint failure of banks belonging to the same banking group. As this type of joint default is not taken into account, the risk of contagion is underestimated. In the study of Degryse and Nguyen [2004] one side of the shield is mentioned, that is, the application of non-consolidated data lead to the overestimation of contagion risk.

The underestimation of contagion is related to the fact that credit risk stemming from interbank loans and deposits is the only source of interbank contagion. The interlinkages through payment and settlement systems, derivative and other off balance sheet exposures, such as contingent claims, undrawn facilities or guarantees are ignored. Additionally the models do not handle the effect of certificates of deposits and commercial papers traded in the interbank market. 42 Moreover, the systemic effect of cross holding of shares is also not captured. Systemic risk implications of the above mentioned exposures are complex, the risk of contagion is probable underestimated.

In all of the models the authors solely capture credit risk. Liquidity risk is set aside, which also leads to underestimation of the risk of contagion.

It is worth mentioning, that as shown in Table 4 except the model of Furfine [1999a] each previous study estimated the matrix of bilateral interbank positions from aggregate data reported to the regulatory authorities. According to Sheldon and Maurer [1998], Degryse and Nguyen [2004] and Lelyveld and Liedorp [2004] the distributional assumption of maximum dispersion of banks' interbank exposures leads to an underestimation of contagion risk. In other words, maximizing entropy minimizes the amount of idiosyncratic risk in the system. In

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41 The authors could have assumed that the first, the second, etc. most important banks can not fail.
42 The role of certificates of deposits and commercial papers in the interbank market vary from country to country. According to the estimation of Wells [2004] in the United Kingdom around 25% of uncollateralized interbank exposures are accounted for commercial papers and certificates of deposits.
my opinion irrespective of the dispersed nature of interbank exposures, the possibility that the risk of contagion is higher can not be excluded. Firstly, a small bank with high interbank exposures relative to its capital is more risky than a big bank with the same attributes. Secondly the completeness and the concentration of the interbank market are also of major importance. The influence of dispersed interbank exposures on the risk of contagion is not clear, what is sure, is that the additional assumption bias the quantification of risk of contagion. The effect of dispersed interbank exposures on the probability of contagion will be tested on page 160-161 by means of the eleventh hypothesis.

In conjunction with the disposable data the study of Furfine [1999a], and Upper and Worms [2002] solely focus on the interbank market of the United Stated and Germany respectively. The contagious effects imported from another country and contagion exported to another country are ignored. In contrast, the analysis of Wells [2002], Degryse and Nguyen [2004], and Lelyveld and Liedorp [2004] handle the risk of contagion imported from abroad. However in the case of UK, Belgian and Dutch banks the opposite, the analysis of exported contagion should also be carried out, as banks resident in these countries are important market players in many other interbank markets.

Another source of the underestimation of the risk of contagion is related to the definition of bank failure. In each empirical model a conservative definition of bank failure is used, banks fail when their tier 1 capital is exhausted. However a bank could be unable to operate even if it suffers smaller capital losses than its tier 1 capital.

The analysis of Upper and Worms [2002], Wells [2002], and Lelyveld and Liedorp [2004] is based on end-year data of 1998, 2000 and 2002 respectively. As we will see in subsection 4.2.1. apropos of the description of the Hungarian data, the end year data are not representative and in this sense also biases the outcome of the simulation.

According to Cifuentes, Ferrucci and Shin [2004] a further critique of empirical studies analysing the severity of contagion relies on the assumption of unchanged portfolio choices of banks and simulations are assessed based on fixed prices that do not change through time. Such an assumption would be appropriate if the assets of the institutions do not undergo any changes in price, or if solvency is assessed based on historical prices. Consistent finding of papers presented in subsections 2.1.1. – 2.1.2. is that systemic contagion is never significant in practice, even in the presence of large shocks. According to Cifuentes, Ferrucci and Shin in the absence of price effects, this is hardly surprising, as interbank loans and deposits represent only a limited fraction of banks’ balance sheets.

In the model of Cifuentes, Ferrucci and Shin [2004] when a bank fails its assets are liquidated, and sales by distressed institutions depress the market prices of such assets. As a consequence of an idiosyncratic failure of a bank the counterparties suffer losses via direct balance sheet interlinkages to the distressed institution and contagion via changes in asset prices. This second channel of contagion means, that forced sales of assets may feed back on market volatility and produce a downward spiral in asset prices, which in turn may affect adversely other financial institutions. That is, marking to market of the asset book can induce a further round of endogenously generated sales of assets, depressing prices further and inducing further sales. Changes in asset prices may interact with externally imposed solvency requirements or the internal risk controls of financial institutions to generate amplified

\[43\] However Cifuentes, Ferrucci and Shin [2004] highlight the fact that for commercial banks whose assets consist mainly of corporate or retail loans, the use of backward-looking prices in assessing solvency may be a reasonable approach, although even such banks would also hold some financial assets on their trading book that would be marked to market. For financial firms that hold mainly marketable assets – such as insurance companies, hedge funds or investment banks – the assumption of fixed prices would be highly unrealistic.
endogenous responses that are disproportionately large relative to any initial shock. An initial shock that reduces the market value of a firm’s balance sheet will elicit the disposal of assets or of trading positions. In turn, such disposals will have a further impact on market prices. In this way, the combination of mark-to-market accounting and solvency constraints have the potential to induce an endogenous response that far outweighs the initial shock. As a result the initial shock can induce additional contagious failures.

A further critique formulated by Cifuentes, Ferrucci and Shin [2004] is related to the implicit assumption of the generally accepted conventional wisdom according to which collateralisation mitigates the risk of contagion further. Their paper suggests that systemic risk in these networks may be larger than thought, even in the presence of collateralisation. The reason is that the risk that materialises is not a credit risk but a market risk. The value of any collateral backing a credit exposure is clearly subject to market risk, and hence not immune to systemic risk through this channel. This is a new dimension to systemic contagion illustrated by recent events, like the LTCM crisis of 1998, the decline in European stock markets in the summer of 2002 or days following the September 11th attacks.

Sorge [2004] provides an overview of current stress testing methodologies. He argues that the models of contagion through the interbank market are able to assess system-wide vulnerabilities. However time horizon generally used for the analysis is limited, and endogenous portfolio adjustments and feedback on asset prices are not addressed.

The results reported by the models dealing with contagion should be interpreted in much the same spirit as those of stress tests. In spite of several caveats, with this type of models the quantitative assessment of interbank contagion risk is possible. By means of the analytical framework failures of systemic importance can be distinguished from systematically unimportant events. As a consequence regulatory authorities could devote time and effort to analyse institutions generating potentially severe domino effect. Moreover, as this type of exercise has been undertaken by several authors, the severity of domino effect reported by studies using the same methodology can be compared at international level. Furthermore, a consistent use of the methodology with different time-series of data would allow estimating the evolution of contagion risk over time.

### 2.2. Contagion induced by macro shocks

#### 2.2.1. Model of Sheldon and Maurer

The study of Sheldon and Maurer [1998] is situated halfway between the empirical models in the first group and models in the second group. For the key features of the models in

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44 According to Cifuentes, Ferrucci and Shin [2004] the actual asset composition of a bank’s portfolio has a direct bearing on the bank’s capacity to withstand shocks and on its susceptibility to contagion. Banks with significant holdings of liquid assets as a proportion of total assets are generally more resilient to shocks and less susceptible to contagion, as they are overall less exposed to fluctuations of the price of the illiquid asset and face lower credit risk. Additionally, if these banks default or have to resize, they create less externalities on the rest of the system, as they can settle their liabilities through the liquid asset, whose price is fixed. Another important message the authors found, is that liquidity buffers play a role similar to capital buffers, there is a trade off between liquid assets and banks’ capital. Even when the residual demand curve is extremely inelastic, such as during periods of major financial distress, liquidity requirements may be more effective than capital buffers in forestalling systemic effects. It could happen that even a large capital buffer may be insufficient to prevent contagion generated by the price impact of selling into a falling market, since the price impact of sales into a falling market would be very high.
different groups see page 55-56. The paper written by Sheldon and Maurer was the first empirical investigation which did not analyse historical events considered to be a financial crisis, but focused exclusively on the potential threat stemming from present interbank lending relationships. The model is partly related to models classified in the first group, as the authors examine the path based on the interbank loan structure that a shock could take and the effect of this shock on the solvency of those banks linked through loans to the defaulting bank. The study concentrated on the first link in a potential chain reaction, looking to see whether a single bank default is indeed likely to cause other banks to fail or, instead simply dissipate in the first round. The initial shock was assumed to be idiosyncratic. In contrast, the model can be associated with the second-type models, as the authors have estimated the likelihood of a bank defaulting in a given period, which is based on accounting data drawn from banks that operated in Switzerland during the period 1987-95. The probability of default rests on the simple observation that a bank is insolvent by definition when a drop in the bank’s revenue wipes out its equity. The drop in revenue is based on historical data and in this sense all kind of macro shocks are reflected in the data.

In the study of Sheldon and Maurer interbank transactions were restricted to short term, 0-3 months interbank time deposits and loans. Money market papers and derivatives, which also count as interbank financial transactions were ignored for lack of data. As the annual report only publishes aggregate figures, the analysis grouped the 576 banks into 12 bank categories in accordance with the report. At the same time aggregating banks into groups helped to make the estimation problem manageable.

The analysis of Sheldon and Maurer is based on the assumption that a single factor causes a bank to default on its interbank loans. This factor equals to the insolvency of a bank, which was defined as a drop in the bank’s revenue that consumes its equity. More appropriately, should the ROA fall below the default threshold level, the bank is considered to be insolvent. The default threshold equals to the difference of the ratio of overhead to total assets and the capital adequacy ratio. The ratio of overhead to total assets and the capital adequacy ratio were taken as being given at the beginning of a period. In contrast, the value of ROA was viewed as being unknown until the end of the period. The ROA was treated as a random variable with mean $E(\text{ROA})$ and standard deviation $\sigma(\text{ROA})$. The probability distribution of the standardized ROA corresponded to either to the standard normal distribution or the authors assumed than that a bank’s ROA is distributed symmetrically about its mean $E(\text{ROA})$. Additionally, it was assumed that the default is complete, that is, insolvency implies that the lending bank loses the entire book value of its loans to the defaulting banks.

In the model of Sheldon and Maurer the probability of a given bank to be insolvent at the end of the period depended on the relative size of its overhead to total assets, its capital adequacy ratio, the mean and standard deviation of the ROA and the probability distribution of its standardized ROA. Everything else equals, a bank with higher overhead cost, with more volatile or lower rate of return and with lower capital-to-assets ratio is more likely to fail.

After addressing the factors influencing the probability of an individual bank default Sheldon and Maurer tried to identify the path that a default shock would take within a banking system. The authors focused exclusively on the first round contagion, second, third and further rounds of contagion were neglected. The default path was assumed to depend on the structure of the interbank lending relationships. The structure of these relationships was captured by an interbank lending matrix. However, the only information the authors possessed with regard to

ycopied 45 The numerator of ROA composes of the total revenues stemming from all aspects of bank’s business minus interest expenses, paid commissions and fees and loan loss provisions. The overhead is defined as taxes plus expenses on personnel, materials and office space. The capital adequacy ratio is related to tier 1 capital.
this lending matrix were the absolute levels associated with interbank loans and deposits on a
bank basis. The row and column sums of the matrix were obtained directly form bank balance
sheets. Missing data on internal values of the matrix were estimated by means of entropy
optimization presented in subsection 2.1.2.1.

Sheldon and Maurer determined the average value of the probability of default for groups of
banks. The calculated probabilities represented annual risk and gave an average bank’s risk of
being bankrupt at the end of a year, given its financial positions at the beginning of the year
and the variability of its ROA. Regional banks carried the greatest risk of insolvency,
regardless of the assumption of distribution of returns. If normally distributed rates of returns
were assumed the probability of default was 1.6%, meanwhile in the case of symmetric
returns the probability of default accounted for 6.9%. Under the assumption of normally
distributed rates of return the average overall probability of default of a bank is 0.8%, in the
case of symmetrically distributed returns the probability of default rose to 3.5%.

In order to be able to investigate to what extent the default of a borrowing bank will push the
lending bank linked to it into bankruptcy, the typical size of a loan default shock emanating
from a bank group should be estimated. The authors arrived to an estimate by dividing the
exposures of a given banking group by the average number of banks in the corresponding
banking group. This procedure assumed that the borrowed funds were distributed evenly
across the banks making up a banking group. In addition, it also had to be assessed how many
banks within a bank group were hit by the default shock. Sheldon and Maurer compared two
extreme cases. In the first case the authors assumed that just one bank within a bank category
received the shock. In the second case the shock was distributed evenly across all banks
within the bank group. In the first case the authors determined the ROA that an average-size
bank of the bank group could expect to achieve after suffering the full force of a default shock
emanating from an average-size bank in a given bank category. The ROA determined in this
way was compared to minimum, mean and maximum ROA default threshold of the group of
banks receiving the shock. As it could be expected, almost no average-size bank was able to
withstand the full force of a loan default from a large bank. In the second, more realistic case
Sheldon and Maurer showed, that no lending bank was expected to fail. The expected ROA
were barely affected by a single default shock in this case.

To conclude, Sheldon and Maurer verified empirically that the chances of a bank failure
propagating through the banking system via the network of interbank loans are quite low.
First of all, the likelihood of the insolvency of a big bank is low. Secondly, it is unlikely that a
bank within a banking group supply all the loans of that banking group to the defaulting bank.
In spite of the high likelihood of bank insolvency in any given year, the result based on the
interbank market structure of period 1987-95 suggested, that the Swiss interbank lending is
not the foremost threat to financial market stability in Switzerland.
2.2.2. Model of Elsinger, Lehar and Summer

The study entitled *Risk Assessment for Banking Systems* by *Elsinger, Lehar and Summer [2002]* takes a wide range of macroeconomic shocks and the contagion through interbank linkages also into account.\(^{46}\) The main challenge of the working paper was to capture, in a tractable way, the two major sources of systemic risk. First, banks might have correlated exposures and adverse economic shocks may directly result in simultaneous multiple bank defaults. Second, troubled banks may default on their interbank liabilities and hence cause other banks to default triggering a domino effect. Authors assess the insolvency risk of banks for different scenarios of macroeconomic shocks, like interest rate shocks, exchange rate and stock market movements as well as shocks related to the business cycle. In each scenario banks face gains and losses due to market risk and credit risk, which influence the feasible payment flows between banks and net values of banks. The basic framework of the model is standard risk management techniques in combination with a network model of interbank exposures. The model explains feasible payment flows between banks endogenously from a given structure of interbank liabilities and net values of banks arising from all other bank activities. The model determines endogenously probabilities of bank insolvencies, recovery rates and a decomposition of insolvency cases into defaults that directly result from movements in risk factors and defaults that arise indirectly as a consequence of contagion.

Elsinger, Lehar and Summer [2002] estimated the matrix of bilateral interbank exposures based on bank balance sheet data and supervisory data reported monthly to the Austrian Central Bank. The data contained for each bank in the system an aggregate number of on balance sheet claims and liabilities towards other banks in the system, banks abroad and the central bank. For the estimation of bilateral exposures information that is revealed by the sectoral organization of the Austrian banking system is also exploited. The Austrian banking sector consists of joint stock banks, savings banks, state mortgage banks, Raiffeisen Banks, Volksbanken, construction savings and loans associations and special purpose banks. As of September 2001 the sample covered 908 independent banks. All interbank exposures obtained from the balance sheets were taken into account. As the sectoral structure of the Austrian banking system provided additional information, the major part of the interbank matrix could be determined properly. Two sectors (savings banks, Volksbanken) have a two tier and one sector (Raiffeisen) has a three tier structure.\(^{47}\) Banks in these sectors break down their reports further according to the amount they hold with the central institution. Due to the fact that there are many banks that hold all their claims and liabilities within their sector or only against the respective central institution these pieces of information determine already 72% of all entries of the interbank matrix exactly.

Next to the supervisory data the model of Elsinger, Lehar and Summer also relied on many special data sources, just like database of the major loans register or data on default frequencies in certain industry groups. As some positions on the banks’ asset portfolios are

\(^{46}\) A detailed Hungarian description of the model of Elsinger, Lehar and Summer [2002] was prepared by Lublóy [2003].

\(^{47}\) The savings banks and the Volksbanken sector are organized in a two tier structure as institutions in these sectors have a sectoral head institution. The Raiffeisen sector is organized by a three tier structure, with a head institution for every federal state of Austria. Besides, the federal state head institutions have a central institution, Raiffeisenzentralbank which is at the top of the Raiffeisen structure. In sectors with head institutions the banks transact mostly with the head institutions. This is especially true for smaller banks. The sector of commercial banks, Raiffeisen banks and Volksbanken are pretty closed, three fourth of the interbank liabilities are generated in the corresponding banking group. The interbank liabilities of the special purpose banks are truly diversified by sectors.
subject to market risk, market data had to be collected. The data were used for the creation of scenarios. Specifically the most important data covered exchange rates, stock exchange indices, zero bond prices and zero rates denominated in different currencies.

Similarly to the empirical studies focusing exclusively on contagion Elsinger, Lehar and Summer have also applied the entropy optimization method, presented in subsection 2.1.2.1. in order to estimate interbank liabilities from partial information. As 72% of all entries of matrix $X$ was exactly known, the remaining 28% of the entries of $X$ should have been estimated. Afterwards, a new matrix $\Pi$ was defined by normalizing the entries of $X$ by total obligations. For the sake of simplicity the sum of the elements of a corresponding column $i$ is denoted by $l_i$, meanwhile the vector of $l_i$ is described by $l$. Basically $l_i$ represents the total interbank liabilities of bank $i$. The element of $\pi_{ij}$ of matrix $\Pi$ is 0, if the bank $i$ does not have any interbank liabilities. Otherwise the $\pi_{ij}$ element of matrix can be determined by the ratio of $x_{ij}$ and $a_i$, which is the ratio of interbank credits of bank $i$ from bank $j$ divided by the total interbank liabilities of bank $i$. Formally:

$$\pi_{ij} = \begin{cases} \frac{x_{ij}}{l_i} & \text{if } l_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

Next to matrix $X$ an $N$ dimensional vector $e$ is also required, where $e_i$ denotes the net income of bank $i$. The net income of bank $i$ equals the income position resulting from non-interbank activities. At the beginning the net income of bank $i$ can be obtained from the financial statement of bank $i$. The decomposition of the income into income stemming from interbank activities and income stemming from non-interbank activities will be crucial when macroeconomic conditions are added to the model.

The $N$ dimensional clearing payment vector $p$ of the banking system can be derived through an iteration procedure. Under the clearing mechanism, given the payments of all counterparties in the interbank market, a bank either honours all its promises and pays $l_i$, or is insolvent and pays nothing at all, or if possible, satisfies the creditor banks proportionally. In some way, this is a stylized and simplified description of a bankruptcy procedure. According to Elsinger, Lehar and Summer a bank is insolvent, if the total net value of the bank, that is, the income received from other banks plus the income position of non interbank activities minus the bank's own interbank liabilities becomes negative. In the case of insolvency the claims of creditor banks are not or proportionally satisfied. The setup of the model implicitly contains a seniority structure of different debt claims of banks. By interpreting $e_i$ as net value from all bank activities except the inter-bank business we assume that interbank debt claims

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48 In my opinion in the above mentioned definition of insolvency of Elsinger, Lehar and Summer [2002, p. 10] the term insolvency and liquidity is mixed up. According to the definition of the Austrian researchers a bank fails if the income of a bank does not cover the liabilities of a bank, that is, a bank is illiquid. As it became clear from the presentation of Martin Summer held at Collegium Budapest the stock variables are not mixed up with the flow variables in the model. In reality the change in the value of the bank was added to the initial net value of the bank. To clarify the difference between illiquidity and insolvency, a bank is insolvent if the difference of the bank’s assets and liabilities is negative, meanwhile a bank is illiquid if the bank cannot fulfil its payment obligations due to lack of liquid assets. If a bank is illiquid at the moment, it can be solvent, meanwhile it could happen that a bank is insolvent, that is, operating with insufficient capital, but it is liquid, that is, can fulfil its payment obligations for a longer while. (Király [2001].) However a liquidity crisis can also induce several insolvencies, even at the level of the banking system. This phenomenon was neglected in the literature for a longer while, as it seemed that the system of financial market is so liquid and deep, that a liquidity risk of this kind can never happen. The events of 1990s have falsified this conviction, the markets dried up and contagion shocked the markets. It became clear that everything should be re-evaluated. (Király [2003].)
are junior to other claims, like deposits or bonds. However interbank claims have absolute priority in the sense that the owners of the bank get paid only after all debts have been paid. The clearing payment \( (p_i) \) of bank \( i \) depends on three parameters. First of all, the value of \( p_i \) is influenced by the ratio of \( x_{ij}/l_i \) that is, by the value of \( \pi_{ij} \). Secondly it depends on other banks clearing payments. Finally it is influenced by the net income of the corresponding bank. The \( p_i \) element of vector \( p \) can be derived in the following way:

\[
 p_i = \min \left\{ \frac{l}{\max \{0; \sum_{j}^{N} (\pi_{ij} p_j^*) + e_i\}} \right\}
\]

Thus the clearing payment vector \( p \) shows the systemic risk resistance of banks. The clearing payment vector thus directly gives us two important insights. First, for a given structure of liabilities and bank values – \( a, \Pi \) and \( e \) – it tells us which banks in the system are insolvent. Second, it tells us the recovery rates for each defaulting bank in each state.

The \textit{fictitious default algorithm} developed by Eisenberg and Noe [2001] should be presented a bit more detailed. The algorithm deals with the clearing payments under uncertain conditions. Eisenberg and Noe have proved that under mild regulatory conditions a unique clearing payment vector \( p \) for a given \( \Pi, e \) and \( l \) structure always exists. The algorithm is presented in Figure 5.

Figure 5: Fictitious default algorithm

Source: own figure.
Initially Eisenberg and Noe determine each node's payout assuming that all other nodes satisfy their obligations. If, under the assumption that all nodes pay fully, it is in fact the case, that is, the value of all banks is positive, all obligations are satisfied. At this point the algorithm terminates. If value of some banks is negative, that is, there are insolvent banks, the defaulted banks do not or only partly pays back its obligations. Even when all other nodes with positive value pay unaltered, it could happen that the banks are not able to fulfil their obligations. That is as a consequence of the non-repayment of interbank obligations further insolvencies occurred. The iteration starts form the beginning and terminated if there are no further contagion. Eisenberg and Noe have showed that the iterations end up with an unique clearing vector and if there are only $N$ banks, the process must terminates after $N$ iterations.

By extending and slightly modifying the fictitious default algorithm of Eisenberg and Noe the Austrian researchers could distinguished defaults directly caused by fundamental insolvencies from those triggered by defaults of other banks in the interbank market.

The net income of a bank is influenced by the exchange rate, by the movements in the stock exchanges and by business cycles. The macroeconomic shock basically influences the net income of the bank which does not contain payments stemming from the interbank market. The model of the banking sector uses different states of the world or scenarios to model uncertainty. The credit risk in the interbank network is modelled endogenously while all other risks, like gains and losses from FX and interest rate changes as well as from equity price changes losses from loans to non-banks are reflected in the position of $e$. Thus the state of the economy is modelled through the income position of banks which do not contain the income originating form the interbank transactions.

In each scenario banks face gains and losses due to market risk and credit risk. Market risk, that is, stock price changes, interest rate movements and FX rate shifts are captured by a historical simulation approach for all items except other assets and other liabilities. Credit losses from non-banks are modelled via a credit risk model. The credit risk in the interbank market is determined endogenously.

