Ph.D. thesis – Summary

Ágnes Lublóy:

SYSTEMIC RISK IMPLICATION OF
THE HUNGARIAN INTERBANK MARKET

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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.)
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INTRODUCTION

In the recent past next to the micro prudential regulation macro prudential regulation of the banking system came to the front, the analysis of systemic events is of major importance. In the Ph.D. thesis one aspect of systemic risk, that is, the domino effect in the banking system is captured. 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 from one institution to the other. The two channels of contagion, the information and credit channels of contagion can enhance each others effect or can also exist quite independently. In the thesis contagion through the credit channel, that is, financial linkages of banks are brought into focus. 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. 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.

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.

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 test in Hungary is 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.

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 were related to the analysis of the effect of the non-repayment of interbank exposures on the capital of creditor banks. Despite the several drawbacks of the empirical, 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.
1. Literature Review

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? 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 triggered 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. 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. In most cases systematically relevant banks are identified and the weakening of the banking sector is quantified.

The study of Furfine [1999] 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 of German banks to test whether the breakdown of a single bank can lead to contagion. The analysis covered all type of uncollateralized exposures. The matrix estimation procedure of the interbank
exposures relied on the assumption of dispersed interbank assets and liabilities. 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. The matrix of bilateral exposures was 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. Next to the balance sheet information Wells worked from the large exposures statistics as well. The foreign banks, as possible sources of systemic risk were also incorporated into the model. Degryse and Nguyen [2004] investigated the systemic risk implications of the Belgian interbank market also on the basis of balance sheet and large exposure data sources. Bilateral interbank matrices were estimated in three different ways. 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 second group of empirical models dealing with contagion puts emphasis on different kind of macroeconomic shocks. 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. 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. 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.

The study of Elsinger, Lehar and Summer [2002] takes a wide range of macroeconomic shocks and the contagion through interbank linkages also into account. 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.

The third and newest group of empirical models analyses the systemic risk implication of financial interlinkages by applying the newest findings from network theory. 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 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. The main research objective of the paper of Müller [2003] 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’ largest counterparty exposures and the corresponding credit lines.
2. Research 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] 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. Unfortunately 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 models belonging to the first group. 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? 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? Which factors influence the severity of contagion?
2.1. Procedure of contagion

To capture the credit risk related to uncollateralized interbank exposures the method of simulation was used. My aim was to quantify the effect of the non repayment of interbank loans on the capital of the creditor banks. 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 factors are rare episodes, however potentially could eventuate in practice. As the initial shock if 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. 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. 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 iterative procedure of the simulation is shown in Figure 1. The same type of simulation was used 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.
2.2. 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. That is, 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%.

If bank $i$ failed due to its exposure to bank $j$, further defaults can occur. Bank $k$ will go bankrupt, if its exposure to banks $i$ and $j$ multiplied by the loss rate exceeds its capital. Generally, 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 $j$ has not failed and $\alpha_j = 1$, if bank $j$ has failed.
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. 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 was also taken into account.

2.3. The loss given default

The estimation of the loss given default is not an easy issue. 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 [1999], Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004] and Lelyveld and Liedorp [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 the thesis a similar methodology was followed. 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.
2.4. Data

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 [1999] 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 *bilaterally measured interbank assets and liabilities* should be written in a *matrix* form, presented in Figure 2. In the case of *N* domestic banks we arrive to a matrix of *N x N*. The *x<sub>ij</sub>* 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 2: Matrix of bilateral exposures*

<table>
<thead>
<tr>
<th>Banks</th>
<th>1</th>
<th>2</th>
<th>3…</th>
<th><em>j</em></th>
<th>…</th>
<th><em>N</em></th>
<th>( \sum_{j}^{N} x_{ij} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( a_i )</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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<td>…</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>i</em></td>
<td></td>
<td></td>
<td>( x_{ij} )</td>
<td></td>
<td></td>
<td>( a_i )</td>
<td></td>
</tr>
<tr>
<td>…</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>N</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>( l_j )</td>
</tr>
<tr>
<td>( \sum_{i}^{N} x_{ij} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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*.

