On the Contagion in the Baltic States

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Abstract

This article estimates the systemic risk in banking sector of the Baltic states. The systemic risk is treated as a feature of the structure of interbank market which source is the default of single credit institution. Due to lack of data bilateral exposures are estimated using matrix balancing methodology. To describe systemic relevance of credit institution we use simulation methods and network approach. We find that the bankruptcy of one of the large financial institutions will put a considerable burden on the other credit institutions, but will not lead to a complete collapse of the interbank market. The credit contagion effects of the failure of a smaller bank are limited.

Keywords: credit contagion, systemic risk, default correlation, interbank network

Introduction

Together with establishing and maintaining monetary policy and implementing the price stability, the ensuring the financial stability of whole financial system is an important task of contemporaneous central bank. Financial stability of a country and systemic risk of financial system are strongly dependent on global macroeconomic factors and also are closely related to the default risk of each credit institution or whole industrial sector. Banking crisis and investigation of interbank structures is of interest to us. During the past decade of years much research effort has been devoted by central banks to explaining and modeling contagion. There are a lot of approaches to assess financial contagion (for more details, see [12], [32]) in diverse regions and countries. However relatively little research is made on systemic risk of the banking system of the Baltic states. Therefore the main contribution of this paper is the beginning of such analysis:

- How important is the actual interbank market structure in explaining interbank contagion risk?
- Could the failure of banks in one Baltic country affect banks in another Baltic state through cross-border interbank exposures?
- Could the liquidity shortage of big Scandinavian bank affect their patronized financial institutions (banks) in the Baltic states?

We focus just on preceding issues and we do not analyze the risk of lending concentration to certain economy sectors that also is a source of systemic risk. In addition, we do not analyze the macroeconomic conditions and the causes of the crisis of financial system. In this paper we describe the credit contagion[1] in the banking sector of the Baltic states subject to default risk of credit institution or its counterparty. We describe the contagion induced by default of the counterparty, i.e. we model this phenomenon in terms of correlated defaults. Unlike other authors we analyze the local interbank market in the Baltic states that is not typical case as in the developed interbank markets. The whole banking sector and the interbank market have some specific features. The local banking systems in the Baltic states are very concentrated, i.e. the asymmetric structure of banking sectors is evident: there are few local money centres (i.e. financial institutions that have large market share of total assets and which have many and large interlinkages with another credit institutions) and a lot of small credit institutions. Despite this fact interbank market can not be treated as a structure with just two or three money centres because they are owned by foreign financial institutions and usually obtain capital flows from abroad and not from local interbank market players. In addition, there are no data concerning the information on the interlinkages between individual financial institutions, i.e. interbank exposures. The interlinkages are traditionally defined by exposures and can be weighted by their amounts or by the value of business volume (see [13]). Risk mitigation techniques, such

[1] Or, in the context of this paper, the domino effect.

as collateralized interbank loans (e.g. repos) reduce the risks of contagion. The existence of a repo market may lead, however, to the disappearance of the uninsured international interbank market (for more details, see [17]).

The paper is organized as follows. In sections 1 and 2 we give a short overview of related literature and discuss in more details on the notions of correlated defaults and credit contagion. In section 3 we analyze the financial contagion in local markets and in section 4 we present our survey on financial contagion in common market of the Baltic states. Finally, we give some conclusions in section 5.

1 Review of the literature

The definition of the contagion varies widely across the literature. Definition and measure of contagion depend on identification of financial crisis. Depending on the objective of the analysis, the literature has identified a currency crisis, a stock market crisis and a banking crisis. To our knowledge contagion could be also defined on macro as well as on micro level.

Detailed review of the different definitions and measures of contagion presented in the literature carried out Pericoli and Sbracia [32]. Authors discuss the five most representative definitions of contagion. First, contagion is a significant increase in the probability of a crisis in one country, conditional on a crisis occurring in another country. Second, contagion may occur when volatility of asset prices spills over from the crisis country to other countries. Third, contagion takes place when cross-country comovements of asset prices can not be explained by fundamentals. Fourth, contagion could be a significant increase in comovements of prices and quantities across markets, conditional on a crisis occurring in one or group of markets. Finally, contagion appears when the transmission channel intensifies or, more generally, changes after a shock in one market. Several other streams of empirical research on methodologies how to assess contagion in financial markets are addressed by Dungey et al [12]. They define the key similarities and differences among the various approaches.