Historical simulation approach serves to assess the market risk of the banks in the system. In order to estimate shocks on bank capital stemming from market risk positions in foreign currency, foreign and domestic equity and interest rate sensitive instruments were included. Altogether 26 risk factors were quantified, four foreign exchanges, two equity indices – ATX and MSCI – and 20 zero bond rates and returns for four different maturities denominated in five different currencies. Based on data series form the past the empirical distribution of returns can be calculated and extreme changes in market risk factors can also be captured. The joint distribution of the market risk factors could be captured and correlation structures between interest rates, stock markets and FX markets could also be taken into account. After drawing 10 000 scenarios from the empirical distribution of returns, the profits and losses of banks that arise from a change in the risk factors can be specified and a distribution of profits and losses due to market risk can be determined.

For the modelling of loan losses a historical simulation could not be applied as there were no published time series data on loan defaults. In order to estimate a loan loss distribution for each bank in the sample one of the standard modern credit risk models, the CreditRisk$^+$ was employed. By relying on this estimated loss distribution Elsinger, Lehar and Summer could create for each bank the loan losses across scenarios. The basic inputs of CreditRisk$^+$ consist of a loss distribution of a set of loan exposure data, the average number of defaults in the loan

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The latter one could be calculated from a database that provided time series on recovery rates for the different industry branches. Based on the insolvency statistics at disposal the authors could calculate the average default frequency and its standard deviation for each individual bank portfolio. From these data the distribution of the effect of aggregate shocks on average default frequency of the bank portfolio could be constructed for each bank in the sample. Finally, by means of simulations the loan loss distributions could be quantified.

The combination of credit losses across scenarios with the results of the historic simulations of market risk creates the total scenarios for $e_i$ for each bank. In $e_i$, that is, in the net income position of bank $i$ except the losses or gains related to the credit risk in the interbank market all losses or gains are reflected. For each scenario the estimated matrix of bilateral exposures and the income positions determine via the network model a unique vector of feasible interbank payment and thus a pattern of insolvency.

As a consequence of a macro shock all banks that realize high enough losses, defaults. This default is called fundamental default, as it is due to the losses arising from exposures to market risk and non-bank credit risk. Those, otherwise solvent banks which became bankrupt due to fundamental default of another bank which did not fulfil its promises in the interbank market are victims of contagious defaults. That is, contagious defaults threatening the systemic stability could occur only in the second round of the clearing payment in the interbank market. The set-up of the model of Elsinger, Lehar and Summer is summarized in Figure 6.

As a result of the simulations Elsinger, Lehar and Summer came to the conclusion that the Austrian banking system is stable, the mean default frequency of Austrian banks accounts for 0.8%, meanwhile the median default frequency is around 0.5%. Very few banks however have a very high probability of default. For a supervisor, such banks should be identified and looked at more closely to get a more precise idea, of what the problem might be. As the model is able to decompose insolvencies into fundamental and contagious defaults the authors found that the relative importance of contagious default events as compared to the importance of contagious defaults is relatively low. In fact approximately 94% of default events are directly due to movements in risk factors whereas 6% can be classified as contagious. The risk of contagion is relatively small, in the case of an average bank the probability of contagious defaults is less than 0.1%. The result is remarkable, as contagious default from interbank relations plays only a minor role, bankruptcies are much more dependent on macroeconomic conditions. However contagious failures happen rarely, but when it occurs, the effect is severe. There exists one scenario in which 75% of the failures are contagious.

\[50\] In Austria these data can be obtained from the major loans register of Grosskreditevidenz, which database contains all loans exceeding a volume of 350 000 euro and from Austrian Rating Agency Kreditschutzverband which collects default rates for the different industry branches since 1870.
The endogenously determined median recovery rate in the banking system is 66%. Thus for more than half of the banks in the entire banking system the value of their interbank claims is not reduced by more than a third in case of default of a counterparty. This also refers to the suggestion that the Austrian banking sector is rather safe. The authors found no evidence that the interbank market actually increases correlations between banks or whether it allows banks to diversify risk which reduces correlation. It was showed that the interbank market changes the pairwise correlations of many bank values considerably, but there is no obvious trend.

The model of Elsinget, Lehar and Summer can also be used as an experimentation tool.\textsuperscript{51} It was interesting to ask, what would be the consequences if technical insolvencies actually would destroy asset values. For instance at a loss rate of 10% of total assets, the maximum number of contagious defaults was 413 compared to 46 with a loss rate of 0%. Another important issue was in the spirit of a value at risk model the question of how much funds the regulator needs to avoid fundamental or contagious defaults in 99 percent of the scenarios. According to the calculation of the Austrian researchers by only focusing on avoiding

\textsuperscript{51} This paragraph would like to highlight the experimental possibilities of the model. The proper estimation methodologies and the underlying theoretical framework will not be presented.
fundamental defaults in 99% of the scenarios the regulator would require 0.31% of all total banking assets. In contrast the complete avoidance of contagion had costs of 0.13% of total assets. The analysis can be extended by the consequences of default of international counterparties. The number of defaults grows dramatically with increasing foreign losses. Under the assumption of 40% loss given default 472 banks defaulted in the worst case. The hypothetical defaults of significant institutions in the banking system were also analysed. The authors concluded that it is not easy for regulators to identify the systematically relevant banks, as activity in the interbank market is not the right criterion to determine the system relevance of a bank. In the 40% loss rate simulation the authors found that the medium number of contagious defaults is larger for the tenth most significant bank than for the first two combined. Finally Elsinger, Lehar and Summer showed, that there exists a dramatic maximum contagion effects once a certain threshold of loss ratios is exceeded.

In another paper Elsinger, Lehar and Summer [2003] distinguished between short run and long run perspective. The short run perspective was modelled by assuming that there will be no interbank payments after netting following a bank default. The long run perspective was modelled by assuming that the residual value of an insolvent bank can be fully transferred to the creditor institutions up to some bankruptcy costs according to the rules of the clearing mechanism. Additionally on the basis of probability of bank default and estimated interbank recoveries the authors determined capital charges for interbank loans.

The model of Elsinger, Lehar and Summer [2002, 2003] focusing on macroeconomic shocks have many advantages. One of the most important is that the system perspective can uncover exposures to aggregate risk that are invisible for banking supervision relying on the assessment of single institutions only. Besides, the initial failure of a bank is not idiosyncratic but reflects the impact of a set of macroeconomic risk factors on banks in combination with a network model of mutual credit relations. As a consequence the model can differentiate between risks that come from fundamental shocks and risks that come from contagious bank failures. It is also an important headway, that the default probability differ from bank to bank, and as the recovery rate is endogenously determined in the model the recovery rates more realistically, also differ from bank to bank. Additionally the model is designed to exploit existing data sources. The authors did not build a fairly complicated and complex model, but rather tried to read between the existing data. However the model is based on special data sources, just like equity prices for banks, a major loan register or a database with time series of default rates for various industry branches. In many countries, including Hungary, this type of data is not available for researchers, as they simply do not exist.

In the newest study of Elsinger et al. [2004] in order to map the systemic risk of the banking sector the authors take correlations between individual bank asset risks, which are reflected in correlations between bank asset portfolios and interbank linkages explicitly into account. According to the authors correlated exposures and mutual credit relations that may cause domino effects are two major sources of systemic risk, these two properties of financial networks will usually result in simultaneous bank failures. If banks have correlated exposures a consequence of an adverse economic shock may directly result in multiple bank defaults. Banks in distress may default on their interbank liabilities and hence cause other banks to default triggering a domino effect. The method suggested in the paper can exclusively be applied for the analysis of banking systems of financially highly developed economies. Elsinger et al. [2004] adopted the model to the major UK banks relying mostly on market data. In the model one year time horizon was employed. The analysis no more relies strongly on loan register data, like the model of Elsinger, Lehar and Summer [2002]. However time series of equity prices for the banks are needed. The equity prices, the market value of the equity and the market value of the bank’s asset portfolio were determined on the bases of
weekly stock market data for 2003. The authors exploited the idea of Merton, that is, equity can be viewed as a call option on the bank’s assets with a strike price given by the face value of debt. In the model covariance structure of banks’ assets were studied, the potential risk situations for the banking system as a whole were based on this analysis. Finally, by means of network theory the probability of default, the expected recovery rates and the contagion could be quantified.

The model heavily relies on the network model of Eisenberg and Noe [2001], just like the study of Elsinger, Lehar and Summer [2002], which framework was extended to include uncertainty. Another building block of the model was the method of entropy optimization to estimate the matrix of bilateral exposures form partial information. However the parameter $e$, which reflects the net income position of the bank becomes a random variable. To model the random nature of $e$ the authors assume that the value of each bank’s total assets is governed by a Geometric Brownian motion. In the model the asset value of banks correlate. Given the time series of equity prices for the banks and the level of total liabilities the required parameters of the processes were estimated using an extension of the maximum likelihood estimator approach. By deducting non interbank liabilities and interbank assets from the simulated value of banks’ asset the net income position $e_i$ for this particular scenario can be derived.\(^{52}\)

For the estimation of the risk of the value of total assets information on the future development of asset values and the face value of debt was needed. The problem was that the actual market value of assets was not directly observable. What was however observable was the market value of equity and the face value of debt for each publicly traded bank. By viewing equity as a call option on the bank’s assets with a strike price given by the face value of debt, on the basis of the theory of Black-Scholes and Merton an estimate of the market value of equity for each publicly traded bank can be obtained. As in the market a time series of equity prices is observable, the value of equity can be determined in this way as well. Given the information about the value of debt and the assumptions made on the stochastic process of bank assets the Black–Scholes option pricing formula can be used to estimate the parameters of the underlying asset value processes. An extended maximum likelihood approach was applied to estimate the time series of all banks’ asset values simultaneously. To simulate future asset values the Cholesky decomposition was used on the basis of the variance–covariance matrix, which was estimated from stock market data.

Elsinger at al. [2004] compared the simulated number of joint defaults for three different procedures. First, based on the marginal distributions only, that is, assuming that the covariances are zero as the asset values of banks do not correlate. The second scenario based on the joint distribution, that is, the probability of joint defaults was estimated by taking the correlation structure into account. The third scenario based on the joint distribution taking the financial linkages between banks into account. In the first case the UK banking system, at least as far as the 10 major institutions were concerned appeared to be extremely stable. There were scenarios with 9 defaults in total, however their probability was practically zero, since it occurs in only one scenario out of 100 000. The probability that one or more defaults occur in the entire system over one year horizon given the December portfolio was 4.7%, mostly due to fundamental defaults. On the level of individual banks looking at the distribution of the

\(^{52}\) Elsinger, Lehar, and Summer [2004] working with Austrian data take a different route. They decompose $e$ into the various portfolio components of bank assets and liabilities that do not belong to the interbank market. Then they model a joint distribution of risk factors for market and credit risk. Random draws from this distribution are taken and the respective portfolio components are evaluated for each draw. For the UK this approach is not possible because a sufficient decomposition of $e$ into subcomponents, in particular loan portfolios to enterprises, is not available.
individual default probabilities of the 10 banks there could be observed significant
differences.

Taking the correlation structure into account the estimates changed quite a bit. The number of
scenarios with a single defaulting bank decreased. The number of scenarios with no default at
all and the number of scenarios where two or more banks fail increased. This result was
amplified when contagion is taken into account. The analysis showed that from the viewpoint
of systemic stability both correlated exposures and interlinkages do matter. Ignoring the
system perspective leads to a considerable underestimation of the probability of systemic
crises. By means of stress testing a more sophisticated analysis of hypothetical bank failures
was carried out to quantify the impact of a failure on the conditional distribution of asset
returns of all other banks. In contrast, the literature on interbank linkages and domino effects,
presented in subsection 2.1. applied stress tests that assumed that one institution at a time is
removed from the system and the sudden removal of a bank from the system will leave
everything else unchanged. However Elsinger et al. [2004] determined the impact of the
changed return distribution on asset risk and via this channel on domino effects and
contagion. In the model the unconditional default probability was close to zero, but the
conditional default probability, that is, probability of default conditional on the failure of one
bank was significant. There exists a bank whose default has a high impact on the others, as
the conditional default probabilities vary from 49% to 98.8%.

Finally, by distinguishing between idiosyncratic and systematic shock, the authors concluded
on the basis of expected losses, that because of fraud idiosyncratic shocks will have a much
smaller impact on the banking system than a system wide shock of similar magnitude.

The model of Elsinger et al. [2004] relies on publicly available stock exchange data. At the
same time this is one of the most important advantages and disadvantages of the model. It is
easy to get access to the data, however the analytical framework can not be used in several
countries, just like in Hungary, where three banks – FHB, IEB, OTP – out of 39 are listed on
the stock exchange. Additionally the model relies on several unrealistic assumptions, just like
all debt are insured, have a maturity of one year, and grow at the risk-free rate. Besides the
time horizon taken is one year, however the portfolio composition of banks remains
unchanged. The most important advantages of the model include the decomposition of
defaults into fundamental and contagious defaults, the quantification of the probability of
default and identification of systematically relevant institutions.

2.3. Network theoretical models

The third group of empirical models investigates the systemic risk implications of the
financial sector by means of network theory. During the last couple of years several studies
and book have been written about the nature of networks. Albert-László Barabási, a
Hungarian physicist living in the United States highlights in his book *Linked* the main
research questions of complex networks. (Barabási [2002].) A key insight of the research of
Barabási has been the discovery of surprising structural similarities in seemingly very
different networks, ranging form Internet, world wide web, telecommunication networks and
power grids to economic and ecological networks. Nowadays it is well known that the
formation of these growing complex systems, just like networks in cell biology and social
networks investigated by sociologist is not random. In many cases there exist key nodes in the
networks that are more intensively related to the nodes of the network than most of the other
nodes to each other. In general, in the case of complex systems the random network theory
can not be verified, as for example in the case of the world wide web it is not true that every webpage is linked to the same number of other web pages on average. In the Internet we can find a couple of more central pages that are linked to millions of other pages. The functioning of the major part of networks depends on the centrally positioned nodes. Besides, the distribution of the number of relationships is also not random. „The behaviour of financial markets bears similarities to the functioning of complex organ networks. Additionally, the infrastructure which provides the base for functioning of the financial system and the telecommunication networks which transmit fundamental information for the system are also networks. In this sense the findings of modern physics are valid for the financial markets from several points of view.” (Jaksity [2003].)

The network theory is based on graph theoretical findings. Probably the oldest and most investigated random network model was introduced by Erdős and Rényi in 1959. Erdős and Rénly were the first to study the statistical aspects of random graphs by probabilistic methods. The finding of Erdős and Rénly based on the observation that networks are not nice and regular in reality, but unbelievable complex. In their model, in order to be able to examine the structure of complex real networks Erdős and Rénly started with \( N \) vertices and no bonds. With a given probability Erdős and Rénly connected each pair of vertices with a line (bond or edge), generating a random network. Random networks are based on the idea of total equality. Nodes are connected randomly, each node possesses the same probability to be either a starting or a closing point of an edge. If the network is huge, than in spite of the randomly set edges approximately the same number of edges belongs to each node. Basically Erdős and Rénly used the term complexity and randomness as synonyms, which became widely accepted for a couple of decades. Aiming to describe the transition from a locally ordered system to a random network, Watts and Strogatz recently have introduced a new model, that is, often referred to as small-world network. Watt and Strogatz also examined real networks, and came to the conclusion that in many networks the small-world phenomenon is present, which is partly inconsistent with the theory of random networks. The model of Watts and Strogatz begins with a one-dimensional lattice of \( N \) vertices with bonds between the nearest and next-nearest neighbours and periodic boundary conditions. Then each bond is rewired with a given probability, where rewiring in this context means shifting one end of the bond to a new vertex chosen at random from the whole system, with the constraint that no two vertices can have more than one bond, and no vertex can have a bond with itself.

Driven by the computerization of data acquisition, topological information on various real-world networks was increasingly available. Albert-László Barabási and his research group found some evidence by e.g. mapping the world wide web, that the web contains a couple of nodes with significantly high number of in and outgoing edges. This phenomenon could not be explained with none of the previous models. In the egalitarian model of Erdős and Rénly the existence of nodes with huge number of relations would be rare. The model of Watts and Strogatz also would not permit that several points possesses of much more relations than an average node. The research group of Barabási experienced by investigating large data bases, that the connectivity distribution (distribution of number of relationships follows a power law. (Barabási [2002].)

The structure of the network influences the stability, the dynamic behaviour and the fragility of the underlying system. According to the classical analytical framework, one key feature of networks is the connectivity distribution \( P(k) \), giving the probability that a node in the network is connected to \( k \) other nodes. According to Barabási, Albert and Jeong [1999] the

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53 In my Ph.D. thesis the term graph and the term network is used as synonyms. According to the literature network analysis refers to the application of the graph theoretical framework to real data.
existing empirical and theoretical results indicate that complex networks can be divided into two major classes based on their connectivity distribution. The first class of networks is characterized by a connectivity distribution that peaks at an average $k$ and decays exponentially for large $k$. The most investigated examples of such exponential networks are the random graph model of Erdős and Rényi and the small-world model of Watts and Strogatz, both leading to a fairly homogeneous network, in which each node has approximately the same number of links, $k$. The connectivity distribution of exponential networks follows normal distribution, most of the nodes dispose of the average number of links, meanwhile only a limited number or even none of the nodes have only a few or lots of links. In contrast, results on large networks indicate that many systems belong to a class of inhomogeneous networks, called scale-free networks, for which $P(k)$ decays as a power law, free of a characteristic scale. The connectivity distribution follows a Pareto distribution, that is, many nodes have few links and a few nodes have many links. Whereas the probability that a node has a very large number of connections is practically prohibited in exponential networks, highly connected nodes are statistically significant in scale-free networks. Barabási, Albert and Jeong [2000] found that scale-free networks display a surprisingly high degree of tolerance against random failures, a property not shared by their exponential counterparts. The exponential network is more fragile, in the case of malfunctioning of its nodes (they can be also banks) the network can break easily into many isolated fragments, which can reduce the efficiency of the network dramatically. The scale-free networks are more resistant, form these networks we can eliminate a large number of nodes randomly and the network will not fall into fragments. However, the error tolerance comes at the expense of attack survivability. The diameter of scale-free networks increases rapidly and they break into many isolated fragments when the most connected nodes are targeted.

As a result of the most important contributions to recent network theory, a couple of empirical models were published on interbank interlinkages and its systemic risk implications, which apply results from general network theory. The network representation allows a system-wide assessment of the financial relationships between different kind of institutions since it takes the interdependences into account. The network topology of the interbank market refers to the stability, robustness, and efficiency of the system. In this way the analytical framework enables us to put a new face on the matter of probability and severity of contagion. 

Aleksiejuk and Holyst [2001] focused on the interbank market and introduced a new model of directed percolation as a simple representation for contagion process and mass bankruptcies in banking systems. The analytical framework of Aleksiejuk and Holyst is fairly simple. In

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54 Looking at the normal and at the Pareto distribution there is a striking quantitative difference at the right side of the distribution, in the so called tail. The right tail of the normal distribution decreases exponentially, which is a much deeper drop than in the case of power distributions. Concerning the Gaussian distribution the exponential tail is responsible for the fact that there are no central nodes. In contrast, power distributions decreases more slowly and in this way allow the existence of such rare events like key nodes. (Barabási [2002].)

55 As presentation of further findings of game theory are beyond the scope of this Ph.D thesis, henceforward only those network theoretical questions will be handled, which are inevitable in order to understand the empirical papers related to systemic risk implications of interbank market.

56 Percolation theory is part of physics and provides an analytical framework related to random network theory, which was developed independently from the model of Erdős and Rényi. Suppose, we connect nodes of a network step by step, by adding additional edges to the network. If all nodes have one edge on average, then one huge network, the so called giant component is established. Most of the nodes belong to a network, in which a randomly selected node is easily accessible form every other node. Mathematicians call this phenomenon as the creation of giant component. Physicists call this phenomenon as percolation, in their opinion there happened a phase transition. After adding critical number of edges to the network, the properties of the network change dramatically. At the beginning there were many isolated components, meanwhile at the end there exist one giant component, which contains most of the nodes. (Barabási [2002].)
the model, banks are represented by vertices in a lattice, which for simplicity has a square or cubic symmetry. Directed connections which simulate flows of money, are randomly distributed between junctions of bank lattice. Initially, each bank is solvent. The first bankrupt is selected at random without the specification of the reason for the bankruptcy. During the next time step, neighbouring banks lose their solvency if they gave a loan to the bankrupt, regardless of the number of creditor banks. This process is repeated until no bank survives that gave a bad interbank credit. The authors have shown that in analogy with the traditional percolation theory one can expect a critical value of mean concentrations of existing interbank deposits, when an avalanche composed of bankrupts can spread all over the banking network. Avalanches of bankruptcies can be related to clusters in the random directed percolation problem. Both in the static and dynamic model Aleksiejuk and Hołyst have proofed that at the percolation threshold, the probability that a random bank causes $n$ avalanches (failures of $n$ other banks) fulfils the power law.

In the model of Iori, Jafarey, Padilla [2003] and Iori and Jafarey [2004] the banks receive stochastic deposits from customers and stochastic investment opportunities form entrepreneurs based in the non-financial sector. Additionally banks can participate in the interbank market, have to keep a minimum reserve in cash, and above a given capital deposit ratio can pay dividend. Credit linkages between banks are defined by the connectivity matrix. Whether a credit linkage exists between any two pairs of banks is determined randomly at the beginning of the simulation. As a consequence of deposit withdrawal it could happen, that the cash holding of a bank becomes negative. In this case a bank can issue negotiable debt certificate, which have to be redeemed at the end of the period through borrowing from other banks. If a bank can not obtain sufficient amount of interbank credit, the bank fails and its debt certificate becomes worthless. Iori and Jafarey have showed that if banks are homogenous in size and exposures the contagion is less probable. In the case of homogenous banks by strengthening the role of interbank market, that is, by increasing the density of the interbank results in a more stable banking system. In each period the higher the density of the interbank network, the higher the number of survived banks. By increasing the heterogeneity of banks – different size of banks, different investment opportunities – the probability of contagion could increase. Additionally, if the density of the interbank market reaches a critical threshold, interbank lending can create higher knock on effects and in this way reduces the stability of the banking system.

The empirical study of Boss et al. [2003] is one of the first studies dealing with the interbank market which is based on network theory. The authors provide an empirical analysis of the network structure of the Austrian interbank market, the network topology of the Austrian interbank market is presented. In spite of the fact, that the authors did not link the network topology of the interbank market to contagion, the short review of the study is of major importance. The reasoning behind this is the following: the analytical framework provides the possibility to connect the network topology of the market with its systemic risk implications. The authors characterized the interbank network by the liability or exposure matrix $X$ shown in Figure 3. All, about 900 Austrian banks, the central bank and an aggregated foreign banking sector were incorporated into the model. The data consisted of 10 $X$ matrices, each

57 The model is far from reality from several points of view. First of all, the interbank linkages are not randomly selected in reality. Secondly, a default of a bank does not necessarily lead to the default of the creditor bank. Whether contagion happens, depends on the volume of interbank exposures, on the excess capital of the creditor banks and on the volume of the loss given default.

58 One critic of the model is that a bank becomes bankrupt if the bank is illiquid and not if it is insolvent. Additionally, the interbank linkages are not randomly selected in reality. It is also far from reality that a borrowing bank does not receive actual funds until has lined up enough credit to ensure that it will not fail during the current period.
representing liabilities for quarterly single month periods between the years 2000 and 2003. From the monthly balance sheet returns of Austrian banks and from the Major Loans Register, which contains all interbank loans above a threshold of 350 000 euro, about 90% of the $X$ matrix entries could be obtained exactly. The missing part of the interbank exposure matrix was estimated by means of entropy optimization method which presented in subsection 2.2.2. related to the model of Elsinger, Lehar and Summer [2002].