In the absence of adequate data Upper and Worms [2002], Wells [2002], Degryse and Nguyen [2004], Lelyveld and Liedorp [2004] have estimated the matrix of bilateral exposures. This was done on the basis of observed aggregate interbank assets and
liabilities reported to central banks or supervisory authorities. However, without an assumption about the distribution of the bilateral exposures the matrix cannot be identified. All of the authors applied entropy optimalization method, however different assumptions about the distribution of the bilateral exposures were used.

In Hungary concerning the distribution of exposures no assumptions should be made. The daily statistics on the interest rate of interbank loans and deposits include information about transactions between Hungarian banks and specialized credit institutions. 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 proper knowledge of the exact bilateral positions has important consequences. First and foremost, 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 features of the data used in the analysis of the severity of the domino effect in the Hungarian interbank market could be summarized in the following way. The research covers each of the 39 Hungarian banks. The data reflects uncollateralized interbank transaction on a bilateral basis. The time horizon of the investigation is 50 working days of 2003. I would like to emphasize again, that as we do 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.
3. EMPRICAL RESULTS

3.1. The structure of the interbank market

The analysis of the Hungarian interbank market was based on data of uncollateralized interbank loans and deposits denominated in Hungarian forints. The following three hypotheses were 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.

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. Thus, on the basis of the maturity breakdown of the interbank turnover data the first hypothesis was accepted. The high volume of interbank exposures with long term maturity seems to contradict the first, already accepted hypothesis. However this deviancy can be explained basically with high volume of interbank assets of two banks. Thus the relatively high volume of interbank transactions with longer maturity is not a general market tendency, but rather can be explained with the special role and management of two banks. By analyzing the volume data of the uncollateralized interbank loans and deposits we could see, that 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. The daily volume of the interbank transactions is pretty volatile.
In the thesis the *structure of the Hungarian interbank market* was analysed in detail, as according to the study of Allen and Gale [2000], and Freixas, Parigi and Rochet [2000] the severity and probability of contagion is strongly related to the structure of the interbank market.

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. 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. 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*. A couple of graphs of the interbank market are presented in Figure 3.
3.2. Severity and probability of contagion

The aim of the empirical research was to examine the severity and probability of contagion in the Hungarian interbank market. In different scenarios eight further hypotheses were formulated and tested.

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 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 base case of the simulation was formulated in the fourth hypothesis. The severity of contagion was 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. 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.

In the worst case scenario, on the 19th 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 1. As the table 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 1: Base case: the losses realized by the banking sector on the 19th and 21st of March

<table>
<thead>
<tr>
<th>Realized losses (in the percentage of the tier 1 capital)</th>
<th>Number of banks</th>
<th>19th March</th>
<th>In percentage of total banking system assets</th>
<th>Number of banks</th>
<th>21st March</th>
<th>In percentage of total banking system assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10%</td>
<td>9</td>
<td>49.77%</td>
<td></td>
<td>12</td>
<td>71.96%</td>
<td></td>
</tr>
<tr>
<td>Between 10-20%</td>
<td>2</td>
<td>3.88%</td>
<td></td>
<td>1</td>
<td>0.49%</td>
<td></td>
</tr>
<tr>
<td>Between 20-50%</td>
<td>2</td>
<td>1.61%</td>
<td></td>
<td>4</td>
<td>4.75%</td>
<td></td>
</tr>
<tr>
<td>Above 10%</td>
<td>0</td>
<td>0%</td>
<td></td>
<td>1</td>
<td>5.61%</td>
<td></td>
</tr>
<tr>
<td>Default</td>
<td>1</td>
<td>0.23%</td>
<td></td>
<td>0</td>
<td>0%</td>
<td></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 21st 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 1.

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.
In order to test the fifth hypothesis in the light of the current Hungarian regulation the default definition was modified. In this scenario contagious failure occurred if there existed at least one bank whose capital adequacy ratio fell below 4%. That is, the initial definition of default was modified, now a bank failed if its regulatory capital is less than half of the minimum capital required. At the majority of the banks the capital available for losses decreased, at the level of the banking sector by 30%. By applying a more severe definition of default the severity of contagion did not increased significantly. 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. 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%. On average the banking system lost 0.80% of its capital maximum available for losses. The sector realized the highest loss, 10.87% on the 21st of March. Concerning those days, when contagion happened, the maximal loss was 8.33%. The banking sector suffered the highest capital losses again on a day, when no contagion occurred. The capital loss distribution of the banking sector was similar to the loss distribution of base case. Thus, the fifth hypothesis was rejected, as regardless of the more severe definition of default, the severity of contagion did not increase significantly.