Contagion that deals with interbank market can occur in at least three types of situations: (a) when aggregate liquidity is insufficient (Bhattacharya and Gale [3], Allen and Gale (2002) [2]), (b) when market expectations create spillover effects (Diamond and Dybvig [11], Freixas and Rochet [19]), and (c) when the collapse of a bank induces a domino effect (see, for example, [5], [34]). According to empirical evidence there are two approaches to measure contagion of interbank markets. First approach isolates contagion from other shocks affecting the economy and simulates the consequences of an individual bank failure given observed and potential further round effects. Second approach takes account of a larger variety of shocks and simulates the impact of some risks simultaneously, for example, credit risks and market risks on interbank payment flows (see [15]).

There are many factors influencing the level of systemic risk that could be classified at three levels: individual bank level, interbank market level and the authority or supervisory level (for

more details, see [10]).

- At the individual bank level such products as repurchase agreements, collateralized interbank loans, netting agreements and counterparty limits reduce the risks of contagion. In addition, risk management system and internal control of the bank play a crucial role in the financial stability of the bank. Basel II Framework sets bank capital requirements, explains different approaches for calculating minimum capital and provides methodologies for constructing economic capital allocations [22]. Regulators rely heavily on individual risk management models and point out the need to measure systemic risks and strengthen financial stability. It is also hardly possible to assess the systemic risk of banking system based on the evaluation of individual banks. Therefore a system approach is needed. Giving its increasing importance as the risk associated with interbank lending may lead to domino effects, where the failure of a bank results in a failure of other banks, this topic became of an interest to many researchers.

- At the interbank market level the recent theoretical findings show that risk of contagion depends on the precise pattern of interbank linkages. For example, in the model of Allen and Gale (2000) (for more details, see [1]) contagion is less likely to occur in a "complete" structure of claims where every bank has symmetric linkages with all other banks than in incomplete structures, where banks have links only to a few neighboring institutions. A third type of the network structure, where the centres are symmetrically linked to some banks without these banks being linked together performed by Freixas, Parigi and Rochet (see [18]) and it is called "money centre bank" if it is one centralized bank in the market and "multiple money centres" if there are two or more centres. An empirical studies on contagion at the interbank market level performed by Boss et al [5], Degryse and Nguyen [10], Müller [31], Upper and Worms [34], and others (see, for example, [21], [27], [28], [36]). Authors use balance sheet data to analyze the network of interbank linkages and based on the ranking network structure model potential contagion.

- At the authority or supervisory level the posted limits to large exposures and the use of cross-border financial collateral influence the severity of contagion.[2]

2 Concepts of contagion and its intrepretation

The financial contagion penetrates through the countries and the regions (markets) in two levels: macrostructure and microstructure. The macrostructure relates to the sensitivity of credit institutions to common factors, such as changes in inflation, exchange rates and other

[2]The cross border financial collateral has been facilitated by the Financial Collateral Directive and adopted by the European Parliament and the Council in 2002. Moreover, banking supervisory authorities and the central banks of European Union agreed on Memorandum of Understanding on high-level principles of cooperation in crisis management solutions.

macroeconomic fundamentals. The correlation is taken between the asset returns and other common factors. There are many definitions of financial contagion[3] describing the transmission of unanticipated shocks through the countries, regions or financial markets (for more details, see [12], [32]).

In analysis of systemic risk of interbank system, the part of microstructure level, the correlation is defined by the credit institution's counterparty's default (default correlations). The core issue of systemic risk of interbank system is default risk modeling by introducing the concept of counterparty risk.

Definition 2.1. Counterparty risk is the risk that the default of a credit institution's counterparty might affect its own default probability.