According to Boss et al. there are three possible approaches to describe the structure of interbank matrix as a graph. The first approach is to look at the liability matrix as an unweighted, directed graph. The vertices are all Austrian banks, the central bank and the aggregate foreign banking sector are represented by a single vertex each. The set of all starting vertices is the set of banks with liabilities in the interbank market; the set of end vertices is the set of all banks that are claimants in the interbank market. This representation was called the liability adjacency matrix and was denoted by $A_l^l$. $A_l^l_{ij} = 1$ whenever a connection starts from row node $i$ and leads to column node $j$, and $A_l^l_{ij} = 1$ otherwise. By transposing $A_l$ the asset adjacency matrix, $A_a$ can be obtained. A second way to look at the graph is to ignore directions and regard any two banks as connected if they have either a liability or a claim vis-à-vis each other. The third graph representation reflected an undirected but weighted adjacency matrix by defining $A_w^w_{ij} = L_{ij} + L_{ji}$. In this case $A_w^w_{ij}$ measures the gross interbank interaction, that is, the total volume of liabilities and assets for each node. For statistical descriptions of the network structure, each above defined matrices would be sufficient. Finally the authors have chosen the undirected, but weighted adjacency matrix $A_w^w$ for analytical purposes.

On the basis of the $A_w$ matrix Boss et al. have constructed the network topology of the interbank market. Afterwards the authors looked for functional clusters, the global algorithm of Zhou [2003] was applied. The algorithm grouped communities of banks which are organised along a two- or three tier structure, like the Raiffeisen credit cooperatives, Volksbank credit cooperatives and saving banks into separate clusters. For banks which are not structured in a hierarchical way, such as special purpose banks, joint stock banks, state mortgage banks and building and loan associations no strong community structure was found. By the algorithm these banks are grouped together in a cluster called other. Additionally, institutions in the Raiffeisen sector were further grouped into clusters which were clearly identified as Raiffeisen banks within one of the eight federal provinces. By defining the dissimilarity index of different banking groups, which is a measure of the difference of the clusters, the authors came to the conclusion that the interbank network of the Austrian banks reflect the regional and sectoral peculiarities of the banking system.

The degree distribution of the interbank market follows a power law for all three matrix representations. The mean of the clustering coefficient of the undirected graph is $C = 0.12$, which is relatively small compared to other networks. The clustering coefficient provides the probability that two vertices that are connected to any given vertex are also connected with one another. A high clustering coefficient means that two banks that have interbank connections with a third bank have a greater probability to have interbank connections with one another than any two banks randomly chosen on the network. In the explanation of the Austrian authors a small $C$ is a reasonable result, as keeping an interbank link is costly. So if for instance, two small banks have a link with their head institution there is no reason for them to additionally open a link between themselves.

Boss et al. calculated the average path length for the three graphs $A_l^l; A_a^a; A_w^w$ with the Dijkstra algorithm. They found that in the case of directed graphs $A_l^l$ and $A_a^a$, the average path length

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59 The degree distribution is the distribution of the number of connections of the nodes in a given network.
was \( l(A') = l(A'') = 2.59 \). The average path length of the undirected interbank connection network totalled up to 2.26. From these results the Austrian interbank network looks like a very small world with about three degrees of separation.

Next to the study of Boss et al. [2003] the paper written by Müller [2003] is also of major importance. The main research objective of Müller was to investigate by means of network theory and simulations the Swiss interbank market and its systemic risk implications. The data were taken from the Swiss National Bank’s interbank statistics, which also contain the banks’ ten largest counterparty exposures and the corresponding credit lines against Swiss as well as against foreign commercial banks. By carrying out a network analysis potential contagion paths and financial institutions that are on the basis of their relations to other banks systemically relevant could be identified. Additionally, the structure of the interbank market was also described formally. The simulation approach’s main purpose was to check whether the structure of interlinkages of financial institutions has a considerable impact on the system’s inherent instability. By assuming the failure of systemically relevant banks the spill-over effects of the failure on the liquidity and solvency of other banks are measured. When credit lines were introduced into the model, solvent but illiquid banks could draw on their credit lines at solvent banks. However it could happen that banks could not draw on their credit lines because their counterparty banks were illiquid or insolvent.

According to Müller [2003] the systemic importance of an institution can be measured by several network criteria. To determine how important a bank in a certain network is, a standard concept from graph theory was applied. According to this concept, vertices can be ranked due to their centrality. In the context of the interbank market, a central vertex is a bank that is according to certain network criteria systemically relevant. A systemically relevant bank has the following characteristics:

1. It has exposures and liabilities to many other banks.
2. It has large interbank exposures or liabilities.
3. Its failure would directly or indirectly weaken numerous banks.
4. Its counterparties are themselves important banks.
5. It lies on numerous potential contagion paths.

Based on these characteristics Müller has measured the systemic relevance of a bank by eight different so called centrality indices and the correlation among them. The use of different measures was appropriate because they all capture different aspects of systemic relevance. The centrality indices included the following measures:

1. The indegree centrality shows the number of incoming arches, that is, the number of creditor banks. A bank that has many interbank liabilities would be said to have a high indegree. From systemic point of view banks with high indegree can trigger the most severe domino effect.
2. The outdegree centrality shows the number of outgoing arches, that is, the number of debtor banks. A bank that has many interbank claims would be said to have a high outdegree. From systemic point of view banks with high outdegree can be easily affected through the interbank market by a crisis generated by a bank default.
3. A systemically relevant bank has not only exposures to many other banks but it has large interbank positions. This is measured by valued degree centrality, which focuses on the line values. Valued indegree centrality shows the proportion of bank \( i \)'s liabilities to total liabilities.
(4) Valued outdegree centrality reflects the proportion of bank $i$’s interbank assets to total assets.

(5) The distance between two banks is measured by the number of interbank linkages that are needed to reach bank $i$ from bank $j$. To be systemically relevant a bank has to be close to all other banks. As a result, centrality is inversely related to distance. In-closeness centrality is thus defined as the inverse of the sum of all distances.

(6) According to the proximity centrality index a systemically relevant bank is characterized by to facts. First, it has a large influence domain, which consists of direct and indirect creditors of a bank. Second, the average distance from all banks in the influence domain is small.

(7) On the basis of rank centrality a bank is systemically important if it has many relations to other important banks, but these banks again are only important if they have themselves many relations to other important banks and so on.

(8) Finally, a bank is systemically relevant if it lies on numerous potential contagion paths, that is, the bank links many other banks. The betweenness centrality measures thus the sum of probabilities across all possible pairs of banks that the shortest path between bank $j$ and bank $k$ will pass through bank $i$.

By addressing the graph of the Swiss interbank market Müller concluded, that the centralization is pretty high among debtor banks. The two most important debtors have liabilities to more than half of the banks. The Swiss interbank market can be described as a fairly sparse network. It has a density of 0.03, that is, only 3% of all possible interbank linkages are used. By dividing the Swiss interbank market into several subnetworks according to banking categories it became clear, Cantonal banks and Regional banks build both subnetworks that stand out clearly from the whole banking sector. The subnetwork of Cantonal banks is quite homogenous and less sparse than the interbank market as a whole, meanwhile regional banks are highly centralized within the category.

In order to check the banking system’s exposure to aggregate risk, Müller simulated a default situation, which yielded a measure of inherent instability. The effect of a failure of one of those banks that seemed to be systemically relevant according to the network structure was measured by the simulation approach. The contagion was captured through the credit exposure channel and through the credit line channel. The recursive algorithm that was used to analyze contagion in the Swiss interbank market was an extended version of the algorithm presented in Eisenberg and Noe (2001), which was described in Figure 5 of the Ph.D. thesis. The main extensions were a sharp distinction between illiquidity and insolvency and the introduction of credit lines. The clearing payment vector was determined similar to the method applied by Elsinger, Lehär and Summer [2002], which was presented in subsection 2.2.2. If a bank is illiquid, the bank repays as much as it can, which corresponds to its liquid assets plus what it receives from its debtor banks. If a bank is insolvent, the total repayment of the bank is reduced by the loss that cannot be covered with capital. By adding the opportunity to raise credit up to the amount of the bank’s open credit lines at other banks to the model vector of liquid assets is modified. The volume of raised credit is added and all payments to other banks which want to use their credit lines at bank $i$ are subtracted. An illiquid bank always exhausts the whole amount up to the credit line at once. Insolvent or illiquid banks however do not provide liquidity to other banks. In the case of a bank default other banks can face not only problems related to their solvency, but also to liquidity.

Müller came to the conclusion that by neglecting the existence of credit lines, in the worst case scenario, in which two big banks defaulted jointly, 27% of all banks would not be able to
fully repay their interbank liabilities. Most of them are smaller and medium banks with a share of total assets of 14%. Furthermore, 5% of all banks would become insolvent. Again these would be smaller banks with aggregated total assets of about 3%. By allowing for credit lines in the worst case scenario the number of illiquid banks is reduced, from 27% to 20% and in percentage of total assets from 14% to 5%. The number of insolvent banks declines as well, namely from 5% to 4% or in percentage of total assets from 3% to 1%. That is, as long as only solvent banks can draw on credit lines and only at solvent and liquid banks, credit lines enhance systemic stability and systemic risk based on the interbank market is moderate.

Running the simulations in the subnetwork of Cantonal and regional banks gave interesting implications on what role the structure of the banking sector plays for the resilience to contagion. Neglecting the credit lines in the subnetwork of fairly dense and homogenous Cantonal banks no bank triggered a liquidity problem at more than 9% of the other Cantonal banks. All liquidity shortages were direct consequences of the initial failure. The failure of any Cantonal bank does never lead any other Cantonal bank to insolvency. In the second scenario, where the opportunity to draw on credit lines at other solvent and liquid Cantonal banks was introduced, there was no liquidity or insolvency problem at all. In contrast, in the centralized regional banks’ subnetwork if the bank in the centre fails, then in the first scenario 23% of the other regional banks become illiquid and 44% become insolvent. The introduction of credit lines cannot really mitigate the spill-over effects.

The study of Boss et al. [2004] has also captured the conditional contagion impact on default of a specific bank, by addressing the question of the impact of individual bank defaults on other banks. More specifically, if one particular bank became erased from the network, how many other banks became insolvent due to this event? The authors found that only 13 banks – when defaulting – drag more than one other bank into default. There are 16 banks which will cause one single default of one other bank. Boss et al. related the contagion impact of a specific bank to its role in the network. Amongst many possible measures, they found that the betweenness of the defaulting bank, which was also captured by Müller [2003] is directly related to the contagion impact. A positive linear relation between the betweenness and the contagion impact was discovered.60

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60 Concerning the Hungarian literature related to network theory the study of Vedres [1997] is of major importance. The author examined by means of network theory the position of banks in the network of directorate interlocks of the large Hungarian corporations. The research question was whether banks have a central position in the network or do they play a secondary role. If banks are central, does it mean power? The sample used in the analysis consisted of all the banks plus the 100 largest Hungarian companies in respect of the net revenue in 1995. The potential power of the banks was analysed by means of directorate interlocks. Vedres described the centrality of banks by two different measures. The outdegree centrality measures the importance of the information channel related to directorate interlocks. The more complex Bonacich power index weights indirect ties and indicates the power of a bank. Vedres came to the conclusion, that taking outdegree centrality of number of delegations into consideration, banks are locked into centrality, banks have larger collection of connections than companies. However taking indirect connections also into account it became clear that in the middle of 1990s Hungarian banks are not more central than Hungarian companies.

Tóth [1997/98] investigates the inter-enterprise ownership links in Hungary by also building on network theoretical findings. The goal of the study was to examine the popularity of inter-enterprise ownership links and the motivation of these links. Stark et al. [2000 a, b] analyse the ownership linkages among the 200 biggest Hungarian companies and the 25 biggest banks, with respect to companies being in the shadow of the state, that is, relation of post socialist companies to other companies were in the focus of the study.
III. THE HUNGARIAN INTERBANK MARKET

The third chapter of my Ph.D. thesis aims to analyse the Hungarian interbank market based on data of uncollateralized interbank loans and deposits denominated in Hungarian forints. In Chapter III the following three hypotheses are formed and tested.

H1: On the basis of the maturity breakdown of the interbank turnover data, transactions settled in the Hungarian interbank market serve as a tool of liquidity management.

H2: On the basis of the Herfindahl–Hirschman index the Hungarian interbank market is highly concentrated.

H3: The structure of the Hungarian interbank market is mostly similar to a multiple money centre structure.

After the brief review of the role and the main transactions of the interbank market the turnover data of the uncollateralized interbank loans and deposits is analysed. As subsection 3.2. shows, the monthly turnover of the Hungarian interbank money market demonstrates an upward trend. The special year-end-liquidity management of banks and the payment obligations of value added and consumption taxes of companies lead to the cyclicality of the turnover. Concerning the maturity of the interbank loan and deposit contracts overnight transactions dominate the market. In this sense the Hungarian interbank market can be truly seen as a tool of liquidity management. That is, the first hypothesis was accepted. In subsection 3.3. the volume data of the uncollateralized interbank loans and deposits is analysed. The average volume of uncollateralized interbank assets was 208.7 billion forints in 2003, which accounted for 1.71% of total assets and 19.69% of tier 1 capital of the banking sector. Interbank transactions are dominated by overnight transaction, but the amount of transactions with original maturity of one week, two weeks, one month, three months and six months are also important. In 2003 the average volume of transactions with maturity longer than one year is the second highest after the volume of overnight transactions. However this deviancy can not be seen as a general market tendency, but rather can be explained with the special role and management of a couple of banks. The daily volume of the interbank transactions is pretty volatile.

In subsection 3.4. the structure of the Hungarian interbank market is brought into focus, as we have seen in subsection 1.5. the severity and probability of contagion and the structure of the interbank market are related to each other. By analysing the key dimensions of the structure of the interbank market, one can conclude, that based on the Herfindahl-Hirschman index the Hungarian interbank market is moderately concentrated. In this sense the second hypothesis was rejected as it is not true that the Hungarian interbank market is highly concentrated. Concerning the market share of the most significant banks, both in the asset and liability side the three most significant institutions cover 45% of the market, meanwhile the ten most significant banks own about 80% of the market. The Hungarian interbank market is not complete, as there are many banks who do not transact with each other. As we will see the structure of the interbank market is similar to a multiple money centre structure, where the role of money centres is played by ten-fifteen big Hungarian banks. The multiple money centre structure of the Hungarian interbank market coincides with the experience of  

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61 Chapter III. and IV. of the dissertation is based on the research carried out at the Hungarian National Bank. The full paper can be read – in Hungarian – in the 2004/10 MNB Working Papers. (Lublóy [2004].) Any views expressed herein are my own and do not necessarily reflect those of the Hungarian National Bank.
treasurers. In the opinion of financial experts in the interbank market there is a friendly, informal relationship among ten-fifteen banks. The hypothesis of the multiple money centre structure is also supported by the fact, that 60% of interbank transactions are settled among the 15 largest banks, while in 95% of transactions at least one of the partners is among those 15 banks. The network topology and the graphs of the interbank market also refer to a multiple money centre structure, where ten-fifteen banks are situated in the centre. Thus, the third hypothesis was accepted.

3.1. The role and the main transactions of the interbank market

In every modern financial system we can find a well functioning interbank market. The interbank market is playing an important role either in *allocating liquidity* on micro level or strengthening financial integration on macro level. However a well functioning interbank market is not only crucial for the banks, but also for the central banks, as central banks try to achieve their monetary policy by means of their monetary tools, among which interest rates play a significant role. As a result the interbank market serves as a building block for the financial transmission.

In order to manage temporary liquidity problems banks can draw either on the interbank market or on the central bank. In the Hungarian money market between June 2001 and June 2003 the frequency – measured by the number of days of the credit extension – of credits extended by the central bank doubled. At the same time the volume of the withdrawal decreased to one third, one fourth. All these indicate the alteration of the liquidity management of the Hungarian banks. (Balogh and Gáabriel [2003].)

In developed countries in the interbank market there are three main types of interbank transactions: foreign exchange swaps (FX swaps), uncollateralized interbank loan and deposit transactions and repurchase agreements (repos). In Hungary, as a result of the aggregate liquidity surplus of the banking system, the market of central bank deposits with original maturity of one night or two weeks is pretty important, as in many cases banks prefer passing part of their liquidity to the central bank. Balogh and Gáabriel [2003] argue in their study about the Hungarian interbank money market past and future trends that the market is dominated by FX swaps. In the second half of 2002 the turnover of FX swaps was two times higher than the turnover of uncollateralized interbank transactions. The growth of the turnover of the uncollateralized interbank transactions is lower than the growth of the FX swap market, which can be mostly explained by the active foreign participants in the FX swap market. The lower growth of the uncollateralized transactions is due to the narrower interest rate band of the central bank, which lowers the cost of the transactions signed with the central bank. As a result of the lower costs, the banks prefer transactions with the central bank to transactions in the interbank market. In Hungary the role of repos is fairly limited. In contrast, in member countries of EU15 since 2001 the repo market is the most significant segment.

The turnover of the Hungarian interbank money market is growing year to year, however less dynamically. In my Ph.D. thesis I only deal with uncollateralized interbank transactions.

62 However, one could argue that the second half of 2002 can not be seen as a typical period. In the period before the speculative attack against the Hungarian forint, which culminated on 15-16 January 2003, several banks executed a significant volume of FX swap transactions ordered by foreign banks.

63 According to Balogh and Gáabriel [2003] in 2002 the volume of central bank deposits accounted for one third of total interbank transactions on average.
transactions,\textsuperscript{64} I do not cover FX swap transactions, repo transactions and collateralized interbank transactions. Anyway, in Hungary between June 2001 and June 2003 the turnover of collateralized interbank transactions (excluding repos) is accounted for 0.53% of the turnover of the total interbank transactions on monthly average, and none of the months exceeded 2.5%. The volume of collateralized interbank transactions (excluding repos) is also limited, in 2003 the daily average accounted for 1.26% of the total volume of interbank exposures. Unfortunately the Hungarian National Bank does not dispose data of the decomposition of collateralized versus uncollateralized transactions from other countries.\textsuperscript{65}

**Uncollateralized loan and deposit transactions** are deals which involve capital movements. One bank extends a credit or to another bank or deposits money in another bank for a certain period either in Hungarian forints or in a foreign currency. The bank is either extending a credit to another institution or depositing money in that institution, both transactions affect the asset side of the balance sheet of the bank. If the money flows form bank $A$ to bank $B$, this can either mean that bank $A$ has extended an interbank credit to bank $B$, or that bank $A$ has deposited money in bank $B$. Whether the transaction is a loan or a deposit transaction solely depends on what the trader has written on the specific document.\textsuperscript{66}

Interbank loan and deposit transactions serve as a *tool of liquidity management*. The treasury of a bank is either try to invest the liquidity surplus of the bank denominated either in Hungarian forints or in another currency in the market, or try to obtain additional liquidity by means of credits in order to secure that the bank will be able to meets its financial obligations. The daily opening position is obtained from the Back Office. The traders know form the status of the opening position, whether the bank has a liquidity need or liquidity surplus on that given day. The aim of interbank transactions can be the coverage of a given exposure, but speculation or arbitrage purposes are also possible. Interbank loan and deposit transactions can be agreed on phone or through Reuters Dealing, either directly with the interbank partner or by means of an interbank broker.

In spite of the present regulatory practice the analysis includes the Hungarian Development Bank (MFB) and the Export-Import Bank (Eximbank). On one hand according to the current regulation the Hungarian State and Government partly guarantees the liabilities of MFB and Eximbank.\textsuperscript{67} (Act XX of 2001… [2001], 5. § (1)., Act XLII. of 1994… [1994], 6. § (1).) On the other hand this guarantee is partly limited. Additionally as MFB and Eximbank could be

\textsuperscript{64}As a consequence, if not noted otherwise, when I refer to interbank transactions I mean uncollateralized interbank loans and deposits.

\textsuperscript{65}This can be explained by the fact that foreign statistics group the money market transactions in another way. According to a survey covering 121 banks and carried out by the ECB there exist (1) collateralized transactions, just like repos and collateralized deposit and loan transactions, (2) uncollateralized transitions, (3) FX swaps, (4) overnight index swaps and (5) forward rate agreements. (Money Market… [2003].)

\textsuperscript{66}Related to this, in the case of London-based banks, LIBOR is the London interbank rate, at which banks offer to lend money on short maturity to one another in the wholesale markets. In contrast, LIBID, is the London interbank rate, at which a bank is willing to borrow from other banks on short maturity in the wholesale market. Consequently, the LIBOR is the lowest interbank lending rate, meanwhile the LIBID is the highest interbank borrowing rate.

\textsuperscript{67}Under the terms of the Act XX of 2001 on the Hungarian Development Bank the Hungarian State guarantees the payment obligations stemming from credits and loans with original maturity of more than one year and from bond issuance related to foreign capital involvement, and for payment obligations stemming from credit financing and bank guarantees granted for a third party based on the decision of the Government. (Act XX of 2001… [2001], 5. § (1) a). b.) Under the terms of the Act XLII of 1994 on the Export-Import Bank the Hungarian Government guarantees the payment obligations stemming from deposits of foreign and domestic banks at Eximbank, from credits granted to Eximbank by foreign and domestic banks, from bond issuance related to foreign capital involvement and for the potential payment obligations stemming from a bank guarantee, which was granted on the basis of a decision of the Government. (Act XLII. of 1994… [1994], 6. § (1) a). b.).)
significant institutions in the interbank market the exclusion of those two banks could bias the analysis of the interbank market structure and its systemic risk implications. However, as MFB and Eximbank can not be seen as typical commercial banks, the inclusion of these two institutions into the analysis also bias the picture obtained about the structure of the interbank market. Whenever this is the case, I refer to it.

Due to data limitations domestic interbank exposures denominated in foreign currencies and transactions settled with foreign banks are also excluded from this analysis. Financial experts argue that the volume of interbank exposures denominated in foreign currency is limited. On the one side, this can be explained with the counterparty limits set by banks. As a consequence of the limits institutions prefer not to contract in foreign currency, limits are hold for Hungarian forint transactions. On the other side, majority of the Hungarian banking sector is owned by foreign banks, and in several cases foreign exchange transactions with the mother bank are compulsory. According to the estimation of Balogh and Gábröl [2003] in 2002 about 15-20% of the uncollateralized transactions of the Hungarian banks are settled with foreign banks. However, it can happen that the distribution of this 15-20% is much more concentrated. A study by Manna [2004], which examines the integration of the banking systems in the euro area, shows, that cross border interbank transactions are mainly settled with neighbouring countries. As a result of the regional feature of the markets the transactions settled with foreign banks are also of major importance, especially in Hungary, where the neighbouring Austrian banks own a significant portion of the total assets the banking sector.

3.2. The turnover of the interbank market

Figure 7 shows the monthly turnover of the interbank transactions denominated in Hungarian forints between June 2001 and March 2004. The data presented in the thesis is from the FED database of the Hungarian National Bank (HNB). The data contains from May 2001 onwards all transactions denominated in forints and settled between Hungarian banks. Hungarian banks should report every day the volume of their transactions, their counterparty bank, the opening and the closing day of the transaction, the interest rate and the type of the transaction, which can be deposit or loan, and collateralized or uncollateralized.

The polynomial trend line in Figure 7 shows that the monthly turnover of the interbank transactions has increased on the whole, starting from 1481 billion Hungarian forints in June 2001 and finishing at 2792 billion Hungarian forints in March 2004. However there are significant differences among the months, the monthly turnover has increased by 3.77% on average.

We can also observe some kind of cyclicality in the monthly turnover data. In a given calendar year the monthly turnover reaches its maximum at the end of that year. In the opinion of financial experts this phenomenon did not happen by chance. In December the banks make an effort to possess liquidity surplus and try to avoid the year-end liquidity deficit. As a result the higher interbank turnover in December can be explained by the fact that banks lend to each other on a very short maturity instead of depositing their liquidity surplus at the Central Bank.