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. 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 be rejected. However it is shown, that previously each contagious failure was a consequence of interbank exposures with original maturity less than one week.

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. One could assume that by simulating the joint failure of banks with same risk profile the severity of contagion will increase dramatically. By assuming the joint failure of the two main banks with extended real estate project financing credits and 100% loss given default 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 21st of March. By assuming the joint failure of the two most significant market players in the field of the agricultural credits the 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. By supposing the joint failure of three banks with significant amount of credit extended to financial companies on five days one bank, meanwhile on the 18th June two banks defaulted contagiously. The three initially failed banks altogether dispose 12.3% of total assets of the banking sector. 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. In summary, 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.
In relation with the eighth hypothesis I tested whether the joint failure of banks exposed to a foreign exchange shock can be seen as a systemic event. In this scenario 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. By assuming the joint failure of banks exposed to a foreign exchange shock, the systemic risk implications of the interbank linkages, networks are quantified. Initially failed banks processed 5.31% of total assets of the banking sector. After analysing the simulation result the contagion proved to be fairly limited in this scenario. It was showed, that joint failure of banks exposed to foreign exchange risk is not a systemic event in Hungary. Therefore the eighth hypothesis could 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 was also limited. 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

*Regulatory and policy consequences of contagion* are also of major importance. As a result of previous analysis the Hungarian regulatory authorities could feel comfortable, the domino effect has a limited impact on the banking sector. In 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. By means of the ninth hypothesis I tried to answer the question under which circumstances could it happen that changes in the Hungarian interbank market significantly increase the systemic risk. *The ninth hypothesis was 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.

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. The comparison was carried out in relation with the tenth hypothesis. 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 probably – low impact event. Thus, the tenth hypothesis was accepted.

Due to the fact that the Hungarian data at disposal reflected bilateral interbank transactions denominated in Hungarian forints and settled among Hungarian banks no assumption was needed concerning the distribution of interbank exposures. By means of the eleventh hypothesis it was tested, whether by assuming the diversity 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 was 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 was significantly underestimated.
The limited systemic risk implications of the Hungarian interbank market 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. (Degryse and Nguyen [2004].) 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. However 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.
4. Importance of the Research

The domino effect in the Hungarian interbank market was quantified by means of simulations. The results showed that – even under unrealistic assumptions – next to the present turnover and structure of the interbank market the systemic risk implications of the interbank linkages are fairly limited. This result is of major importance for the Hungarian and international regulatory bodies and for the Hungarian banks.

By means of the presented analytical framework the Hungarian regulatory authority can better model the spill over and liquidity effects induced by an initial shock. As a result, the picture about the ability of the banking sector to absorb different kinds of shocks became more complete. It turned out, that in the case of a potential credit and/or market shock the present structure of the interbank market does not generate significant ripple-over effects. Not even in a case when the loss is concentrated among banks which are characterised by extensive interbank relations. However, if the volume and concentration of interbank exposures increase dramatically, the authorities responsible for financial stability should probably take measures. In this case the idiosyncratic failure of a bank could generate serious stability problems.

The empirical findings of the thesis have also an important message for the international regulatory bodies, just like the BIS. Namely, the results highlight the importance of macro prudential regulation and country specific factors. In the course of regulation the regulators should pay special attention to systemically relevant banks, that is, to banks that are on the basis of their relations to other banks are in key position in the network. However it should be taken into account that the structure of the market vary from country to country, which influences the severity of contagion in a different manner.

The results of the empirical analysis have also important consequences for the Hungarian banks. In the case of uncollateralized interbank lending the internal limit system of banks represent an effective limit. That is, self-regulation of Hungarian banks seems to be an effective way to handle credit risk in the market of interbank exposures.

Finally, concerning the orientation of future research it is worth mentioning, that it was proved that systemic risk in Hungary is much more dependent on macroeconomic conditions, than on contagious default from interbank relations. Thus, modelling effects of different kind of macro shocks should be enhanced.
BIBLIOGRAPHY