Each financial institution has a unique counterparty structure that arises from its relation with other credit institutions in the interbank market. In addition, we treat the credit risk of collateralized loans in interbank markets also as the risk that the value of collateral can decrease.

In addition, a group of banks can be so highly interdependent that a single default of one credit institution can trigger a cascade of defaults (domino effect). A major concern for measuring systemic risk of interbank market is the degree of credit institutions' interdependence through the interlinkages, i.e. payment systems, credit lines, etc. Such dependence may be caused by both macro- and microstructural channels. We focus just on microstructure modeling during the deterministic time period $[0, T]$. Assume that two Bernoulli binomial variables $D_1(T)$ and $D_2(T)$ describe the default status of two credit institutions:

$$D_i(T) = \begin{cases} 1 \text{ if } i\text{-th credit institution defaults by } T, \ i = 1, 2, \\ 0 \text{ otherwise.} \end{cases} \tag{1}$$

Definition 2.2. The default correlation is defined as follows[4]:

$$\text{Corr}\left[D_1(T), D_2(T)\right] = \frac{P\left(D_1(T) = 1 \text{ and } D_2(T) = 1\right) - P\left(D_1(T) = 1\right) P\left(D_2(T) = 1\right)}{\sqrt{\text{Var}[D_1(T)] \cdot \text{Var}[D_2(T)]}}. \tag{2}$$

Similarly as in portfolio credit risk modeling [20], the microstructure captures interdependencies between debtors that go beyond their exposures to common factors, e.g., business or legal interdependencies. These microstructure interdependencies can lead to *credit contagion*.

Definition 2.3. In narrow sense, credit contagion is a transmission effect that underlies a microstructure interdependence. Contagion risk is then the risk that through microstructural channels, the credit deterioration of a counterparty triggers the credit deterioration of other counterparties (for more details, see [13]). In large sense, the credit contagion is the transmission

[3] Recent developments in this literature concern the inclusion of contagion indicators defining vulnerability to external shocks, often stemming from financial linkages between domestic and foreign credit institutions (see [32]).

[4] On the other hand, the correlation of default captures the correlation of the assets' returns (for more details, see [35]).

of unanticipated local shocks from one credit institution (banking sector) to another. In both cases credit (or default) contagion is the increase in default correlation of credit institutions during a crisis period $[0, T]$ (for more details, see [16]).

Credit contagion is a result of the interbank market structure, i.e. the size and number of linkages between credit institutions in the interbank market (for more details, see [27]). The channel of credit contagion is the credit line. Credit contagion means the two empirical facts: that the default of one credit institution can trigger the default of other related credit institutions and that default times tend to concentrate in certain periods of time, i.e. $[0, T]$, in which the default probabilities of all banks are increased. The literature of default contagion in reduced form models of credit risk includes two main approaches: the infectious defaults model of Davis and Lo (1999) [9], and the model of Jarrow and Yu (2001) [23], i.e. propensity model.

In order to account for the clustering of defaults in specific periods, Jarrow and Yu (2001) [23] include the counterparty risk.[5] In a first attempt, they assume that the default intensity of a firm depends on the status (default/not default) of the rest of the firms, i.e. symmetric dependence.[6]

The broader definition reflecting the financial contagion through the regions and countries is as follows.

Definition 2.4. Financial contagion is a significant increase in the probability of the crisis in one country, conditional on a crisis occurring in another country. Or in the same sense, financial contagion is a significant increase in comovements of prices and quantities across markets, conditional on a crisis occurring in one market or group of markets.

Systemic risk defined in such way captures the credit risk of single financial institution and its propagation through the interlinkages in the interbank market. In general, there are two kinds of default contagion, namely, *counterparty risk* and *information effect*. We analyze just the contagion through counterparty risk.

In the remaining part of this paper, we analyze just the credit contagion in microstructure level defined in Definition 2.3. Partly, we investigate the possibility of financial contagion in the sense of Definition 2.4 when we analyze the whole banking sector in Baltic states and possible external risk factors related to the patronizing financial institutions.