68 It is worth mentioning that banks indebted in a foreign currency have mostly obtained a credit with long maturity, and in accordance with the long maturity the credit is probably collateralized.
The special year-end liquidity management of the banks on the one side can be related to the fact, that banks try to avoid to manifest an exaggerated balance sheet on the 31st of December which is party financed by the high interbank liability position. On the other hand banks also try to improve their capital adequacy ratio measured on the 31st of December. Financial experts argue that this special year-end liquidity management can be verified by the time series of the EURIBOR or LIBOR, as on the 31st of December a structural break can be observed in the interest rates of credits which mature after 31 December. By examining the time series of the EURIBOR this phenomenon could be truly captured. The results are shown in Figure 8. In the figure the structural break in the time series of the interest rates of interbank credits with different original maturities are shown. The figure demonstrates that the interest rate of interbank credits with maturity of four weeks increases dramatically little more than one month before the end of the year. The curve of the three-month interest rate shows a jump one week later, a little more than three weeks before the end of the year. Similar jump can be experienced in the curve of the two-week and one-week interest rate.69 It is also notable, that on the 2nd of January the interest rates of interbank credits with different maturities tend to converge, the interest rates are situated in a relatively narrow band of 2.089-2.099%. I have also analysed the time series of BUBOR (Budapest Bank Offer Rate), however in the case if BUBOR similar tendency can not be found.

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69 In December 2003 before the last working day was 24 December, meanwhile the last working day was 29 December.
Figure 8: The time series of the EURIBOR

Note: In percentage, at the end of 2003 and at the beginning of 2004.
Source: Own calculation based on data obtained from http://www.euribor.org/html/content/euribor_data.html.

In the first half of 2001 the average daily turnover of the Hungarian interbank market was 68.7 billion Hungarian forints, which increased to 110 billion forints in the second half of 2003. In the interbank money market we can observe certain cyclicality not only in the monthly, but also in the daily turnover data. The turnover is definitely higher around the days, that is, every 20th of each month, when the companies have to pay their value added tax obligations into the budget. On the 20th of each month the companies have to pay not only the value added tax of goods and services into the budget, but also the corporate tax allowance, the difference between the net amount and the paid allowance of the consumption taxes, part of the employer and employee contribution, the environmental product fee, the tax after services related to the playing industry and the energy tax. (Tax Calendar…[2004]). On the 28th of each month the companies have to pay in the tax allowance of consumption goods, which also regularly increases the turnover of the interbank market. Additionally the turnover of the money market is also influenced by the limited disposal (every week Tuesday) of the central bank deposits with original maturity of two weeks. According to an anonym financial expert concerning the limited time disposal of the central bank, the problem can be related to the game theory. Basically the bank should figure out in advance how much money the other banks have deposited in the two-week deposit at the central bank. If most of the banks have deposited significant amounts at the central bank, than those banks who have deposited less can be better off, as they probably can ask for a higher interest rate in the interbank market for their surplus liquidity.

The maturity breakdown of the total turnover of the interbank transactions realised in year 2003 is shown in Figure 9. In 2003 overnight transactions accounted for 88% of the total turnover. I would like to emphasise, that due to the liquidity cushion nature of the interbank market by analysing the turnover or the volume data of the interbank market it is hard to draw a conclusion concerning the cyclicality or special management of the banking business. The arguments highlighted in this chapter are based on observations of financial experts, which are not against the observed data, however due to the volatile nature of the interbank market (see Figure 13) it would have been hard to verify all of the above mentioned influences.
turnover, transactions with maturity between one day and one month displayed 1 to 4% of the transactions, meanwhile transactions with maturity of more than one month accounted for less than 0.5% of the turnover. The maturity decomposition of the interbank transactions realized in year 2002 shows a similar maturity breakdown feature to year 2003. As shown in Figure 9 the interbank market is dominated by the overnight and short term transactions. In relation with this, we can come to the conclusion, that the Hungarian interbank market supports the liquidity management of banks. Thus, on the basis of the maturity breakdown of the interbank turnover data the first hypothesis was accepted. Transactions settled in the Hungarian interbank market serve as one of the tools of liquidity management.

Figure 9: The maturity breakdown of the uncollateralized interbank transactions

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The maturity breakdown of the uncollateralized interbank transactions in year 2003 (turnover data)

Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.

3.3. The volume of transactions in the interbank market

After the analysis of the turnover data of the Hungarian interbank market the stock data of the Hungarian money market is examined. Figure 10 shows the pretty volatile volume of the average interbank exposures in 2002 and 2003 calculated from daily data. The data is obtained from the FED database of the Hungarian National Bank. The average volume of the uncollateralized interbank assets was 184.4 billion forints in 2002, which increased to 208.7 day after the agreement has made, and the credit has to be paid back on the following working day. In the case of spotnext transactions the interbank credit is granted two days after the agreement has been signed, and the credit has to be paid back on the following working day. The interbank transactions within one week have an original maturity of 1-4 days, the transactions with maturity of one week mature after 5-11 days, the transactions with maturity of two weeks mature after 12-20 days, the transactions with maturity of one month mature after 21-45 days. According to the grouping of the Hungarian National Bank the transactions with maturity of two month mature after 45-75 days, the transactions with maturity of three month mature after 76-135 days, the transactions with maturity of six months mature after 136-225 days, the transactions with maturity of nine months mature after 226-315 days, the transactions with maturity of one year mature after 316-266 days, meanwhile the transactions with maturity longer than one year mature more than 366 later.
billion forints in 2003. The average volume of the exposures accounted for 1.89 and 1.71% of the monthly average of total assets. In 2002 and 2003 the uncollateralized interbank assets total up to 19.64 and 19.05% of the modified tier 1 capital\textsuperscript{72} of the banking sector.

Figure 10: Average volumes of uncollateralized interbank exposures in 2002 and 2003

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{average_volumes.png}
\caption{Average volumes of uncollateralized interbank exposures in 2002 and 2003 (million Hungarian forints)}
\end{figure}

Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.

As shown in Figure 10 interbank transactions are dominated by overnight transactions, but the amount of transactions with original maturity of one week, two weeks, one month and six months are also important. In 2003 there is a jump concerning the amount of transactions with maturity longer than one year, the average volume of transactions with maturity longer than one year is the second highest after the volume of overnight transactions. This jump is surprising in the light of the literature, which suggests that uncollateralized interbank transactions support the liquidity management of banks. The high volume of interbank exposures with long term maturity seems to contradict the first, already accepted hypothesis. However if we examine out data in detail, it can be shown, that this deviancy can be explained basically with the high volume of interbank assets of two banks. On the 1\textsuperscript{st} of September 2003 50% of the interbank credits with maturity longer than six months were granted to a big bank, meanwhile nearly 30% of the credits were offered to a small “niche” bank mostly providing consumption loans. Two other big banks also own a significant part of the market, their market share accounts for about 5-5%. The 50% market share of the big, special purpose state owned bank is not surprising. On one hand, the Hungarian State can

\textsuperscript{72} The need and the method of modification of the tier 1 capital will be explained in subsection 4.2.2.
finance project without burdening the budget. On the other hand, the creditor banks are also better off. First of all, the payback of the credit is granted by the Hungarian State, and as a result, by calculating the capital requirement of the given credit a 0% weight can be allocated to that exposure. Secondly, the creditor banks can earn a return above the return of the government bonds.

The relative high market share of the small bank specialized in consumption loans can be explained by the nature of consumption loans. In Hungary the majority of the consumption loans have a maturity of 6-36 months. According to an interview with a financial expert on one side the small bank would not like to broaden its maturity gap. On the other side the small bank can not assume that a credit will be granted to him any time, so the bank can not bear the risk of financing its business monthly. This can also be verified by the argument that many banks work against their own business, when they grant interbank credit to this small specialized bank, as they make the competition in the field of consumption loans fiercer. The relatively high volume of interbank transactions with longer maturity thus can not be seen as a general market tendency, but rather can be explained with the special role and management of a couple of banks. Despite the ostensible contradiction, on the basis of interbank volume data the first hypothesis can also be accepted. The Hungarian interbank market indeed supports the liquidity management of banks.

The most significant interbank creditor owns 45% of the market, meanwhile the second most significant market participant has a market share of 25%. In this part of the market the concentration of exposures can be explained by a couple of large peculiar transactions.

Figure 11 shows the maturity breakdown of daily averages of uncollateralized interbank exposures in 2002 and 2003. The market share of the overnight transactions is above 30% in both years, the market share of the transactions with original maturity of two weeks and one month is around 10%.

Figure 11: Maturity breakdown of uncollateralized interbank exposures in 2002 and 2003

![Maturity breakdown of the uncollateralized interbank transactions](image)

Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.
The interbank exposures with maturity of one week, three months and one year have a market share of around 5-8%. The market share of interbank transactions with maturity of one day, less than one week and nine months is less than 3% in both years. The market share of the interbank exposures with maturity of six months decreased form 11% to 3%, which refers to a structural change. Due to a couple of large transactions the market share of transactions with maturity longer than 1 year increased form 2% to 12%. As this latter jump is clearly related to large, confidential transactions, the transactions can not be handled as “normal” interbank transactions, and the upward trend can not be seen as a general tendency.

Figure 12 shows the daily volume of interbank exposures in 2003. The maximum is reached in the middle of March and at the beginning of December, when the exposure accounted for 294.3 and 292.2 billion Hungarian forints respectively. On the 20th of March not only the volume of total interbank assets was the highest, but the volume of overnight transactions, and transactions with maturity less than one week as well.

As the interbank market serves as a puffer for liquidity management the daily volume of interbank exposures is pretty volatile. By analysing the volatility of the interbank exposures with different maturities we can conclude, that the standard deviation of the overnight exposures is the highest, namely 33 billion Hungarian forints. Additionally the standard deviation of exposures which mature within one day, in one week, in two weeks, in one month and in three months is also significant and total up to 10 billion forints. Figure 13 displays the coefficient of variation (standard deviation divided by the mean) of the interbank exposures with different maturities. The figure highlights the fact, that the transactions with short maturity – exposures that mature within one week, exposures with maturity of one day and two weeks – have the highest coefficient of variation. Exposures with maturity of nine and three months are also volatile. The coefficient of variation of the overnight transactions and exposures with maturity of two and six month is around 45%.
Concerning the high volume of interbank assets, we can not say anything about the internal structure of those assets and its systemic risk implications. In the case of lower volume of interbank exposures, it could happen that the distribution of transactions is concentrated and as a result the probability and severity of domino effect is more significant. For analytical purposes six periods were selected, containing altogether 50 days, which covers 20% of the working days. In Figure 13 the selected turbulent and less turbulent periods are marked. The marked days serve as an input for the analysis of the structure of the interbank market. In order to analyse the severity of contagion these days also serve as an input for the simulation, whose results are presented in chapter IV. The marked periods include days between 7-20 January, 19 March – 1 April, 13-26 June, 9-15 July, 15-20 October and 2-13 December. The four ten-day periods are grouped among the days, where the volume of total interbank assets reached 250 billions. One of the two five-day periods includes days, where the daily average of the volume of interbank assets was the lowest. The other five-day period in October covers a period when the volume of overnight exposures was surprisingly small.
One important dimension of the structure of the interbank market is the concentration of exposures, which can be measured by the market share of the most significant banks. The concentration of the Hungarian interbank market is examined on the basis of the selected 50 days by means of the concentration ratio and the Herfindahl-Hirschman index. The second hypothesis captures the concentration of the Hungarian interbank market. We could expect that as a consequence of the limited number of participants and special characteristics of the Hungarian banking sector the Hungarian interbank market is – on the basis of the Herfindahl–Hirschman index – highly concentrated.

Table 6 shows the minimum, mean and maximum of the cumulative market share of the most significant banks in percentage of the total volume of interbank exposures. The concentration of interbank assets and liabilities is nearly the same. Both in the asset and liability side the three most significant institutions cover 45% of the market, the five most significant banks own about 60%, meanwhile the ten most significant banks cover 80% of the market. In both market segments the fifteen most active institutions acquire more than 90% of the interbank market.

Table 6: Concentration in the Hungarian interbank market

<table>
<thead>
<tr>
<th>Concentration in the intrabank market</th>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td>Market share of the 3 biggest banks</td>
<td>35.23%</td>
<td>45.16%</td>
</tr>
<tr>
<td>Market share of the 5 biggest banks</td>
<td>49.55%</td>
<td>58.50%</td>
</tr>
<tr>
<td>Market share of the 10 biggest banks</td>
<td>71.78%</td>
<td>78.94%</td>
</tr>
<tr>
<td>Market share of the 15 biggest banks</td>
<td>85.18%</td>
<td>90.30%</td>
</tr>
<tr>
<td>Market share of the 20 biggest banks</td>
<td>93.72%</td>
<td>96.76%</td>
</tr>
</tbody>
</table>

|                                       | Minimum| Average     | Maximum |
|---------------------------------------|--------|-------------|
| Market share of the 3 biggest banks    | 36.65% | 45.12%      | 51.78%  |
| Market share of the 5 biggest banks    | 49.38% | 59.48%      | 67.41%  |
| Market share of the 10 biggest banks   | 72.60% | 80.90%      | 87.27%  |
| Market share of the 15 biggest banks   | 87.74% | 92.23%      | 96.85%  |
| Market share of the 20 biggest banks   | 94.884%| 97.66%      | 99.72%  |

Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.

Based on the selected 50 days the market share of the biggest interbank lender is 23% on average, meanwhile the second most significant lender owns 12% of the market. There are two big banks with market share of 7.5% and 6%. In this way the four biggest banks own circa 50% of the market, all with a strong residential customer base. A market share of higher than 4% can be found in the case of three other banks.

On the other side, the market share of the biggest interbank borrower is above 20%. At the same time the second most important borrower has 10% of the market. The third biggest market player owns 8.3% of total interbank liabilities. The market shares of two other big banks exceed 5% with their 7.5% market share. Concerning the borrowing side of the market the profiles of the biggest market participants are mixed. Most of the banks are rather retail than corporate banks. However among the active banks there are institutions that neither have a massive retail base, nor extended corporate customer base.

Several banks share less than 1% of the market. Concerning the asset side of the market there are fourteen banks whose market share is less than 1%. On the liability side of the market ten

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73 The concentration ratios in Table 6 were obtained by lining up in a decreasing order the market participants on the basis of their daily volume of interbank exposures. Afterwards, the percentage market share of the banks was calculated and cumulated. The maximum, mean and minimum of these cumulative market shares are presented in Table 6. As a consequence of the volatility of exposures and the dominance of transactions with short term maturity during the 50 day period the role of the most significant institutions vary among different banks.
banks own less than 1% of the market. During the examined 50 days seven banks did not get any interbank credit, while on the interbank liability side ten banks did not granted any credit at all.

Using the data of the selected 50 days the Herfindahl-Hirschman index (HHI) was calculated. The index shows the sum of the squares of the individual banks’ market share expressed in percentage. Concerning the market of interbank assets the maximum of the HHI was 1581, the mean accounted for 1045 and the index never fall under 729. Concerning the market of interbank liabilities the concentration is a bit lower, the maximum of the HHI was 1283, the mean accounted for 988 and the minimum for 699. According to the Horizontal Merger Guidelines of the Hungarian Competition Authority the market is not concentrated if its HHI is under 1000, the market is moderately concentrated if its HHI is between 1000 and 1800, and the market is highly concentrated if its HHI is above 1800. In the highlight of the numbers both segment of the Hungarian interbank market is moderately concentrated. (Horizontal Merger Guidelines... [2001].) The second hypothesis is thus rejected. On the basis of the Herfindahl–Hirschman index the Hungarian interbank market can be rather characterized with moderate concentration.

For further analysis of the structure of the interbank market the bilateral interbank positions should be examined. Again, the data is obtained from the FED database of the Hungarian National Bank. Interbank assets and liabilities can be best captured by a matrix, which was shown in Figure 3. However in Figure 3 the interbank positions of the foreign banks are also presented, as I have mentioned earlier due to data limitations the analysis do not covered foreign banks.

As bilateral positions of individual banks can not be disclosed on the basis of the selected 50 days Table 7 shows by means of six intervals the average size of interbank assets and liabilities for each bank. The names of the banks are also not disclosed, banks are numbered from 1 to 39. The green cell in the intersect of first row and sixth column for example shows that the sixth bank borrowed funds from 500 to 1000 million forints on average from the first bank. The matrix indicates that many banks have no interbank assets or liabilities at all. 68.9% of the cells of the matrix equal zero, in 1021 from the potential 1482 interbank relations banks did not settle any transaction at all. The Hungarian interbank market is not complete. There are many banks who do not transact with each other. In 9.3% of potential relations bilateral interbank exposures range an average from 0 to 100 million forints. In 15.2% of potential relations the average interbank exposure is between 100 and 500 million forints. Bilateral interbank exposures between 500 and 1000 can be found in 3.4% of potential relations. In 2.6% of potential relations bilateral interbank exposures range an average from 1000 to 3000 million forints. Average exposures higher than 3000 million forints can be found in 9 cases, representing 0.6% of potential relations.

It is worth mentioning, that the data used is unique. In many European countries, just like United Kingdom, Germany or Belgium only aggregate exposures were given. (Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004].) On one hand the ongoing trends of the interbank market can be better captured by means of the unique data: On the other hand the mentioned statistics burden significantly the banks’ reporting duties. The number of potential relations is \((39 \times 39) - 39 = 1482\), that is, number of rows multiplied by the number of columns minus the number of elements in the diagonal, as a bank can not have interbank assets or liabilities from itself.

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Table 7: The matrix of the Hungarian interbank market

Note: Based on the selected 50 days, in million Hungarian forints.
Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.

In order to assess the structure of the Hungarian interbank market from another point of view the banks were grouped together according to their asset size. Table 8 presents the distribution of interbank assets and liabilities by means of banking groups.

Table 8: Interbank market share of different banking groups

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Total assets</th>
<th>Cumulated assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.32%</td>
<td>20.94%</td>
<td>5.49%</td>
<td>5.92%</td>
<td>3.05%</td>
<td>3.06%</td>
<td>0.55%</td>
<td>0.00%</td>
<td>43.33%</td>
<td>43.33%</td>
</tr>
<tr>
<td>2</td>
<td>2.16%</td>
<td>2.37%</td>
<td>1.13%</td>
<td>0.57%</td>
<td>0.70%</td>
<td>0.05%</td>
<td>0.16%</td>
<td>0.06%</td>
<td>7.21%</td>
<td>54.53%</td>
</tr>
<tr>
<td>3</td>
<td>5.63%</td>
<td>5.90%</td>
<td>3.09%</td>
<td>2.05%</td>
<td>2.14%</td>
<td>0.00%</td>
<td>0.18%</td>
<td>0.00%</td>
<td>18.99%</td>
<td>73.52%</td>
</tr>
<tr>
<td>4</td>
<td>1.28%</td>
<td>1.69%</td>
<td>0.65%</td>
<td>0.65%</td>
<td>0.50%</td>
<td>0.34%</td>
<td>0.00%</td>
<td>0.36%</td>
<td>5.47%</td>
<td>78.99%</td>
</tr>
<tr>
<td>5</td>
<td>2.20%</td>
<td>2.88%</td>
<td>1.31%</td>
<td>1.26%</td>
<td>0.82%</td>
<td>0.868%</td>
<td>0.04%</td>
<td>0.29%</td>
<td>9.66%</td>
<td>88.64%</td>
</tr>
<tr>
<td>6</td>
<td>1.47%</td>
<td>3.64%</td>
<td>0.38%</td>
<td>0.45%</td>
<td>0.13%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>6.07%</td>
<td>94.71%</td>
</tr>
<tr>
<td>7</td>
<td>1.54%</td>
<td>1.72%</td>
<td>0.44%</td>
<td>0.51%</td>
<td>0.27%</td>
<td>0.29%</td>
<td>0.09%</td>
<td>0.00%</td>
<td>4.86%</td>
<td>99.57%</td>
</tr>
<tr>
<td>8</td>
<td>0.19%</td>
<td>0.06%</td>
<td>0.05%</td>
<td>0.12%</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.43%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Total liabilities 22.79% 39.20% 12.54% 11.53% 7.63% 4.59% 1.02% 0.71% 100.00%
Cumulated liabilities 22.79% 61.99% 74.52% 86.05% 93.69% 98.27% 99.29% 100.00%

Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.
The 50 day average of interbank positions accounted for 251.7 billion Hungarian forints in total. On the basis of the asset size of banks on the 31st of December 2003 the first group of banks contains the five biggest banks, the second group includes from the 6th to 10th biggest banks, and so on. As the Hungarian banking sector consists of 39 banks, the last group only contains four banks. The value of 5.49% in the intersect of the second row and fourth column for example shows that 5.49% of the total interbank exposures were settled between banks of the first and the third banking group.

By virtue of Table 8 the concentration of interbank assets and liabilities is interesting. Concerning the asset side of the interbank market the market share of the first group is 47.32%, while on the liability side the given market share is only 22.79%. This anomaly can be explained by the fact, that the banks of the first group funded a state bank with a special role in the second group. Generally speaking, by examining the cumulative market share of the banking groups we can conclude that the liability side of the market is more concentrated, than the asset side. This statement is especially valid concerning the market share of the ten and twenty biggest banks.

We can also see from Table 8 that there are only six relations from the 64, where the market share is higher than 5%. More than half of the interbank exposures are related to these six relations. In four cases this can be explained with liabilities of banks of the first banking group, while in two cases with liabilities of banks of the third banking group. It is worth mentioning that banks in the third banking group are more significant interbank lenders, than banks in the second banking group. The third banking group provided 18.99% of the total interbank credits, meanwhile the second banking group accounted for a market share of solely 7.21% of the interbank lending volume. In more than 60% of interbank transactions at least one of the partners is among the first five biggest banks. We can find a market share higher than 1% in 17 cases, which covers altogether 36% of the market.

According to Table 8 the Hungarian interbank market can not be described with any clear structure (see subsection 1.5.). We can arrive to the same conclusion if we group banks by their interbank importance, where the most important bank is the bank with the highest average asset and liability position. In this case – concerning the volume of interbank transactions – in about 70% of the interbank exposures at least one of the partners is among the first five biggest banks. The structure of the interbank market is similar to the multiple money structure. This statement is captured in the third hypothesis. The role of the money centres are played by ten-fifteen big Hungarian banks, where money centres are closely linked to each other. The money centre structure of the Hungarian interbank market can partly be verified by the fact, that about 60% of the interbank transactions are settled among the fifteen largest banks, while in 95% of transactions at least one of the partners is among those fifteen banks. The multiple money centre structure of the Hungarian interbank market coincides with the experience of the treasurers. In the opinion of financial experts in the interbank market there is a friendly, informal relationship among ten-fifteen banks. The market of this inner circle can be described with the principle of reciprocity. That is, if one of the counterparty banks requires additional liquidity, the other banks try to provide it under fair conditions and vice versa. The market participants outside the inner circle mostly settle transactions through the money centres. However, if we compare the structure of the Hungarian interbank market with structure of the Belgian interbank market, we can conclude, that the Belgian market is more similar to a multiple money centre structure. Among the four largest Belgian banks –
owning 85% of total banking assets – circa 35% of interbank transactions are settled, and in 90% of the transactions at least one of the partners is among those four banks. (Degryse – Nguyen [2004].)

However the structure of the interbank market is similar to a multiple money centre structure, it could be an excessive statement that in a banking system of 39 banks there are ten-fifteen money centres. In Figure 14 a special kind of network topology of the Hungarian banks is presented. The distance between bank i and bank j was measured by the distance function of $1 / (x_{ij} + x_{ji})$, where $x_{ij}$ represents the average interbank credits of bank i extended to bank j. As a consequence of the distance definition banks are near to each other if they are closely linked through the interbank market. By assuming several initial coordinates the optimalization was carried out by the Solver function of Excel. We would arrive to a very similar network topology of the banks if we had measured the distance between bank i and bank j by the function of $1 / \max\{x_{ij}, x_{ji}\}$. In Figure 14 it can be easily seen that there exist an inner circle of ten-fifteen banks around which the other banks are situated. The obtained figure also supports the third hypothesis, that is, the structure of the interbank market is mostly similar to a multiple money centre structure.

Figure 14: The network topology of the Hungarian banks I.

Note: Based on the average volume of interbank transactions.

In Figure 15 the network topology of the banks is based again on the distance function of $1 / (x_{ij} + x_{ji})$. However in this case $x_{ij}$ represents the sum of the credits extended by bank i to bank j in 2003. That is $x_{ij}$ shows one part of the interbank turnover between bank i and bank j. In this figure the link between the banks that are situated in the inner circle seems to be more

77 I have also tried to draw the network topology of the bank by assuming the commonly used distance function of $1 / (x_{ij} \cdot x_{ji})$. However in this case I could not minimalize the sum of the square of the errors, as the target cell in Solver did not converge.
cohesive. The banks outside the inner circle are spread around banks which act as the money centres.

Figure 15: The network topology of the Hungarian banks II.

![Network Topology](image)

*Note:* Based on turnover data of 2003.

In Figure 14 and 15 the banks that are closely linked to each other can be observed, however the figures do not reflect the proper link between pairs of banks. In order to overcome this problem I have prepared the graph of the Hungarian interbank market by means of UCINET from Analytic Technologies, which is a software used in social network analysis. (Borgatti – Everett – Freeman [2002].) The input data composed of a matrix showing bilateral interbank positions based on the turnover data of uncollateralized interbank transactions from year 2003. Based on geodesic distances, the graph obtained with the initial setting of Netdraw is shown if Figure 16. Two banks are situated in the left upper corner of the figure, these banks had no interbank transactions in 2003. By virtue of Figure 16 half of the banks are strongly connected to each other, meanwhile the other half of the banks has relationships with few banks in the centre. The graph also confirms the acceptance of the third hypothesis. As the graph is directed the figure also shows whether a bank is solely a borrower or lender in a given relationship. If the arrow points from bank \( A \) to bank \( B \), it means that in 2003 solely bank \( A \) deposited its liquidity surplus at bank \( B \). If the arrow points back and forth, than not only bank \( A \) deposited its liquidity surplus at bank \( B \), but bank \( B \) also passed its liquidity surplus to bank \( A \). In Figure 16 five banks are marked with square, which means that they were in every relationship net lender.\(^78\) 16 banks marked with triangular were not in every relationship a net lender, but altogether the banks lent more funds than borrowed. Banks marked with circle were altogether net borrowers. There is only one bank marked with diamond that was net borrower in every relationship.

\(^78\) If a bank is marked with a square the arrows can point back and forth, which means that the bank not only lent to another bank, but also borrowed money from that bank. However concerning the net bilateral interbank position of the banks, the bank marked with a square lent more funds, than borrowed.
Interbank assets and liabilities of the 39 Hungarian banks could be best captured in a 39 dimensional frame of reference. However the 39 dimensional frames of reference have many possible projections in two dimensions. Six of them are shown in Figure 17. One commonly used illustration is the circle layout. The circle layout of the interbank linkages of the banks is shown in Figure 17a. Figure 17b is obtained by means of principal components. The principal components are the first two eigenvectors of the adjacency matrix of the interbank market. In Figure 17b banks are close to each other if they have direct relationship to the same banks. Figure 17c is based on Gower scaling, which is a metric multidimensional scaling of geodesic distances. Banks are close together if they have short path distance to each other. Figure 17d is obtained by means of the Kruskal non-metric multidimensional scaling, which is the same as Gower scaling except that path distances are converted to rank-orders first. As a result the relationship between path distance and distance on the map is not linear. Finally Figure 17e banks are allocated on the basis of the principle of node repulsion, meanwhile Figure 17f applies the principle of node repulsion and equal edge length bias.

After the analysis of the structure of the Hungarian interbank market it is still an open question how the above mentioned the moderately concentrated market and the multiple money centre structure influences the probability and the severity of contagion. The results of the simulation exercise are presented in the next chapter.
Figure 17: Additional graphs of the interbank market

- **Figure 17a: Circle layout**
- **Figure 17b: Principal components**
- **Figure 17c: Gower metric**
- **Figure 17d: Kruskal distance**
- **Figure 17e: Node repulsion**
- **Figure 17f: Node repulsion and equal edge length bias**
IV. DOMINO EFFECT IN THE HUNGARIAN INTERBANK MARKET

4.1. Hypotheses and the model

The aim of the empirical research is to examine the severity and probability of contagion in the Hungarian interbank market. The Hungarian adaptation of the model of Elsinger, Lehar and Summer [2002], which was presented in subsection 2.2.2, would be desirable from several points of view. Just to mention the most important ones, it would be possible to quantify how macroeconomic shocks affect the wealth of the bank portfolios and as a consequence the solvency of the banks through the channel of market and credit risk. This would be an interesting research question by itself. On the basis of the weakening of the banking sector and the volume of interbank transactions the severity of contagion in the interbank market could be captured. As the feedback between individual banks and potential domino effects from bank defaults are taken explicitly into account, we could not only estimate the probability of contagion, but we also could make a distinction between fundamental and contagious bank defaults. In a model similar to the model of Elsinger, Lehar and Summer the initial failure of a bank would not be the consequence of an idiosyncratic shock, but would depend on the quality of the bank portfolios and on the changes in the macroeconomic variables. However special databases are required for this model, just like a complete credit register for the different industry branches with time series of couple of years or even decades. As I already have mentioned in subsection 2.2.2, a complete credit register is not available for researchers in Hungary, as it simply does not exist. As a consequence due to data limitations an analysis similar to Elsinger, Lehar and Summer [2002] can not be carried out in Hungary.

A second approach to the measurement of the domino effect in the interbank market is related to the papers presented in subsection 2.1. In my Ph.D. thesis I also follow the way marked out by these studies. In this case the empirical research solely focuses on the domino effect. The research question to answer is whether as a consequence of a financial crisis induced by an idiosyncratic failure of a bank, it is possible, that the non-repayment of interbank loans of the failing bank leads to further failures. In the worst case how many banks could go bankrupt as a result of the initial failure? What percentage of total banking assets is represented by defaulting banks? What can we say about the weakening of the banking sector measured by the tier 1 capital losses? Can it happen that the initial failure of a bank affects the whole financial system and in this way distresses also the real side of the economy? In relation with this in chapter IV eight further hypotheses are formulated and tested in different scenarios.

H4: Moderately concentrated interbank exposures and the multiple money centre structure of the market imply that an idiosyncratic failure of a bank – assuming 100% loss given default and total depletion of tier 1 capital – probably can not generate severe contagion.

H5: By assuming a more severe definition of default the severity of contagion will probably increase significantly.

H6: If banks withdraw their short term interbank claims against the failing bank in time, no contagious defaults occur.

H7: By assuming the joint failure of banks with same risk profile – exposures stemming from concentrated credit portfolios, just like extended real estate project financing credits, agricultural credits and credits to financial enterprises – the severity of contagion will probably increase dramatically.
H8: Joint failure of banks exposed to a foreign exchange shock can be seen as a systemic event.

H9: By doubling the uncollateralized interbank exposures of Hungarian banks an idiosyncratic failure of a bank never leads to severe contagion. However by tripling the interbank exposure systemic risk is high. By increasing the market concentration banks suffering contagious defaults solely affect a small part of the total assets of the banking system.

H10: In international comparison contagion through interbank market is a low probability and high impact event, meanwhile in Hungary contagion is a low probability and low impact event.

H11: By assuming the dispersity of interbank exposures the probability of contagion is lower than the contagion experienced next to the real matrix of interbank assets and liabilities.

The method of the empirical research is based on the simulation, which was presented in detail in subsection 2.1.2.2. and in Figure 4. The empirical part of the Ph.D. thesis aims to quantify the effect of the non repayment of interbank loans on the capital of the creditor banks. The credit risk stemming from the interbank market and the effect of contagion is captured by means of the iterative procedure of the simulation. In the base case of the simulation every bank goes bankrupt due to an idiosyncratic event, which means that the failed bank does not or only partly honours its obligation. If there is no bank, which fails as a result of the initial failure, there is no contagion and the iteration stops. If at least one other bank fails as a result of the initial failure, the failed bank does not or only partly pays back its liabilities. In this case there is a contagion in the first round. Again, as a consequence there can exist banks that become insolvent. The iteration stops if in the next round there is no insolvent bank.

4.2. Description of the data

4.2.1. Bilateral interbank positions

As I have mentioned earlier, the data used for analytical purposes stems form the FED database of the Hungarian National Bank. The daily statistics on the interest rate of interbank loans and deposits include information about transactions between Hungarian banks and specialized credit institutions. The statistics contains data about the interbank money market transactions which was agreed on the day of reporting under the specified market conditions. The transactions should be reported on the day of agreement until the closure of VIBER, the Hungarian real time gross settlement system. The Hungarian National Bank registers under the K12 identification number the overnight transactions, meanwhile under the K02 identification number all other transactions are stored. The Hungarian banks are obliged to report the credits drawn form the credit lines and the interest rates valid at the moment of the credit extension. The features of the reported data were presented in the first paragraph of the subsection 3.2.

The data reported by the 39 Hungarian banks reflect bilateral turnover data. The banks have to fulfil their reporting duty via the GiroXMail, no later than half an hour after the closure of VIBER. The data are sent directly to the Hungarian National Bank in a text file format. Table 9 shows a couple of transactions from data base. Column a of Table 9 is the data
identification number. Column b of the table reflects the day of the credit agreement. Column c stands for the identification code of the reporting bank. Column d represents the day of the database query. Column e is the identification code of the interbank partner. Column f covers the credit amount agreed. Column g reflects the opening day of the transaction, meanwhile column h stands for the closing day of the interbank exposure. Column i contains the nominal interest rates in the given transaction. In column j F stands for the received interbank credit, while K means extended interbank credit.

Table 9: The FED database of the Hungarian National Bank

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Source: HNB, Daily statistics on the interest rate of interbank loans and deposits.

In column k B indicates that the transaction is uncollateralized, meanwhile E denotes that the transaction is secured by a stock or a bond. The transactions covered by a security also include a smaller part of the repo-type transactions. Column l shows the original maturity of the interbank transaction measured by the number of calendar day, meanwhile column m reflects the maturity of the transaction in number of working days. In column n the type of the transaction is indicated, 1 means that the transaction is conjugate, that is, both the interbank lender and borrower has reported the transaction. If the transaction had only been reported by one of the counterparts – as a result of the database management this could not happen after 2003 – the transaction would be registered as an unexampled transaction. Unexampled exposures are marked with 0 in column n.

The empirical research solely captures the direct credit relationship on the basis of the uncollateralized interbank loan and deposit transactions of the Hungarian banks denominated in Hungarian forints. The analysis does not cover the interbank transactions of the Hungarian banks which were settled in a foreign currency. The interbank transactions agreed with foreign counterparts are also ignored. I also disregard the collateralized loan and deposit transaction and the repos.\(^{79}\) In my Ph.D. thesis I also ignore the risk stemming from the payment and settlement systems and from the cross holding of shares. Additionally, the off balance sheet exposures, just like interbank linkages through derivative positions, contingent claims, guarantees and undrawn facilities are also not handled. Besides the complex systemic risk implications of the above mentioned exposures, the data required for the mapping of the risk is not at my disposal. Finally, I do not aim to handle the liquidity risk imposed on banks.

\(^{79}\) Under normal market conditions the systemic risk implications of the collateralized interbank transactions as a result of the even incomplete collateral supposed to be limited. However as a consequence of a financial distress it could happen that the value of the securities offered as collateral decreases dramatically. In this case the systemic risk implications of the collateralized transactions could not be ignored.
as it could be an other topic to investigate what the national bank could do and what the lender of last resort function exactly means in the case of a liquidity crisis stemming from the interbank market.

As I have mentioned on page 103 the simulation do not handle separately the Hungarian Development Bank and the Export-Import Bank. As both banks can be significant institutions in the interbank market, if we would exclude those two banks from the analysis it would not reflect the systemic risk implications of the interbank linkages properly. The reasoning behind this is related to the fact described in subsection 2.1.2.4. apropos of the loss given default. In practice the expected losses at the moment of a bank failure is much more important than the finally realized losses. As a result, the long juridical procedure of the bailout of the HDB and Eximbank could lead to technical insolvency of other banks.

As the exact volume of the uncollateralized bilateral interbank positions denominated in Hungarian forints is known, we do not have to estimate it. Previous studies estimated the bilateral interbank positions by means of entropy optimization based on the aggregate position of interbank assets and liabilities. The method of entropy optimization was presented in subsection 2.1.2.1. The proper knowledge of the exact bilateral positions has two important consequences. Firstly, in a given year the matrix of bilateral exposures can be estimated for several days and not only for the middle or end of the year. The data of the middle or end of the year do not necessarily reflect the proper bilateral exposures during the whole year. As a result of the dominance of the short term exposures in the interbank market the structure and decomposition of the bilateral exposures can change dramatically from day to day. This is especially true at the end of the year, when the banks try to window dress their balance sheets and capital adequacy ratios. This year-end anomaly was mentioned on page 105-106, which can also be supported by one of the empirical studies of Furfine [1999b]. Furfine showed in his paper that by examining the federal funds transactions the probability that a bank participates in the federal funds market increases noticeably at year-end, suggesting the tendency of banks to use the funds market to alter their balance sheet ahead of quarterly disclosure dates. When only banks that participate on 10 or fewer days out of 100 days are counted, Furfine found a significant year-end effect. For banks that rarely participate in the funds market the year-end is one day on which they are generally more likely to participate. The findings of Furfine were consistent with the study of Allen and Saunders [1992]. According to the authors the federal funds and repo markets are the most important markets where banks can alter their balance sheet for window dressing purposes.

Secondly, as the proper volume of the bilateral interbank position is known, we do not have to assume anything about the distribution of the aggregate exposures. In contrast, the researchers applying the method of entropy optimization assumed that banks seek to spread their borrowing and lending as widely as possible across all other banks. In this case the relationship lending was ruled out, the phenomenon that in the interbank market a bank may prefer some counterparties to others. However, as we have seen in the previous chapter in the Hungarian interbank market there exists a friendly, informal relationship among ten-fifteen banks. The same market structure could be easily valid for other interbank markets as well. As a result, the assumption about the dispersion of the exposures probably leads to the underestimation of the proper severity of contagion. The study of Wells [2004] highlights the fact, that the estimation methodology of bilateral interbank matrices from partial information significantly influences the severity of contagion. The effect of dispersed interbank exposures on the probability of contagion will be tested on page 160-161 by means of the eleventh hypothesis.
From the FED database on the interest rate of interbank loans and deposits by means of a data base query we can obtain those bilateral interbank transactions which indicated open positions on a given day. After filtering the data we can determine the items which reflect bilateral interbank exposures on a given day. The filtering of the data consists of two steps. First of all, half of the data should be eliminated from the spreadsheet. We should delete from column \( j \) of Table 9 either the transactions marked with \( F \) or \( K \), as every credit agreement is reported twice, both from the creditor and the lender. Secondly, by taking the opening and closing dates of the transaction into account, we should filter and then eliminate those positions which either matured or was even not settled on a given day. Afterwards by the help of pivot tables function of Excel the bilateral interbank matrix could be determined for a specified day. As the following description shows from the turnover data we can obtain the matrix of bilateral interbank positions in several steps. As a consequence of time consuming operations, the systemic risk implications of the Hungarian interbank market was not quantified for every working day of 2003. Instead, as described in the first paragraph of subsection 3.4. for simulation purposes six periods were selected. The periods contain altogether 50 days and cover 20% of the working days in 2003. In Figure 12 the selected 50 days were marked. The selection covered turbulent and less turbulent periods of interbank transactions.

According to Table 4 we could summarize the features of the data used in the analysis of the severity of the domino effect in the Hungarian interbank market in the following way. The research covers each of the 39 Hungarian banks. The data reflects uncollateralized interbank transactions on a bilateral basis. The time horizon of the investigation is 50 working days of 2003. I would like to emphasize again, that as the Hungarian National Bank does not dispose reliable data about the interbank transaction of the Hungarian banks denominated in a foreign currency, the research solely captures the interbank transactions denominated in Hungarian forints. Similarly, due to data limitations the domino effect induced by a foreign bank is also not measured.

### 4.2.2. Capital endowment of banks

According to subsection 2.1.2.3. the necessary condition for contagion to occur is that the realised loss suffered by a bank is higher than the bank’s capital. Just to repeat, bank \( i \) fails if,

\[
\sum_{j=1}^{N} x_{ij} \alpha_{j} \theta \geq c_{i},
\]

where \( \alpha_{j} \) is a dummy variable. \( \alpha_{j} = 0 \), if bank \( j \) did not go into bankruptcy, and \( \alpha_{j} = 1 \), if bank \( j \) did default.

In the simulation similar to the study of Furfine [1999a], Wells [2002], Degryse and Nguyen [2004] and Lelyveld and Liedorp [2004] under the capital of a bank the modified tier 1 capital is considered. In this way we can obtain internationally comparable results. That is, the \( c_{j} \) capital equals to the value of the modified tier 1 capital of the bank \( j \), given in the previous month. Thus, if for example the input for the simulation is the data of 20\(^{th}\) March, the used modified capital is that of 28\(^{th}\) February. The modification of the tier 1 capital is needed, as the main part of banks’ profit after tax will be in form of net profit and general provisioning only part of their tier 1 capital after the general meeting and auditing. However the net profit is generated during the whole year. I modified the tier 1 capital of December 2002 with the cumulative profit after tax with the time proportionately. Additionally not all of the cumulative profit after tax becomes part of the tier 1 capital, as besides the general provisioning a bank can also pay dividend. The dividend payment is also taken into account. Concerning the modification of the tier 1 capital I assumed the following:

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80 General provisioning is also part of the tier 1 capital of banks.
- I suppose that those 21 banks that did not pay dividend in the last three years will follow this practice in 2003 as well, and their whole cumulative profit after tax will be the part of their tier 1 capital.

- For those banks that have disclosed, but the general meeting has not accepted their dividend payment ratio (\(dpr\)), I acknowledge this preliminary ratio and the cumulative profit after tax is multiplied by the reinvesting ratio.\(^{81}\)

- There are 8 banks that have paid dividend at least once in the last three years, but the dividend payment ratios for the last year have not been disclosed yet. In this case I suppose that the banks will pay 35\%, which is a proxy based on the average dividend payment ratio of the last three years. In the last three years the average of the dividend payment ratio, concerning the banks that have paid dividend, was 33\%.

- Thus, if the cumulative profit after tax of the bank was positive, the modification of tier 1 capital equalled to 65\% of the cumulative profit after tax. If profit after tax was negative, banks’ tier 1 capital was decreased by the bank’s loss

4.2.3. The loss given default

In subsection 2.1.2.4. we have seen how complicated the estimation of the loss given default could be. In the case of a bank failure the proper value of the loss given default mostly depends on the country of origin, on the specific situation and on the features of the failed bank. As a consequence of the uncertainty about the proper value of the LGD Furfine [1999a], Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004] presented their results for a range of loss given defaults. The authors did not handle one specific loss given default, but the severity of contagion was quantified next to several loss given default ranging from the minimal 0\% to the maximal 100\%.

In addition to the empirically observed loss given defaults which were presented in subsection 2.1.2.4. it is worth mentioning the guidance provided by the revised Capital Accord of Basel II. The final Accord was accepted on the 26\(^{th}\) of April 2004 and a fierce debate surrounded the approval of the new legislation. Under the foundation IRB approach, banks should only estimate internally the probability of default, a loss given default of 45\% is set for senior claims on banks not secured by recognised collateral. For subordinated claims on banks a 75\% LGD is assigned.\(^{82}\) (Basel II… [2004], 287-88. §.) If a transaction is covered with eligible financial collateral the Committee allows for the modification of the above mentioned loss given defaults, as a result an effective loss given default can be calculated. (Basel II… [2004], 289-294. §.)

We can also find defaulted banks in Hungary. The Ingatlanbank failed in 1991, the Ybl Bank in 1992, the Inofinance was liquidated in 1994. The Leumi Hitel Bank was carried through the market in 1995, the Iparbankház in 1996. Finally the Realbank was liquidated in 1998. (Várhegyi [2002].) Concerning the proper value of the loss given defaults a study of the National Deposit Insurance Fund of Hungary (NDIF) could provide some kind of guidance. (Jánossy et al. [2003].) In the case of five defaulting banks Table 10 presents the crisis management measures taken by the National Deposit Insurance Fund of Hungary, the costs of

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\(^{81}\) Modification of tier 1 capital = monthly cumulated profit after tax * the reinvesting ratio, where the reinvesting ratio = (1 - dividend payment ratio). The dividend payment ratio is the ratio of the planned volume of the dividend and the profit after tax.

\(^{82}\) If a bank accepts the advanced IRB approach the bank has to provide their own estimates of the risk components, just like the probability of default (PD), the loss given default (LGD), the exposure at default (EAD) and the maturity (M).
the intervention, and finally the rate of return at the end of the procedure. The table includes each situation in which the NDIF took measures during the last decade in Hungary.

The similarity between the Heves savings co-operative and the Agrobank cases in terms of the National Deposit Insurance Fund was that expenses were not or only partially recovered. In the case of the Iparbankház Rt. crisis-solving method initiated by the NDIF and implemented together with the State Banking Supervisory Authority was the quiet removal from the market. The Fund granted a loan of nearly HUF 1 billion before the liquidation was ordered and HUF 340 million of this was recovered before the securities included in the credit contract had to be used. As security for the disbursed loan the Fund reserved a right to purchase the assets of the bank and used the right after cancelling the loan and acquired the existing properties, tangible assets, investments, invoices and credit receivables of the bank. Most of the received assets and receivables have been sold since then. In the case of Iparbankház Rt. the recovery ratio of the Fund exceeds 90% at present. On the fourth anniversary of starting the liquidation the NDIF received its total creditor receivable of HUF 5,078 million lodged under the title of indemnifying Realbank depositors. Under the title of additional costs, the NDIF reported a claim of HUF 60 million over a period of four years, of which HUF 51 million was recovered by the beginning of 2003. Taking into account the lost invested capital, the rate of recovery was 63%. It is obvious, however, that the value of our currency today is not the same as four years ago. At discount value, the recovery is around 45%. The liquidation of the Rákóczi Credit Co-operative was ordered by the Budapest Court on the 26th of October 2000. In autumn 2003 the estimated ratio of recovery stood at 35%. (Jánossy et al. [2003].)

As Table 10 shows the recovery rates of the NDIF in the case of the five analysed banks vary in a wide range of 0% to 92.5%. However the recovery rates presented in the last column of the table reflect the recoveries of the Hungarian Fund and not the recoveries of uncollateralized interbank exposure. After further data collection and analysis a case study could be conducted to estimate the proper loss given default of an uncollateralized interbank transaction from the previous Hungarian failures. However given the limited number of bank failures and the questionable reliability of the data, one could easily question the accuracy and soundness of the result. As the conducted case studies would not decrease the uncertainty about the proper value of the LGD I disregard this analysis and follow a similar methodology to Furfine [1999a], Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004], and Lelyveld and Liedorp [2004]. However instead of handling a range of loss given defaults I assume an LGD of 100% in each scenario. One could argue that a 100% loss given default is improbable high. However, if the number of contagious failures is still limited under this unrealistic assumption, than systemic risk implications of the Hungarian interbank market are surely also limited. As after running a couple of simulations the severity of contagion seemed to be limited even by assuming a 100% LGD, I do not handle further loss given defaults. Instead, the break even point of the recovery rate is calculated in each case of a contagious default. The break even point of the recovery rate is the highest rate at which the bank would not default as a consequence of its interbank linkages.
### Table 10: Crisis management methods and success rates

<table>
<thead>
<tr>
<th>Start of co-operation</th>
<th>Credit institution</th>
<th>Method and content of co-operation</th>
<th>Expense (million HUF)</th>
<th>Recovery (million HUF)</th>
<th>Recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.09.1993</td>
<td>Heves and Vicinity Savings Cooperative</td>
<td>Deposit payout on insured deposits</td>
<td>262 +30 additional costs</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>25.05.1995</td>
<td>Agrobank Rt</td>
<td>Advance indemnity payments to depositors, then capital allocation with share subscriptions</td>
<td>500 + 26 additional costs</td>
<td>25 (10+15)</td>
<td>4.7%</td>
</tr>
<tr>
<td>25.08.1995</td>
<td>Iparbankház Rt.</td>
<td>Backing” the action plan of Supervisory Authority with lending, participation in controlling execution, sale of collateral</td>
<td>990 + 2 indemnity</td>
<td>918</td>
<td>92.5%</td>
</tr>
<tr>
<td>04.09.1998</td>
<td>Realbank Rt.</td>
<td>Phase I.: Capital allocation to avoid closure, acquisition of majority holding for purposes of selling the bank</td>
<td>(I.) 3,062 equity</td>
<td>5129</td>
<td>62.6%</td>
</tr>
<tr>
<td>18.01.1999</td>
<td></td>
<td>Phase II.: Indemnity payments on insured deposits</td>
<td>(II.) 5,078 indemnity +58 additional costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.10.2000</td>
<td>Rákóczi Credit Cooperative</td>
<td>Indemnity payments on insured deposits</td>
<td>304</td>
<td>102</td>
<td>33.6%</td>
</tr>
</tbody>
</table>

*Source: Jánossy et al. [2003], p. 47.*

### 4.3. Simulation results

#### 4.3.1. Base case

The base case of the simulation was formulated in the *fourth hypothesis*. As the hypothesis states, the *moderately concentrated interbank exposures and the multiple money centre structure of the market imply that an idiosyncratic failure of a bank – assuming 100% loss given default and total depletion of tier 1 capital – probably can not generate severe contagion*. The severity of contagion is measured by the maximal number of contagious
defaults and rounds of contagion and by the distribution and extent of capital losses suffered by the banking sector.

In the base case 1950 different scenarios were simulated.\(^{83}\) Initially, a bank failed if it lost its modified tier 1 capital totally. By analyzing the worst case a 100\% loss given default was assumed. First round contagion occurred only in 11 cases, that is, 0.55\% of the scenarios. There was no second round contagion. The 11 first round contagious failures were due to the failure of a head institution of a banking group, which caused the failure of its subsidiary.\(^{84}\)

In the worst case scenario, on the 19\(^{th}\) of March, – one of those days, when contagion occurred – the banking system lost 3.53\% of its tier 1 capital. This is shown in the second and third column of Table 11. As Table 11 shows 9 banks suffered losses less than 10\% of their tier 1 capital. Two banks lost between 10\% and 20\%, and between 20\% and 50\% of their tier 1 capital respectively. However the affected two banks account only for 3.88 and 1.61\% of total assets of the banking system. The systemic importance of the failed bank is limited.

Table 11: Base case: losses realized by the banking sector on the 19\(^{th}\) and 21\(^{st}\) of March

<table>
<thead>
<tr>
<th>Realized losses (in the percentage of the tier 1 capital)</th>
<th>19th March</th>
<th>21st March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of banks</td>
<td>In percentage of total banking system assets</td>
</tr>
<tr>
<td>Less than 10%</td>
<td>9</td>
<td>49.77%</td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>2</td>
<td>3.88%</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>2</td>
<td>1.61%</td>
</tr>
<tr>
<td>Above 10%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Default</td>
<td>1</td>
<td>0.23%</td>
</tr>
</tbody>
</table>

The break even point of the recovery rate is 45.72\%, which means, that if the loss suffered by the subsidiary is less than 45.72\% of its total exposure, the subsidiary would not fail in the first round.

During the examined 50 days, the banking sector lost 0.53\% of its modified tier 1 capital on average. However, it is worth mentioning, that on many days the banking sector realized losses higher than 3.53\% of its tier 1. The highest losses, 7.58\% of the tier 1 capital were realized on the 21\(^{st}\) of March, when a big Hungarian bank failed. In this case the weakening of the banking sector is shown in the last two columns of Table 11.

To summarize, the fourth hypothesis can be accepted. In spite of the moderately concentrated interbank exposures and the multiple money centre structure of the market an idiosyncratic failure of a bank – assuming 100\% loss given default and total depletion of tier 1 capital – can not generate severe contagion regardless of the fact whether we measure contagion by the maximal number of contagious defaults and rounds of contagion or by the distribution and extent of capital losses suffered by the banking sector.

\(^{83}\) 50 days x 39 banks = 1950 scenarios.

\(^{84}\) In Hungary there are three banking groups with a subsidiary: to the HVB Bank Hungary group belongs the Hypovereins Mortgage Bank, the Konzumbank is owned by the Magyar Külkereskedelmi Bank, and the Merkantil Bank, the OTP Building Society and the OTP Mortgage Bank belongs to the OTP group.
4.3.2. Modified default definition

The scenario of the modified default is based on paragraph 151. part (3) a) of Act CXII of 1996 on Credit Institutions and Financial Enterprises, which has been modified several times since its came into effect. In the light of the Hungarian regulation the “Financial Supervisory Authority – by reconsidering the data and information at its disposal – should take the necessary or exceptional measures if the capital adequacy ratio of one of the supervised credit institution fall bellow half of the level set in a law or in one of the orders of the Authority.”

The exceptional measures are designated as measures substituting liquidation in paragraph 157 part (1) of Act CXII. (Act CXII of 1996 on … [1996].) The systemic risk implications of an initial idiosyncratic failure was analysed on the basis of this specific Hungarian prudential regulation. In this scenario contagious failure occurs if there exists at least one bank whose capital adequacy ratio falls below 4%. Basically this was captured in the fifth hypothesis, according to which we can expect, that if a more severe definition of default is applied the severity of contagion will probably increase significantly. That is, the initial definition of default is modified, now a bank fails if its regulatory capital is less than half of the minimum capital required. In the base case a bank defaulted if it lost 100% of its tier 1 capital. In this scenario a bank defaults if it operates with an insufficient regulatory capital base, that is, the bank’s capital adequacy ratio is less than 4%. At the majority of the banks the capital available for losses decreased, at the level of the banking sector by 30%. In some cases the diminution was even 50-65%. However there exist several banks whose capital available for losses increased, as their tier 1 capital was lower than the difference between their actual regulatory capital and half of the minimum capital required.

Given a 100% LGD first round contagion occurred in 51 from the 1950 cases, that is, 2.62% of the scenarios. Second round contagion never occurred. 43 out of the 51 first round contagious failures were due to the failure of a head institution of a banking group, which caused the failure of its subsidiary.

Two contagious failures can be explained by an idiosyncratic failure of a big bank, a small bank failed on two different days. Five events of contagion are related to the failure of four different big banks, whose default caused the bankruptcy of two medium banks. In one case, a failure of a small bank led to a failure of a medium bank. The result of the simulation is summarized in Table 12.

Table 12: Modified default definition: evolution of contagion

<table>
<thead>
<tr>
<th>Initial default</th>
<th>Contagion</th>
<th>Number of days</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>head institution</td>
<td>subsidiary</td>
<td>43</td>
<td>Each day except 7, 9-10, 13-15 January and 18 June</td>
</tr>
<tr>
<td>big bank 1</td>
<td>small bank 1</td>
<td>2</td>
<td>13. and 18. June</td>
</tr>
<tr>
<td>big bank 1</td>
<td>middle bank 1</td>
<td>1</td>
<td>17. October</td>
</tr>
<tr>
<td>big bank 2</td>
<td>middle bank 2</td>
<td>1</td>
<td>17. January</td>
</tr>
<tr>
<td>big bank 3</td>
<td>middle bank 1</td>
<td>2</td>
<td>12-13. December</td>
</tr>
<tr>
<td>big bank 4</td>
<td>middle bank 1</td>
<td>1</td>
<td>3. December</td>
</tr>
<tr>
<td>small bank 2</td>
<td>middle bank 2</td>
<td>1</td>
<td>15. January</td>
</tr>
</tbody>
</table>

---

85 The numerator of the capital adequacy ratio consists of the regulatory capital and not the tier 1 capital.
Concerning the evolution of contagion over time in 2003 – neglecting the frequent failure of the subsidiary – contagion is still fairly limited and random. In January and June contagion occurred two times, in October one time and in December three times.

On average the banking system lost 0.80% of its capital maximum available for losses.\textsuperscript{86} The sector realized the highest loss, 10.87% on the 21\textsuperscript{st} of March. Concerning those days, when contagion happened, the maximal loss was 8.33%, the minimal 0.66%, and the mean 2.47%. The banking sector suffered the highest capital losses again on a day, when no contagion occurred. Table 13 demonstrates the capital losses realized by the banking sector.

Table 13: Modified default definition: distribution of capital losses on the 21\textsuperscript{st} of March

<table>
<thead>
<tr>
<th>Realized losses (in the percentage of capital maximum available for losses)</th>
<th>Worst case</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When contagion occurred</td>
<td>When no contagion occurred</td>
<td></td>
</tr>
<tr>
<td>Number of banks</td>
<td>In percentage of total banking system assets</td>
<td>Number of banks</td>
<td>In percentage of total banking system assets</td>
</tr>
<tr>
<td>Less than 10%</td>
<td>6</td>
<td>33.83%</td>
<td>10</td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>3</td>
<td>27.54%</td>
<td>3</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>4</td>
<td>9.12%</td>
<td>4</td>
</tr>
<tr>
<td>Above 10%</td>
<td>0</td>
<td>0.00%</td>
<td>1</td>
</tr>
<tr>
<td>Default</td>
<td>1</td>
<td>0.23%</td>
<td>0</td>
</tr>
</tbody>
</table>

The second and third column show the worst case scenario when contagion occurred. The fourth and fifth column show the distribution of capital losses in the absolute worst case, no contagion occurred, but the banking sector lost 10.87% of its capital.

The break even point of the recovery rate is 68.69% in the case of the failure of the head institution of the banking group, while in other cases it is less, than 11.5%.

In summary, the fifth hypothesis can be rejected, as regardless of the more severe definition of default, the severity of contagion did not increase significantly. Contagion occurred only in the first round, altogether in 2.62% of the scenarios. The distribution and extent of capital losses suffered by the banking sector was similar to that of experienced in the base case.

### 4.3.3. Market expectations

In reality the failure of a bank is not a sudden, unexpected event, it is rather a result of a process, e.g. bad credit policy. As a consequence, other banks can limit or even partly withdraw their interbank claims. In the light of the sixth hypothesis, if banks withdraw their short term interbank claims against the failing bank in time, no contagious defaults occur. By building this kind of market expectation into the model, I assumed that the initially failed bank could not obtain interbank credit in the recent past. That is, the failing bank does not have any interbank obligations with original maturity less, than one week. This is basically the result of the behaviour of market participants, who do not provide longer term loans to the

\textsuperscript{86} The capital maximum available for losses is the difference between the actual regulatory capital and half of the minimum capital required. If a bank’s loss equals the capital maximum available for losses than the capital adequacy ratio is definitely 4%. It the bank’s loss is higher than this, than the bank defaults as it capital adequacy ratio falls below 4%.
bank which is to default. This part of the analysis focuses solely on those 51 scenarios, where contagion occurred. A 100% loss given default is assumed, and a bank fails if its capital adequacy ratio falls below 4%.

After building market expectations into the model contagion occurred only in 9 cases from the 51, mostly due to short term, 14-day claims. All of the contagious failures are related to the failure of the subsidiary. Thus, the sixth hypothesis can also be rejected. However it is shown, that previously each contagious failure was a consequence of interbank exposures with original maturity less than one week. Having a further look at Figure 11, this is not surprising, as about 40% of the interbank exposures have an original maturity less than one week.

4.3.4. Multiple failures

By testing the seventh hypothesis, in separate scenarios instead of the effect of an idiosyncratic failure the effect of multiple bank failures with same risk profile was captured. Scenarios of joint failures are based on exposures stemming from concentrated credit portfolios, just like extended real estate project financing credits, agricultural credits and credits to financial enterprises. According to the hypothesis it is assumed that by simulating the joint failure of banks with same risk profile the severity of contagion increases dramatically.

The market of real estate project financing is fairly concentrated. The two major banks own 50% of the market. Credits extended to the real estate sector account for 14% of total assets in both cases. The volume of real estate project financing credits is two times higher than banks’ capital available for losses.

Assuming 100% loss given default, the joint failure of the two above mentioned banks generated further contagion. Contagion occurred on 43 from the 50 days in the first round. However, just like under the assumption of modified default definition each failure was related to the initial failure of the head institution of the banking group. Second round contagion never occurred.

The banking sector lost 3.03% of its capital maximum available for losses on average. The sector realized the highest loss, 9.67% on the 21\textsuperscript{st} of March. On the level of individual banks the highest loss measured by the capital maximum available for losses varied form 0% to 319.4%. The average of the ratio was 7.64%.\textsuperscript{87} The average ratio of the Hungarian banks varied from 0% to 182.3%. In relation to the 37 initially not failed banks the median of the suffered losses measured in the capital maximum available for losses were in five cases higher than 0%, (81%, 3.21%, 5.62%, 10.82% and 177.23% respectively).

Concerning the market of agricultural credits the four most significant creditors have nearly 70% market share and the three most significant banks own circa 60% of the market. The two most significant institutions engaged in agricultural credits have a market share little above 52%. In the case of three significant market player the agricultural credits account for 5-6% of total assets. The market share of the fourth most significant bank engaged in agricultural credits is less than 1% of the balance sheet of the bank. In the case of two banks out of the three (bank whose agricultural credits indicate a significant proportion of the total assets), the volume of agricultural credits is significantly, nearly three times higher than the banks’ capital available for losses. The scenario is based on the joint failure of the above mentioned two banks. In the case of the third bank out of that three, the volume of agricultural credits is only

\textsuperscript{87} The above mentioned numbers are the minimum, maximum and mean of 1850 individual capital losses (37 banks * 50 days).
1.8 times higher than the banks’ capital available for losses. Contagion occurred only in two cases, on the 12th and 13th of December, when a medium bank failed on two different days. The banking sector lost 3.07% of its capital maximum available for losses on average. The sector realized the highest capital loss, 6.83% on the 4th of December. On the level of individual banks the highest loss measured by the capital maximum available for losses varied form 0% to 100.04%. The average of the ratio was 4.26%. The average ratio of the Hungarian banks varied from 0% to 43.71%. Concerning the 37 initially not failed banks the median of the suffered losses measured in the capital maximum available for losses were in most cases 0%. In six cases the ratio varied form 1% to 7%, meanwhile in one case totalled up to 48.13%. The relatively high mean and median ratio were basically the result of the default of one of the subsidiaries of a head institution.

In Hungary it is a general tendency that banks finance their financial companies in a sophisticated manner. In 2002 credits extended to financial companies increased by 72%, in 2003 the volume of credits enlarged by 89%. And not only the volume of credits increased, but also its share in the portfolio, as the growth rate of the credits extended to financial companies was higher than the growth rate of corporate and residential credits. In 2003 the share of credits extended to financial companies was 15.8% of the corporate and residential credits compared to 13% in 2002. The market of credits extended to financial companies is fairly concentrated. The three major banks own more than 50% of the market, meanwhile the four most significant institutions possess more than 60% of this market segment. At five banks credits to financial corporations accounted for more than 15% of total assets. At one bank the ratio of credits to financial corporations and total assets was higher than 10%. At three banks the volume of credits is significantly – 7 times, 5.3 times and 3.3 times – higher than the banks’ capital available for losses. In this scenario the above mentioned thee banks fail jointly, as next to their high market share they are relatively badly endowed with capital. The results are presented in Table 14 in chronological order.

<table>
<thead>
<tr>
<th>Contagion</th>
<th>Number of days</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>middle bank</td>
<td>1</td>
<td>15. January</td>
</tr>
<tr>
<td>small bank 1</td>
<td>2</td>
<td>13. and 18. June</td>
</tr>
<tr>
<td>specified credit instituion</td>
<td>2</td>
<td>18. and 25 June</td>
</tr>
<tr>
<td>small bank 2</td>
<td>1</td>
<td>15. October</td>
</tr>
<tr>
<td>Sum</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

The three initially failed banks altogether dispose 12.3% of total assets of the banking sector. However its systemic risk implication is considerably higher than in the previous scenarios, when the two failing banks owned 14% of total assets in both cases. As Table 14 indicates, on five days one bank, meanwhile on the 18th of June two banks defaulted. Second round contagion was never generated, as the volume of interbank liabilities of additionally failed banks was not significant. The banking sector lost 4% of its capital maximum available for losses on average. The sector realized the highest capital loss, 9.63% on the 26th of June.

88 In this scenario the contagion occurred in the same relation as the relation marked big bank 3 – middle bank 1 in Table 12.

89 There are two other banks whose ratio of credits extended to financial companies and the total assets are above 2.
Concerning those five days when contagion happened in the worst case — on the 25\textsuperscript{th} of June — the banking sector lost 9.18\% of its capital maximum available for losses. In the best case, on the 15\textsuperscript{th} of October the suffered loss was 2.55\% measured in the capital maximum available for losses.

On the level of individual banks the highest loss measured in the capital maximum available for losses varied form 0\% to 149.16\%, the mean was 6.02\%. The average ratio of the Hungarian banks varied from 0\% to 34.32\%. Concerning the 36 initially not failed banks the median of the suffered losses measured in the capital maximum available for losses were in most cases 0\%. In three cases the ratio was 1.74\%, 1.82\% and 5.66\% respectively, meanwhile in two cases totalled up to 28.93\% and 32.63\%. The latter relatively higher median ratios were related to banks that defaulted on one of the 50 days.

To summarize, similar to the sixth hypothesis the seventh hypothesis can also be rejected. By assuming joint failures the severity of contagion did not increase dramatically. Contagion only occurred in the first round. Capital losses measured in the percentage of the capital maximum available for losses never exceeded 9.67\%. On average the banking sector lost around 3-4\% of its capital maximum available for losses.

4.3.5. Exchange rate shock

The aim of the stress testing carried out by the Hungarian National Bank is to capture the ability of the banking sector to absorb different kind of shocks. Stress tests address the implication of abnormal changes of risk factors, like exchange rates, domestic and foreign interest rates or quality of credit portfolio. The main objective is to re-evaluate the market value of bank portfolios and investigate the changes in tier 1 capital. By means of hypothetical and historical scenarios the market and credit risks are quantified both separately and integrated. The market risk – domestic and foreign interest rate shocks – is captured by means of duration-based indicators on the basis of the repricement of the balance sheets of banks. The effect of credit risk is analysed though the provisioning related to the non-performing loans, as it is assumed that the volume of non-performing loan is correlated with the macroeconomic factors. (Stress test …[2001].)

However, stress test in Hungary is not able to handle spill over and liquidity effects induced by the initial shock. As a consequence it may occur that the system-level credit and/or market risk is relatively moderate but, when the loss is concentrated among banks which are characterised by extensive interbank relations, then significant spill over effects may multiply the magnitude of the risk. In this section those banks are identified that in the case of an exchange rate shock could lose a significant part of their tier 1 capital. The identification is carried out on the basis of the outcome of stress tests. By assuming the joint failure of banks exposed to a foreign exchange shock, the systemic risk implications of the interbank linkages, networks are quantified. According to the eighth hypothesis joint failure of banks exposed to a foreign exchange shock can be seen as a systemic event. Systemic risk implications of a potential interest rate shock are ignored, in this case losses suffered by the banking system are assumed to be much more limited.

In this scenario I analyzed the joint failure of those banks whose foreign exchange exposure against the euro and the US dollar was significant on the last days of each quarter of 2003. Due to the substantial foreign exchange positions the joint 40\% devaluation or appreciation of the euro and the dollar in several cases induced capital losses higher than the banks’ tier 1 capital. The joint devaluation of the euro and the dollar resulted in several failures, but nearly
in every quarter different banks defaulted. Thus the fundamental failures of banks are not robust over time. In the case of the joint 40% appreciation of the euro and the dollar there exist three banks whose capital loss exceeded the bank’s tier 1 capital at the end of every quarter during the year 2003. The scenario of foreign exchange shock is based on the joint failure of the above mentioned three banks.

Initially failed banks processed 5.31% of total assets of the banking sector. The contagion is fairly limited in this scenario, as well on the 20th and 31st March one big bank, while on the 15-16th of January one middle bank defaulted. The break even point of LGD is 95.43% in the first case, and 60.29% in the second case. That is, no first round contagion occurs if at least 4.57 and 39.71% of the interbank exposures recover.

Second round contagion occurred in none of the scenarios. The banking system lost 8.09% of its capital maximum available for losses on average. In the worst case the sector realized the highest loss, 15.94% on the 31st of March, on a day, when contagion occurred. The distribution of capital losses is shown in Table 15.

Table 15: Exchange rate shock: distribution of capital losses

<table>
<thead>
<tr>
<th>Realized losses (in the percentage of capital maximum available for losses)</th>
<th>Number of banks</th>
<th>In percentage of total banking system assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10%</td>
<td>9</td>
<td>27.53%</td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>2</td>
<td>20.77%</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>2</td>
<td>28.81%</td>
</tr>
<tr>
<td>Above 10%</td>
<td>0</td>
<td>0.91%</td>
</tr>
<tr>
<td>Default</td>
<td>1</td>
<td>5.90%</td>
</tr>
</tbody>
</table>

On the level of individual banks the highest loss measured by the capital maximum available for losses varied from 0% to 165.86%. The average of the ratio was 7.82%. The average ratio of the Hungarian banks varied from 0% to 55.98%. Concerning the 36 initially not failed banks the median of the suffered losses measured in the capital maximum available for losses were in half of cases 0%. In twelve cases the ratio was below 10%. Finally, in two cases the ratio totalled up to 10.88% and 43.44%. The latter relatively higher median ratio can be related to a bank that defaulted twice on one of the 50 days.

It was showed, that joint failure of banks exposed to foreign exchange risk is not a systemic event in Hungary. Therefore the eighth hypothesis can be rejected. The domino effect was still fairly limited, contagion occurred only in the first round, altogether in four cases. Capital losses – mean or maximum – suffered by the banking sector were also limited.

4.3.6. Changes in the interbank market

In the following scenarios regulatory and policy consequences of contagion are assessed. As a result of previous analysis the Hungarian regulatory authorities could feel comfortable, the domino effect has a limited impact on the banking sector. As the analytical framework is simple, further simulations could address questions like the critical volume and concentration of exposure, at which the authorities responsible for financial stability should probably take
measures. I also would like to answer the question under which circumstances could it happen that changes in the Hungarian interbank market significantly increase the systemic risk.

The link between the changes in the interbank market and the evolution of systemic risk was assessed in the ninth hypothesis. According to the hypothesis we expect that by doubling the uncollateralized interbank exposures of Hungarian banks an idiosyncratic failure of a bank never leads to severe contagion. However by tripling the interbank exposure systemic risk will be high. By increasing the market concentration banks suffering contagious defaults will solely affect a small part of the total assets of the banking system.

In the first scenario I assumed, that keeping everything unchanged uncollateralized interbank exposures have doubled. I would like to emphasize, that neither the number of banks, nor the capital endowment of the institutions, nor the structure of the interbank exposures have been modified. From historical data it is known, that the average volume of interbank exposures was 184.4 billion forints in 2002, which increased to 208.7 billion forints in 2003. On a yearly basis this correspond to a growth rate of 13.18%. The reality of the scenario can be partly verified by the fact, that assuming a constant growth rate the exposures in the interbank market can double in 5-6 years.

During the simulations a 100% loss given default was assumed and a bank defaulted if its capital adequacy ratio fell below 4%. The analysis covered 50 days and each bank defaulted once, that is, altogether 1950 different cases were studied. Contagion happened in 151 cases, which corresponds for 7.74% of the cases. This basically means that considering the scenario of the modified default definition as a base case, the probability of contagion has tripled. First round contagion occurred in 151 cases and all together 184 banks defaulted. There were three cases in which the idiosyncratic default of a bank generated three contagious defaults in the first round. The first one was related to the initial default of a special purpose bank on the 9th of January, the second one to the default of the above mentioned bank on the 13th of January, and the third one to the default of a big bank again on the 13th of January. In 27 cases the initial default of a bank generated two contagious defaults in the first round, meanwhile there were 121 cases in which only one bank defaulted as a consequence of an idiosyncratic shock. Surprisingly nearly half of the banks, altogether 16 banks were able to generate contagious defaults. Among the 16 banks we could find seven big banks, seven middle banks and two small banks. All types of banks defaulted in the first round, in 17 cases one of the two big banks, in 67 cases one of the five middle banks, in 35 cases one of the five small banks and in 66 cases one of the two specialized credit institutions failed.

By assuming the duplication of the uncollateralized interbank exposures second round contagion will also occur, however only in eight cases. Table 16 presents these eight cases. The initially failing bank was either one of the three big banks or one small bank. This latter case is surprising, a small bank is able to generate the default of a big bank. In the first round one bank defaulted in four cases, two banks in three cases and three banks in one case. In the second round in seven cases one further bank defaulted. On the 16th of January, shown in the last row of Table 16, there were three banks – one middle bank and two small banks – who defaulted in the second round. Third round contagion never occurred.
Table 16: Second round contagion

<table>
<thead>
<tr>
<th>Idiosyncratic failure</th>
<th>Banks defaulting in the first round</th>
<th>Banks defaulting in the second round</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>big bank 1</td>
<td>middle bank 1</td>
<td>small bank 4</td>
<td>24. June</td>
</tr>
<tr>
<td>big bank 1</td>
<td>middle bank 1, small bank 2</td>
<td>specialized credit institution</td>
<td>17. October</td>
</tr>
<tr>
<td>big bank 2</td>
<td>middle bank 1, small bank 2</td>
<td>small bank 4</td>
<td>15. October</td>
</tr>
<tr>
<td>small bank 1</td>
<td>big bank 4</td>
<td>small bank 4</td>
<td>15. January</td>
</tr>
<tr>
<td>big bank 3</td>
<td>big bank 5, middle bank 3, small bank 3</td>
<td>small bank 4</td>
<td>13. January</td>
</tr>
<tr>
<td>big bank 3</td>
<td>middle bank 3</td>
<td>middle bank 3</td>
<td>13. January</td>
</tr>
<tr>
<td>big bank 3</td>
<td>middle bank 3, small bank 3</td>
<td>middle bank 3</td>
<td>25. June</td>
</tr>
<tr>
<td>big bank 3</td>
<td>small bank 3</td>
<td>middle bank 3, small bank 4, small bank 5</td>
<td>16. January</td>
</tr>
</tbody>
</table>

**Assumption:** duplication of uncollateralized interbank exposures.

Concerning solely first round effects the banking sector lost 1.61% of its capital maximum available for losses on average. In the worst case, which occurred on the 21st of March, the sector realized a loss of 17.64%. The idiosyncratic failure of a big bank generated the default of two further banks, a big bank and a small bank defaulted on that day. Capital losses realized on the 21st of March by the banking sector are summarized in the second and third column of Table 17. The systemic importance of the defaulting banks is limited, the banks represent solely 6.48% of the total assets of the banking system.

Table 17: Distribution of capital losses on the 21st of March

<table>
<thead>
<tr>
<th>Realized losses (in percentage of capital maximum available for losses)</th>
<th>21st March</th>
<th>25th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Based on first round contagions</td>
<td>Based on second round contagions</td>
</tr>
<tr>
<td></td>
<td>Number of banks</td>
<td>In percentage of total banking system assets</td>
</tr>
<tr>
<td>Less than 10%</td>
<td>4</td>
<td>40.85%</td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>6</td>
<td>25.89%</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>3</td>
<td>5.71%</td>
</tr>
<tr>
<td>Above 10%</td>
<td>3</td>
<td>5.15%</td>
</tr>
<tr>
<td>Default</td>
<td>2</td>
<td>6.48%</td>
</tr>
</tbody>
</table>

**Assumption:** duplication of uncollateralized interbank exposures.

If cases of second round contagion are also considered, in the worst case the banking sector lost 23.82% of capital maximum available for losses. On the 25th of March an idiosyncratic failure of a big bank generated the default of a middle and small bank in the first round and a failure of a small bank in the second round. It is worth mentioning, that the highest capital loss realized by the banking sector was not on the day when the number of defaulting banks was the highest. Capital losses of the banking system realized on the 25th of March are presented in the fourth and fifth column of Table 17. The systemic importance of the three defaulting banks are limited again, the banks represent only 7.76% of the total assets of the
banking system. However, it is surprising, that nine banks representing 45% of the total assets of the banking system lose 20-50% of their capital maximum available for losses.

As a consequence of the idiosyncratic failure of a head institution of a banking group a subsidiary defaulted every day except 18th of June. Regardless of this head institution-subsidiary relation, the average loss of contagiously defaulting banks was 135.69% of capital maximum available for losses. If the loss given default rate would be less than 44.26%, that is, 55.74% of the exposures would recover, there would be no contagious defaults at all. The average loss of the subsidiary belonging to the banking group is 3.39 times higher than its capital maximum available for losses. In the most favourable case the subsidiary would not default if 7.55% of its exposure against the head institution would recover. However, in the worst case the default of the subsidiary can only be avoided if at least 82% of the exposure against the head institution recover.

In summary, by assuming the duplication of the uncollateralized interbank exposures the probability of contagion has increased significantly. Taking the scenario of the modified default definition as a base case, the probability of contagion has tripled. However, the probability of contagion is still low, contagion only happened in 7.74% of the cases. The rounds of contagion never exceeded two. The maximum number of failing banks was four. In the worst case the banking system lost nearly one quarter of its capital maximum available for losses. However, the contagiously defaulting banks only affected a small part (7.76%) of the total assets of the banking system. To conclude, even by assuming the duplication of uncollateralized interbank exposures an idiosyncratic failure of a bank can not be seen as a systemic event, as it never lead to severe contagion.

By prognosticating the historically observed growth rate of uncollateralized interbank exposures for the future, the volume of interbank obligations can easily double in the next 5 to 6 years. Similarly, by assuming the same growth rate in nine years the exposures can be three times higher. However, an ever changing market, just like the interbank market can be influenced by many factors in nine years. Taken the currently low volumes of interbank exposures into account, it is still an interesting question whether the contagion becomes a systemic event if the uncollateralized bilateral interbank obligations are three times higher.

First round contagion occurred in 404 cases out of 1950, representing 20.72% of the potential events. In 312 cases, that is, in 16% of events solely one bank defaulted. In 67 cases corresponding 3.44% of the events an initial default of a bank generated two further bankruptcies, while in 18 cases three banks defaulted as a consequence of an idiosyncratic bank failure. Altogether there were seven cases when the initial default of a bank caused the default of four further banks in the next round. More than half of the banks, precisely 22 out of 39 banks are able to generate contagious defaults. Banks defaulting in the first round include four big banks, seven middle banks, six small banks and two specialized credit institution.

Second round contagion occurred in 53 cases, third round contagion happened in five cases, meanwhile fourth round contagion could be observed in two cases. Contagion in the second round was initiated either by the idiosyncratic failure of one of the five big banks, two middle banks or three small banks. Third or fourth round contagion was initiated by the default of one of the two big banks. It is worth mentioning, that in the third and fourth round mostly middle banks defaulted, however two specialized credit institutions, one small bank and even one big bank are also among the contagiously defaulting banks.

The number of defaulting banks reached its maximum on the 15th of July, when altogether eight banks defaulted. On the 31st of March and on the 1st of April seven, meanwhile on the 16th of January, 11th of July, 17th of October and 8th of December six banks went into
bankruptcy. Taken all scenarios into account the banking sector realized the highest capital loss on the 31st of March, when one big bank defaulted initially. The capital loss distribution of the banking system is shown in Table 18. On the 31st of March the banking sector lost 48.66% of its capital maximum available for losses. By assuming that a bank defaulted if its capital adequacy ratio fell below 4% the number of rounds when contagion happened was four, and altogether seven banks defaulted representing 35.24% of the total assets of the banking sector. Six banks lost more than 50% of its capital maximum available for losses, corresponding to 22.93% of the total assets of the banking system.

Table 18: Distribution of capital losses on the 31st of March

<table>
<thead>
<tr>
<th>Realized losses (in percentage of capital maximum available for losses)</th>
<th>Modified default definition (Default: capital adequacy ratio of the bank falls below 4%)</th>
<th>Default: total depletion of modified tier 1 capital</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of banks</td>
<td>In percentage of total banking system assets</td>
</tr>
<tr>
<td>Less than 10%</td>
<td>1</td>
<td>4.61%</td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>2</td>
<td>5.01%</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>4</td>
<td>14.61%</td>
</tr>
<tr>
<td>Above 10%</td>
<td>6</td>
<td>22.93%</td>
</tr>
<tr>
<td>Default</td>
<td>7</td>
<td>35.24%</td>
</tr>
</tbody>
</table>

Assumption: triplication of uncollateralized interbank exposures.

Column four and five of Table 18 reflects the capital loss distribution of the banking sector in a case when a less severe default definition was used. Instead of assuming that a bank defaulted if its capital adequacy ratio fell below 4% it was assumed, that a bank defaulted when its modified tier 1 capital was exhausted totally. In this case the banking sector lost 31.94% of its modified tier 1 capital. The number of contagious defaults was four, however the number of defaulted banks decreased form seven to five. The contagiously defaulting banks represented a smaller portion, namely less than 12% of the total assets of the banking sector. However the weight of banks losing 10-20%, 20-50% and more than 50% of the modified tier 1 capital increased.

To summarize, by assuming the triplication of uncollateralized interbank exposures the probability of contagion is high, in one fifth of the cases at least one bank defaulted. The maximum number of the rounds of contagion reached four, and there was a scenario in which altogether eight banks went into bankruptcy. In the worst case the banking sector lost nearly half of its capital maximum available for losses. Besides, the contagiously defaulting banks represented a significant proportion of the banking sector, 35.24% of the total assets of the banking system was affected by contagious defaults. However, by softening the default definition in the worst case scenario the maximum number of defaulting banks decreased to five. At the same time the defaulting banks affected solely 11.64% of the total assets of the sector. Notwithstanding we can conclude, that keeping the structure of the interbank market and level of capital endowment of the institutions unchanged and assuming the triplication of exposures an idiosyncratic failure of a bank can generate a systemic event. I would like to emphasize, that in spite of the fact, that the triplication of the exposures is likely to happen in ten years, it is improbable that the present structure of interbank exposures and the capital endowment of banks will remain unchanged. As a consequence, the scenario of three times higher interbank exposures should be rather considered as an experimental tool. By means of
this experimental tool we could see that a significant increase in the volume of interbank exposures increases the risk of systemic events notably and it could happen that the authorities responsible for financial stability should take measures in order to be able to avoid large scale breakdown of the financial system.

Finally, the impact of higher concentration of exposures on the severity and probability of contagion was analyzed. Several factors can influence the concentration of interbank exposures. Concentration can be higher either as a result of mergers and acquisitions or as a consequence of smaller number of market participants, that is, could happen that a couple of institutions leave the banking sector and operate in the future as a financial company. It also leads to an increment in the concentration ratio if the most significant institutions are able to acquire a higher market share in the interbank market. As it would be impossible to predict which banks will keep on operating in Hungary, for the sake of simplicity in this scenario it was assumed, that all the exposures of the three most significant institutions will double both on the asset and liability side of the market. As a consequence of duplicating the exposures of the most significant market participants the 50 day average of the Herfindahl-Hirschman index increased by 23.28% on the asset side and by 24.24% on the liability side of the market. Concerning both the interbank claims and obligations the market share of the three most important institutions has increased form 45% to 53%.

Contagion was either generated by the idiosyncratic default of one of the eight big banks or by one of the two middle banks. Contagion was occurred in 109 cases, representing 5.59% of the scenarios. The maximum number of rounds of contagion was two, which occurred in three cases, on the 15-16th of January and on the 25th of March a big bank defaulted. The maximum number of defaulting banks peaked at three, which happened in six different cases. Among the defaulting banks we could find one big bank, six middle banks, five small banks and two specialized credit institutions.

Concerning the scenarios in which contagion occurred, on average the banking system lost 8.29% of its capital maximum available for losses. In the worst case the loss totalled up to nearly one quarter, more precisely to 23.58% of the capital maximum available for losses. In this latter case on the 25th of March the initial default of a big bank generated the joint default of a small and a big bank in the first round and the default of a middle bank in the second round. The defaulting banks represented 7.76% of the total assets of the banking system. By analysing the weakening of the banking sector we could see, that three banks corresponding to 5.74% of the total assets of the banking system lost more that 50% of its capital maximum available for losses. There were nine banks that lost 20-50% of their capital maximum available for losses. The nine banks composed 46.13% of the total assets of the banking sector.

By increasing the concentration of the interbank market the probability and severity of contagion became higher. However, even by duplicating the interbank exposures of the most significant market participants contagion is not to be considered as a systemic event. In the worst case three banks defaulted affecting less than 8% of the total assets of the banking sector.

In summary, the ninth hypothesis can be accepted, as all of the three partly separate statements dealing with the relationship between potential changes in the interbank market and severity of contagion proved to be true. It was shown that by tripling the interbank exposure of Hungarian banks there were scenarios when the idiosyncratic failure of a bank generated serious stability problems. At the same time this never happened in the case of doubling the exposures. It was also demonstrated that in the case of a 25% increment in the
market concentration measured by the Herfindahl-Hirschman index banks suffering contagious defaults solely affect a small part of the total assets of the banking system.

4.4. International comparison

In this subsection of the Ph.D. thesis the Hungarian outcomes and the results of previous studies using the same simulation methodology made in other European counties are compared. As it was formulated in the tenth hypothesis, *in international comparison contagion through interbank market is a low probability and high impact event, meanwhile in Hungary contagion is a low probability and low impact event.*

Results of comparison are summarized in Table 19. The first column of the table shows where the study was made and which year’s data was used. The second column presents the value of LGD that was used in this comparison. Foreign banks in brackets refer to a scenario, where the initial defaulter was a foreign bank. The third column shows the maximal number of failed banks and the number of banks in the banking sector. The fourth and fifth columns capture the severity of contagion.

Table 19: Comparing the results

<table>
<thead>
<tr>
<th>Country and the year of data used</th>
<th>LGD</th>
<th>Maximal number of failed banks (Total number of banks)</th>
<th>Maximal number of rounds, when contagion occurred</th>
<th>Total assets of defaulted banks under the worst case scenario (in % of total assets of the banking sector)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany (1998)</td>
<td>40%</td>
<td>115 (3246)</td>
<td>3</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>2800 (3246)</td>
<td>8*</td>
<td>85%</td>
</tr>
<tr>
<td>Great Britain (2000)</td>
<td>40%</td>
<td>2 (33)</td>
<td>n. d.</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>4 (33)</td>
<td>n. d.</td>
<td>25.2%</td>
</tr>
<tr>
<td></td>
<td>40% (foreign bank)</td>
<td>3 (33)</td>
<td>n. d.</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>100% (foreign bank)</td>
<td>9 (33)</td>
<td>n. d.</td>
<td>15.7%</td>
</tr>
<tr>
<td>Netherlands (2002)</td>
<td>50%</td>
<td>17 (88)</td>
<td>5</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 (88)</td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>24 (88)</td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29 (88)</td>
<td></td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>50% (foreign bank)</td>
<td>20 (93)</td>
<td></td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21 (93)</td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>100% (foreign bank)</td>
<td>56 (93)</td>
<td></td>
<td>96%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45 (93)</td>
<td></td>
<td>73%</td>
</tr>
<tr>
<td>Belgium (2002)</td>
<td>40%</td>
<td>7 (65)</td>
<td>3**</td>
<td>2.74%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>21 (65)</td>
<td></td>
<td>4.38%</td>
</tr>
<tr>
<td></td>
<td>40% (foreign bank)</td>
<td>2 (65)</td>
<td>n. d.</td>
<td>20.01%</td>
</tr>
<tr>
<td></td>
<td>100% (foreign bank)</td>
<td>7 (65)</td>
<td>n. d.</td>
<td>18.08%</td>
</tr>
<tr>
<td>Hungary (2003)</td>
<td>40%</td>
<td>1 (39)</td>
<td>1</td>
<td>0.23%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>1 (39)</td>
<td>1</td>
<td>0.23%</td>
</tr>
</tbody>
</table>

* level of LGD is 75%  
** level of LGD is 60%

Source: Based on the study of Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004] and Lelyveld and Liedorp [2004]
Simulation methodologies have many common features, however they are prepared for different point in time. For example the study of Wells [2002] and Upper and Worms [2002] are based only on end-year data. The Hungarian analysis is the only one, which handles a bilateral dataset of 50 days. If bilateral positions were not known, which was mostly the case, as we have seen in subsection 2.1.1. assumptions about the distribution of interbank exposures were also different. The authors assumed either dispersed bilateral exposures or exposures modified with the data of the statistics of large exposures. Finally, the way of interpreting result was also varied from study to study. The assumed level of LGDs and the way of measuring the severity of contagion – for example either the average or the median of the assets of the defaulting banks was determined – vary across counties.

The study of Upper and Worms [2002] highlights the fact that by assuming a loss given default of 5% there always exist 17 banks that became bankrupt regardless of the initially defaulting bank. However those 17 banks only account for 0.25% of the total assets of the banking sector. In the opinion of the authors this phenomenon could be related to the dispersion of interbank assets and liabilities, which assumption probably does not hold in reality, as smaller banks tend to extend interbank credits only to a couple of banks.

According to Upper and Worms assuming a loss ratio of 75%, in the worst case the maximum number of bank failures caused by domino effect is 2 444 from the potential 3246, corresponding to 76.3% of total assets. With a loss given default of 100%, the initial failure could trigger the failure of up to 2 800 banks. With LGD = 75%, on average 30.3 banks were affected, corresponding to 0.85% of total assets. There is a striking difference between the contagion patterns of low and high loss ratios. In Germany the critical value of LGD is somewhere around 40-45%. For smaller LGDs the severity of contagion is limited even in the worst possible case. For LGD > 45% the contagion is sever, however with higher LGDs the marginal increment of the number of failing banks is limited. By analysing the impact of contagion on different banking groups Upper and Worms came to the conclusion that the most sever effect is induced by the default of the head institution of the savings and cooperative banks. The limited effect of a failure of a commercial bank was striking, if a commercial bank is a first defaulter the domino effect is fairly limited. According to the authors this may in part be due to the fact that a large proportion of the interbank claims of large commercial banks are on foreign banks which are not included in our dataset. Another reason could be that due to the absence of detailed information on intra-group lending. The authors have also found evidence on the theoretical findings of Allen and Gale [2000]. It was shown that contagion is less likely in a banking system characterized by a complete structure of claims relative to a more concentrated system.

Upper and Worms have also incorporated the effects of prudential regulation of banks and the existence of a safety net into the analysis. The safeguards present in the German system basically meant three additional assumptions. The authors found, that contagion is much more limited in scope but still possible. For LGD in excess of 75%, about 100 banks were affected in the worst case of contagion, which corresponds to 15% of the banking system in terms of assets.

After estimating the matrix of bilateral exposures from the aggregate data Wells [2002] found that the contagion is rather exceptional than typical. One approach, which assumes banks seek to spread exposure as widely as possible, suggests that if multiple bank failure were to occur,
it would most likely be triggered in the first round by the assumed insolvency of a large UK-owned bank. Even if none of the exposure is recovered (i.e. the LGD = 100%), the insolvency of a single bank triggers additional failures in only four of the 33 cases. With a lower, more realistic level of loss-given-default, even fewer events lead to the failure of other banks in the system. Wells analyses the severity of contagion by means of the size of the banks involved measured by total assets. The failures involve a relatively small percentage of banking assets, 8.8% in the median case of spill-over and 25.2% in the worst insolvency case. If LGD = 80% the percentage of affected banking assets decreases to 1% in the median case and 6.7% in the worst case. Assuming an LGD of 40% balance sheet assets affected decreases to zero in both cases.

A comparison of the exposures estimated by incorporating the pattern of large exposures into the bilateral positions with the matrix of bilateral exposures from the aggregate data suggests that the latter understates the exposure of the biggest UK-owned banks to foreign banks. In contrast, the reported large exposures between the biggest UK-owned banks were on average slightly higher when aggregate data was used. This can be explained either by the difference in the reported data, or may also reflect the inappropriateness of the assumption of wide dispersion of interbank exposures. Incorporating the pattern of large exposures into the estimates of bilateral positions involves the possibility of group of foreign banks to trigger the direct failure of UK-owned banks. This increases the number of insolvencies that trigger additional failures, although the average size measured in terms of banking system assets affected is smaller. Under the extreme assumption of 100% loss-given-default, knock-on failures are experienced in nine of the possible 33 cases. But, in terms of size only 15.7% of balance sheet assets are affected in the worst case, meanwhile in the median case it reduces to 0.1%. However, it is interesting that in this second case more banking system assets were affected in the worst case for loss-given-default rates of between 60% and 90%.

From a financial stability perspective, Wells found it useful to characterise the distribution of losses realised by banks that do not fail but which do suffer a large loss of capital. By estimating the matrix of bilateral exposures from the aggregate data Wells found, that under the assumption of a 40% loss given default only one or two small banks lose more than half of their tier 1 capital. Some larger banks lose more than 20% of their tier 1 capital and together these banks account for 11% of total banking system assets. Further, banks accounting for 38% of total assets lose more than 10% of tier 1 capital. By assuming a higher loss rate the above mentioned figures obviously increase. By incorporating the pattern of large exposures into the bilateral positions Wells experienced that for loss given default rates higher than 60%, the model implies a similar distribution of losses compared to the previous model. In this case banks accounting for around 64% of total balance sheet assets lose more than 10% of their tier 1 capital.

Wells [2004] has also examined the severity of contagion in a world, where the major banks were assumed to act as a money centre for all other banks participating in the UK interbank market. It was assumed, that small and medium sized banks and foreign banks in this system carried out all interbank activity with the major banks. For loss given default rates below 80% the change of the interbank market had little impact on the amount of contagion, the effects were similar to those implied in the previous simulations. However for loss given defaults above 80%, the worst case of contagion became more severe than in the earlier models. This severity reflected both in terms of the number of defaulting banks and in terms of the weakening of the banking sector. For 100% loss given default, banks accounting for 42% of balance sheet assets fail as a result of domino effects.
Additionally, Wells [2004] captured the effect of a narrow shock hitting a single bank during a period of distress for the entire banking system. To model this, the author assumed that the idiosyncratic shock hits when the capital of all banks has been reduced by a fixed proportion. In my opinion the common macroeconomic shock was modelled in a too simple way, a capital loss of 10%, 20%, 30% etc. does not seem a realistic way of modelling a macroeconomic shock. As a result of the simulations Wells came to the not really surprising conclusion that the severe the common macroeconomic shock was, the higher the percentage of total banking assets affected by contagion in the worst case was.

Based on 975 different scenarios (3 different matrix of bilateral interbank exposures, 5 LGDs and 65 banks) Degryse and Nguyen [2004] simulated first the contagion triggered by the default of a Belgian bank. The authors concluded that during the last decade the risk and impact of contagion has decreased and currently contagion risk appears fairly limited. Concerning the bilateral interbank matrix estimated on the basis of aggregate and large exposures and assuming a loss given default of 100% in the worst case 21 banks defaulted from the 65, in terms of banking system assets affected this corresponds to 4.38%. Under the assumption of 40% LGD, number of failed banks decreases to 7, affecting 2.74% of total assets. The number of rounds of contagion in the worst case scenario was 3 in 2002, meanwhile in 1995 with 11 rounds the worst-case scenario reached its maximum.

Under the assumption of 100% LGD the capital loss distribution of the Belgian versus the Hungarian banking sector in the worst case is compared in Table 20.

Table 20: Capital loss distribution of the Belgian versus the Hungarian banking sector

<table>
<thead>
<tr>
<th>Realized losses (in the percentage of capital maximum available for losses)</th>
<th>Number of banks</th>
<th>In percentage of total banking system assets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hungary</td>
<td>Belgium</td>
</tr>
<tr>
<td>0%</td>
<td>24</td>
<td>14</td>
</tr>
<tr>
<td>Less than 10%</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Above 10%</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Default</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Sum</td>
<td>39</td>
<td>65</td>
</tr>
</tbody>
</table>

Source: based on Degryse and Nguyen [2004].

As presented in Table 20 the contagion in Hungary is much more limited. The severity of contagion is smaller, not only in terms of number of failing banks or affected balance sheets, but also in terms of capital losses suffered by surviving banks.

Degryse and Nguyen [2004] extended the contagion exercise to the foreign interbank market as well. Based on Belgian banks’ large exposure data the authors came to the conclusion that given a 100% LGD the default of one large foreign bank can lead to the failure of seven
Belgian banks whose assets account for 20% of total Belgian bank assets. The results also indicate that even for a LGD of 40%, the default of a foreign bank can have in the worst-case scenario a significant impact on Belgian banks: two banks defaulted, which affected 18.08% of total assets. Interestingly under the assumption of a 100% LGD, contagion occurs less frequently, 13 times out of 135 cases, in the foreign bank failure simulations than in the simulations where the first domino is a domestic bank. The contagion analysis could not incorporate indirect effects of the failure of foreign banks that is failure of other foreign banks as a consequence of failure of a given foreign bank. However Belgian banks provide a breakdown of their aggregate interbank exposures by EU member countries. If the interbank exposure of Belgian banks to banks in a particular EU country were only partly recoverable the most severe effect were induced by British, French, German, Dutch and Luxemburg-based banks.

In further sensitivity analysis Degryse and Nguyen aimed at incorporating banks’ expectations by assuming that banks are able to withdraw part of their interbank assets before the failure of the initial bank. As in the model, banks anticipating the failure of its debtor, banks granting loans with maturity less than 8 days can decide not to renew them. Secondly, as the doctrine of too-big-to-fail introduces an implicit deposit insurance, it seemed reasonable to try to assess the impact of a too-big-to-fail policy on the results. To proxy for too-big-to-fail was that large Belgian banks would not be allowed to fail. In both cases the bilateral interbank matrix was estimated on the basis of aggregate exposures. After incorporating expectations into the model in 2002 by assuming a 100% loss given default the number of scenarios when contagion happened was four again, just like in the previous case. When Degryse and Nguyen assumed that large banks are bailed-out, cases of multiple failures disappeared, so that contagion totally vanished. In 2002, again under the assumption of a 100% loss given default the maximal number of failing banks in case of contagion is significantly decreased, from 14 to 7 and 1 respectively. Incorporating the too-big-to-fail doctrine or banks’ anticipation also decreased the percentage of banks’ assets affected by the contagion in the worst-case scenario, from the original 3.3% to 2.5% and 0% respectively.

By incorporating data form the monthly report and statistics of large exposures Lelyveld and Liedorp [2004] found that in the Dutch banking system for a 50% loss rate 14 banks defaulted on average, affecting 1.28% of the total assets. As Table 19 shows by neglecting the contagion from foreign regions for a 50% loss rate the maximum number of failed banks was 17 and affected assets totalled up to 2%. After including the effect of foreign regions the maximum number of failed banks increased to 20, again affecting 2% of the total assets. Under the assumption of a 100% loss rate 19 banks defaulted an average, affecting 4% of the total assets. By ignoring the contagion from foreign regions the maximum number of failed banks totalled up to 24 equalling 3% of total assets. After including the effect of foreign regions 56 banks default in the worst case, affecting 96% of the total assets. However, contagion is only severe if foreign regions are included in the analysis. The four large banks do not fail if the foreign regions are excluded, meaning that the results are driven by the failure of the large banks. If foreign regions are included, the turning point of the loss rate is around 75%, that is, by assuming a loss rate higher than 75% all four large bank defaults. For all loss rates large number of banks fail in the second round, indicating that probably a small number of sometimes large banks topple in the first round, followed by a larger number of small banks. Lelyveld and Liedorp have also analysed the severity of contagion by bank types. Among the banking groups of largest banks, remaining Dutch banks, foreign

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91 Lelyveld and Liedorp assumed that foreign regions can only induce contagion, but foreign regions could never fail as a result of the bankruptcy of other banks or regions.
subsidiaries, foreign branches and investment firms the default of one of the large banks had most severe contagious impact.

Lelyveld and Liedorp [2004] have also created scenarios which included the answers of ten banks to a questionnaire. In this case the systemic risk implications of the interbank linkages were higher, concerning both the average number of defaulting banks and the affected total assets. Under the assumption of 50% loss rate 16 banks defaulted on average, meanwhile for the highest possible loss given default 22 banks became bankrupt, affecting on average 1.64% and 4.98% of the total assets respectively. In Table 19 the result related to these scenarios are in italics. If we exclude foreign regions from the analysis the contagion is more severe from the point of maximal number of defaulting banks and percentage of total assets affected. If contagion form abroad is captured, the severity of contagion is lower, at least for higher loss given defaults. This can be explained by the fact, that under the new matrix estimation procedure interbank exposures of big banks to foreign regions had increased.

To summarize the findings of Lelyveld and Liedorp, regardless of the matrix estimation procedure the Dutch interbank market only seems to carry systemic risks if a large bank fails. However the severity is lower than previously assumed, as the shock mostly affects foreign regions. In fact, none of the large bank failures trigger the failure of another large bank. However a couple of smaller banks could induce several contagious defaults affecting a significant proportion of the banking sector. The most important risks in the Dutch interbank market stem from exposures on foreign counterparties, in particular European and North American counterparties.

In general all of the foreign studies quantifying the danger of contagion came to the conclusion that for low loss given defaults systemic risk implications of the interbank linkages are limited. However for higher loss given defaults, in fairly extreme scenarios the severity of contagion could be very high. In foreign countries the contagion can be seen as a low probability – high impact event, that is, the probability of contagion through the interbank market is low, however once happens, the consequences can be fatal. In contrast, in Hungary even under unrealistic assumptions the domino effect is fairly limited. Not only the probability of contagious banks defaults is low, but the severity of contagion is also limited. The contagion in Hungary can be considered as a low probability – low impact event. Thus, the tenth hypothesis is correct, it can be accepted.

Finally, we should be aware of the drawbacks of the Hungarian model. The disadvantages of the model basically coincide with the drawbacks of the foreign models applying the same simulation methodology, which were presented in subsection 2.1.3. However there are three exceptions. The first exception is related to the market expectations. As it was stated in subsection 2.1.3. in reality the failure of a bank is not a sudden, unexpected event, but it is rather a result of a process. As a consequence, other banks can limit or even partly withdraw their interbank claims. I tried to overcome this critic by adding market expectation into the model. The results were described in subsection 4.3.3. The second exception concerning the drawbacks of the model is related to the phenomenon that most financial crisis affects multiple Institutions and an idiosyncratic failure of one bank is rather improbable. I overcame this critic is subsection 4.3.4, when multiple failures of banks with same risk profile was captured.

Finally, in Hungary no assumption was needed concerning the distribution of interbank exposures. This was due to the fact that the Hungarian data at disposal reflected bilateral interbank transactions denominated in Hungarian forints and settled among Hungarian banks. In this way quantification of the severity of contagion is not distorted by matrix estimation methodologies. This fact was already mentioned in subsection 4.2.1. in relation with the
description of the Hungarian data. By means of the eleventh hypothesis it is tested, whether by assuming the dispersity of interbank exposures the probability of contagion is lower than the contagion experienced next to the real matrix of interbank assets and liabilities. It was described on page 63-64 how researchers can cope with the assumption on dispersity of bilateral exposures. I have applied the same matrix estimation method.

On an international level it is an important question how the assumption of dispersity of interbank exposures influences the probability of contagion. Concerning the real matrix of interbank exposures is the probability of contagion lower or higher? In previous empirical literature the exact volumes of interbank assets and liabilities were not given on a bilateral basis. In the absence of bilateral data the authors estimated the matrix of interbank exposures from aggregate data. The dispersity of exposures was assumed and the method of entropy maximizing was applied. However, in this way the probability of contagion is distorted. According to my knowledge this is the first attempt which tries to measure the misspecification of the probability of contagion in the case when not real bilateral data was used, but the dispersity of interbank exposures was assumed.

In the simulations a 100% loss given default was assumed, and a bank failed if its capital adequacy ratio fell below 4% (modified default definition). By taking the real data of bilateral interbank assets and liabilities into account contagion occurred in 51 cases out of 1950. However, by assuming the dispersity of interbank exposures contagion happened only in one case. On the 15th of January as a consequence of an idiosyncratic failure of a big bank a middle bank defaulted in the first round. It is worth mentioning, that this big bank – middle bank relation does not coincide with the relations presented in Table 12.

Concerning the whole banking system the level of capital losses did not change as the sums of the interbank liabilities and assets remained unchanged. Only the distributions of these aggregates have been modified. In the case when contagion occurred, the banking sector lost 6.5% of its capital maximum available for losses. The highest loss, 10.87%, was realized on the 21st of March, when the same big bank defaulted. However the distributions of capital losses among banks have changed. The capital loss distributions of the banking sector on the 15th of January and on the 21st of March are shown in Table 21.

Table 221: Distribution of capital losses by assuming the dispersity of interbank exposures

<table>
<thead>
<tr>
<th>Realized losses (in percentage of capital maximum available for losses)</th>
<th>15th of January</th>
<th>21st March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of banks</td>
<td>In percentage of total banking system assets</td>
</tr>
<tr>
<td>Less than 10%</td>
<td>17</td>
<td>68.82%</td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>6</td>
<td>14.88%</td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>4</td>
<td>8.75%</td>
</tr>
<tr>
<td>Above 10%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Default</td>
<td>1</td>
<td>1.21%</td>
</tr>
</tbody>
</table>

Comparing Table 21 with Table 13 we can conclude that the initial idiosyncratic bank failure has affected more banks. The number of banks that lost a smaller part of their capital maximum available for losses has increased in all cases. The number of banks losing less than
10% of their capital maximum available for losses has increased significantly. Concerning the worst case scenario of the days when contagion happened (Table 13) and the single scenario when contagion happened (Table 21) not only the number of banks, but the percentage of the total assets of the banking system have also increased significantly. Basically it increased more than double.

I have also analysed how the probability of contagion would change if the duplication and the dispersity of interbank exposures were assumed at the same time. By taking the real data of duplicated bilateral interbank assets and liabilities into account in the first round contagion occurred in 151 cases out of 1950. However, by assuming the dispersity of interbank exposures contagion happened only in 24 cases. That is, the number of scenarios in which contagious failures happened has decreased to less then one sixth of the benchmark cases. In three cases out of the 24 two banks defaulted, meanwhile in one case three banks went into bankruptcy. In all of the other cases as a consequence of the initial failure only one bank defaulted. Second round contagion happened in one case, on the 17th of January. In this case the contagiously defaulting banks have affected only a small portion (3.07%) of the total assets of the banking sector. The assets of the defaulting banks represented in none of the scenarios more than 4.27% of the total assets of the banking system.

In summary, we can conclude that by assuming the dispersity of exposures the number of contagious failures has decreased significantly, from 51 cases to one case, and from 151 cases to 24 cases. Thus, the eleventh hypothesis can be accepted, as by assuming the dispersity of interbank exposures the probability of contagion became lower. This result is also important on an international level, as it became clear that in the previous empirical literature by assuming the dispersity of interbank exposures the authors have significantly underestimated the probability of contagion.
The empirical part of the Ph.D. thesis aimed to map interbank linkages of Hungarian banks and to analyse the systemic risk implication of those relations. The analysis began with the review of turnover and volume data. It was shown that the monthly turnover of the Hungarian interbank money market demonstrated an upward trend. The special year-end-liquidity management of banks and the payment obligations of value added and consumption taxes of companies led to the cyclicality of the turnover. Concerning the maturity of the interbank loan and deposit contracts overnight transactions dominated the market. In this sense the Hungarian interbank market could be truly seen as a tool of liquidity management (H1). Interbank transactions were dominated by overnight transactions, but the amount of transactions with original maturity of one week, two weeks, one month, three months and six months were also important.

As a result of the explicit link between the severity and probability of contagion and the structure of the interbank market the key dimensions of the structure of the Hungarian interbank market was brought into focus. It was shown that based on the Herfindahl-Hirschman index the Hungarian interbank market is moderately concentrated (H2). Concerning the market share of the most significant banks, both in the asset and liability side the three most significant institutions covered 45% of the market, meanwhile the ten most significant banks owned about 80% of the market. The structure of the interbank market was similar to a multiple money centre structure, where the role of money centres is played by ten-fifteen big Hungarian banks (H3). The multiple money centre structure of the Hungarian interbank market coincided with the experience of treasurers. In the opinion of financial experts in the interbank market there is a friendly, informal relationship among ten-fifteen banks. The hypothesis of the multiple money centre structure was also supported by the fact, that 60% of interbank transactions were settled among the 15 largest banks, while in 95% of transactions at least one of the partners was among those 15 banks. A new approach applied in the thesis was the network representation of banks. The network topology and the graphs of the interbank market also referred to a multiple money centre structure, where ten-fifteen banks were situated in the centre.

After the analysis of the structure of the Hungarian interbank market it was still an open question how the moderately concentrated market and the multiple money centre structure influences the probability and the severity of contagion. The domino effect through the Hungarian interbank market was quantified by means of simulations. The model solely focused on the domino effect. By means of pure interbank stress tests the consequence of a financial crisis induced by an idiosyncratic failure of a bank was assessed. The most important value added findings of the thesis are related to the analysis of the effect of the non-repayment of interbank exposures on the capital of creditor banks. In relation with the systemic risk implications of the interbank market eight further hypotheses were formulated and tested in different scenarios.

On the basis of uncollateralized interbank loan and deposit transactions denominated in Hungarian forints by assuming a 100% loss given default rate and defining default as the total depletion of tier 1 capital (H4) contagion occurred only in 11 cases, that is, 0.55% of the scenarios. All first round contagious failures were due to the failure of a head institution of a banking group, which caused the failure of its subsidiary. In the worst case scenario the banking system lost 3.53% of its tier 1 capital. During the examined 50 days, the banking sector lost 0.53% of its modified tier 1 capital on average.
In order to test the next hypothesis (H5) a modified default definition was used which based on the current Hungarian regulation. In this case contagious failure occurred if there existed at least one bank whose capital adequacy ratio fell below 4%. At the majority of the banks the capital available for losses decreased, at the level of the banking sector by 30%. Given a 100% loss given default first round contagion occurred in 51 out of 1950 cases, that is, in 2.62% of the scenarios. Second round contagion never occurred. 43 out of the 51 first round contagious failures were due to the failure of a head institution of a banking group, which caused the failure of its subsidiary. On average the banking system lost 0.80% of its capital maximum available for losses. Concerning those days, when contagion happened, the maximal loss was 8.33%.

In reality the failure of a bank is not a sudden, unexpected event, it is rather a result of a process. As a consequence, other banks can limit or even partly withdraw their interbank claims (H6). By building market expectation into the model, it is assumed that the initially failed bank could not obtain interbank credit in the recent past. That is, the failing bank did not have any interbank obligations with original maturity less, than one week. After building market expectations into the model contagion occurred only in 9 cases from the 51, mostly due to short term, 14-day claims. All of the contagious failures are related to the failure of the subsidiary. This means, that previously each contagious failures were a consequence of interbank exposures with original maturity less than one week.

In further scenarios instead of the effect of an idiosyncratic failure the effect of multiple bank failures with same risk profile were captured. Scenarios of joint failures are based on exposures stemming from concentrated credit portfolios, just like extended real estate project financing credits, agricultural credits and credits to financial enterprises (H7). In the following scenarios those banks were identified that in the case of an exchange rate shock could lose a significant part of their tier 1 capital. The identification is carried out on the basis of the outcome of stress tests carried out by the Hungarian National Bank. By assuming the joint failure of banks exposed to a foreign exchange shock, the systemic risk implications of the interbank linkages were quantified (H8). In all of the scenarios assuming joint failures contagion proved to be limited regardless whether the severity of contagion is captured by the number of defaulting banks or by the mean and maximum losses measured in the tier 1 capital of the banking system. Second round contagion never occurred.

The analysis of the regulatory and policy consequences of contagion is also of crucial importance. Especially as a result of previous analysis the Hungarian regulatory authorities could feel comfortable, the domino effect had a limited impact on the banking sector. By means of further simulations questions like the critical volume and concentration of exposure, at which the authorities responsible for financial stability should probably take measures were addressed. The main goal of the analysis was to look for circumstances under which the systemic risk implications of the interbank market increased significantly. It was shown, that by tripling the interbank exposure of Hungarian banks there were scenarios when the idiosyncratic failure of a bank generated serious stability problems. At the same time this never happened in the case of duplication of exposures. It was also demonstrated that in the case of a 25% increment in the market concentration measured by the Herfindahl-Hirschman index banks suffering contagious defaults solely affect a small part of the total assets of the banking system. (H9)

As it was shown in subsection 4.4, the risk and severity of contagion is mostly influenced by country specific factors, just like the volume of interbank transactions and structure of the interbank market. As several researchers prepared country case studies using the same simulation methodology international comparison of the severity of domino effect through the
interbank markets could be carried out (H10). Comparing the Hungarian outcomes and the results of previous studies made in other European counties we could conclude, that nearly all of the foreign studies quantifying the danger of contagion found that for low loss given defaults systemic risk implications of the interbank linkages were limited. However for higher loss given defaults, in fairly extreme scenarios the severity of contagion could be very high. In foreign countries the contagion can be seen as a low probability – high impact event, that is, the probability of contagion through the interbank market is low, however once happens, the consequences can be fatal. In contrast, in Hungary even under unrealistic assumptions the domino effect is fairly limited. Not only the probability of contagious banks defaults is low, but the severity of contagion is also limited. The contagion in Hungary can be considered as a low probability – low impact event. This can be explained with the low volume of interbank exposures measured by total assets or tier 1 capital of the banking sector.

As we have seen in subsection 3.3, in 2003 the volume of average interbank assets was 208.7 billion forints, corresponding to 1.71% of total assets. However on the level of individual banks slight differences are observable. There exists a bank, whose average interbank assets of the examined 50 days are 34% higher, than its end-year total assets. The interbank liabilities of the Hungarian banks calculated from individual bank data is 5.9%. This highlights the fact, that smaller banks have higher volume of interbank assets measured by percentage of total assets. From the study of Degryse and Nguyen [2004] it is known, that at the end of 2003 in Belgium interbank assets were 176 billion euros, presenting 22.28% of total assets, and interbank liabilities were 228 billion euros, presenting 28.65% of total assets. However, those data contain exposures to both domestic and foreign banks, and both collateralized and uncollateralized positions are captured. If we only consider uncollateralized exposures to domestic banks, the given exposures decreases to share decrease to 25.98 and 32.82 billion euros respectively, representing 3.28% and 4.14% of the total assets. As we also know that 50.5% of total exposures are collateralized, percentage shares are even smaller.

The difference between the Belgian and Hungarian data is only surprising for the first sight. After filtering the data the differences are not that significant any more.

The 208.7 billion forints uncollateralized interbank assets total up to 19.05% of the modified tier 1 capital of the banking sector. Only in four cases are average interbank liabilities higher than the banks’ tier 1 capital, and in six cases higher than the capital maximum available for losses. However this is the necessary condition for contagion to occur. The average of the ratio of uncollateralized exposures over modified tier 1 capital on the level of individual banks is 53.18%, which highlights the fact, that smaller banks have relatively higher volume of interbank assets measured by their tier 1 capital. However higher ratios are not common in Hungary. According to Upper and Worms [2002] in Germany 2758 banks out of 3246, that is, 85% of banks have a higher interbank exposure than banks’ tier 1 capital. In Germany the average ratio of interbank credits over tier 1 capital is 2.96, the ratio of the head institutions of the saving and cooperative bank is 14, ratio of the commercial banks equal to 4.64. In Hungary the above mentioned ratio is only 0.45. In the United Kingdom in the end of 2000 8 banks out of 24 disposed of interbank liabilities higher than their tier 1 capital. In Holland the ratio of interbank claims over tier 1 capital is 2.1. (Lelyveld and Liedorp [2004].) Differences

92 In the Economic and Monetary Union at the end of year 2001 the above mentioned ratios of commercial banks accounted for 22.6 and 26.2% respectively. (Degryse and Nguyen [2004].) In Hungary, concerning balance sheet data at the end of year 2003 interbank assets and liabilities represented 10.92 and 10.30% of total assets.

93 The proper proportions can not be determined, as we are not aware of the decomposition of the collateralized exposures into exposures related to foreign and domestic banks. For further comparison: in the United Kingdom in December 2000 the interbank loans to UK-resident banks accounted for 8% of total assets. At the same time interbank loans to non-resident banks totalled up to 21% of the aggregated balance sheet. However in this case we do not know the proportion of collateralized transactions. (Wells [2004].)
are surely remarkable, as in Hungary a bank with a higher interbank exposure than its tier 1 capital is rather exceptional.

As a result of moderately concentrated multiple money centre structure of interbank market and low volume of exposures, the limited risk of the contagion in Hungary is not surprising any more. Looking forward, by joining the Economic and Monetary Union, the role of the Hungarian interbank market supposed to be appreciated, as Hungarian banks can take a credit denominated in the domestic currency from many other banks. It should be seen clearly that this together with the existence of regional money centres could increase the severity of contagion.

One of the most important findings of the thesis is that by assuming the dispersity of interbank exposures the probability of contagion is lower than the contagion experienced next to the real matrix of interbank assets and liabilities (H11). In previous empirical literature the exact volumes of interbank assets and liabilities were not given on a bilateral basis. In the absence of bilateral data the authors estimated the matrix of interbank exposures by assuming the maximal dispersion of exposures. In contrast, in Hungary the proper volume of bilateral interbank positions is known. It was shown, that in foreign countries due to the applied matrix estimation procedure – maximizing the entropy of the matrix – the probability of contagion is significantly underestimated.

As a consequence of the complexity and diversity of systemic risk, the analysis of the systemic risk implications of the Hungarian interbank market has many places for further research. The possible improvements covered in the following paragraphs go beyond the topics covered in the Ph.D. dissertation.

It would be important to map additional interbank exposures of Hungarian banks. The fundamental contagion channel indicates more than solely interbank credit exposures. Off balance sheet exposures, just like interbank linkages through derivative positions, contingent claims, guarantees and undrawn facilities could mean a significant source of systemic risk. In order to be able to carry out a research in this direction additional data would be required. The quarterly report on 50 highest exposures of banks prepared by the Hungarian National Bank could be a good starting point.

In another research it would be useful to improve the theoretical framework provided by network analysis of the Hungarian banks. If the available data makes it possible it is worthy to extend the analytical framework for other financial institutions, just like savings cooperatives, financial corporations, insurance companies, pension and mutual funds. As we have seen in subsection 1.3. the network representation allows a system-wide assessment of the financial relationships between different kinds of institutions, which made network analysis a popular tool to analyze systemic risk. However, as a consequence of the limited number of market participants of the Hungarian banking sector and the financial system the analytical framework supported by the network theory can not be exploited fully. The analysis of the Hungarian financial sector by means of graph theory can address questions like, does the number of interlinkages – degree distribution – follows a power law? How large is the clustering coefficient of the network and the average shortest path between any two vertices in the network? Which financial institutions can be identified on the basis of their relations to other banks as systemically relevant? What do we know about the potential contagion paths?

Further research is required to address consequences of a macroeconomic downturn. In reality idiosyncratic failure of an institution is rather improbable as most financial crisis affects multiply institutions. Would the severity of contagion significantly increase if the idiosyncratic failure would occur in a distressed economy in which banks have lost significant proportion of their capital as a result of abnormal changes in risk factors? By using the result
of the stress tests carried out by the Hungarian National Bank the most important risk factors consist of market and credit risk. Concerning the market risk the most important elements include a potential exchange rate shocks, domestic and foreign interest rate shocks. As a result of this kind of analysis the severity of contagion can be captured in a situation where many banks have already lost part of their capital.
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