3 Contagion in separate interbank markets

The most obvious problem of modeling financial contagion in the real terms is the lack of data. Default events of credit institutions are quite rare and data collected over many years can hardly

[5] i.e. the risk that the default of a firm may increase the default probability of other firms with which it has commercial or financial relationships.

[6] However symmetric dependence introduces a circularity in the model, which they refer to as looping defaults, which makes it extremely difficult and troublesome to construct and derive the joint distribution of default times.

be supposed to be a sample from a stationary process. Thus reliable statistical estimates of distributional parameters are almost impossible to obtain. In these circumstances there is no point in introducing sophisticated models with lots of additional parameters. Therefore we introduce the simplest models with the smallest number of parameters that capture default contagion in a credible way.

Any assessment of systemic risk which neglects the precise structure of the interbank market is misleading and would imply an underestimation of systemic risk. However no information is publicly available about the size of the claims in the interbank market.

3.1 The features of local interbank markets and main assumptions

Until 2008 year, the structure of Estonian, Latvian and Lithuanian banking sectors are similar, significantly concentrated and can be divided into several categories: big banks, medium banks and small banks.[7] Big banks compose the largest category in the Baltic states banking sector in terms of total assets. The banking systems are dominated by Scandinavian capital. In the Latvian banking sector participate 21 banks and 2 foreign banks that have subsidiaries in Latvia. There are banks with Latvian capital, foreign capital and joint capital. In the Lithuanian banking sector participate 9 banks and 6 foreign banks that have subsidiaries. There are banks with Lithuanian capital and foreign capital as well. There are 7 banks and 9 branches of foreign banks in Estonian banking sector. Due to the management policy of patronizing financial institutions the local interbank markets between the Baltic states are weakly connected.

	Big banks, %	Medium banks, %	Small banks, %
Estonia	75.6	20.0	4.4
Latvia	50.4	34.4	15.2
Lithuania	67.5	25.9	6.6

Table 1: Market shares of assets of different credit institutions' categories in 2007 year.

Since the largest commercial banks in Lithuania, Latvia and Estonia are the net debtors of foreign patronizing banks[8] and are not systemically relevant debtors in the local interbank markets, i.e. they are not a source of credit risk and domino effect, therefore it is not reasonable to make an assumption of directed interbank network as the market with money centres[9] in separate country. Moreover, a highly centralized interbank market is more prone to financial contagion than a homogenous one. This means that, besides the amount of total liquidity in the

[7]Big, medium and small in the extent of the Baltic states. The value of total assets of big banks is not less than 3 billions, medium banks - between 1 and 3 billions, small banks - not greater than 1 billion.

[8]In general, it is not a rule but strongly depends on the internal liquidity management in extent of whole financial group.

[9]In this case the term "money centre" means that this credit institution is the biggest debtor in the interbank market.

banking sector and the credit institution's capital, the structure of the linkages between credit institutions has a considerable impact on its inherent stability (for more details, see [31]).[10]

Since the local interbank markets consists of the small number of credit institutions, it is reasonable to assume that they have direct links with each other, i.e. interbank markets in the Baltic States are complete. It means that each credit institution holds a portfolio of positions with all remaining banks in the interaction based market and that the credit institutions have the same number of partners (linkages) in interbank market.[11]

Consider that the time-span between a perceived increase in credit risk of a bank and the actual failure of a bank is too short for other banks to decrease their exposures to the defaulting bank. The credit loss on a position depends on the credit institution's individual liquidity state resulting from the local interaction with its counterparties, i.e. interbank borrowing and lending. They provide a channel for the direct default contagion of economic distress from one bank to other credit institutions. In addition, we suppose that the loss given default rate θ after the failure of any financial institution is identical for all banks. Linkages between the banks can be cyclical therefore besides the direct impact of counterparty's failure there exists also cyclical interdependence that also serves as credit contagion channel. Nevertheless, different credit institutions can be allowed to be in different states and there are n credit institutions in interbank market. Assume that there are no new credit institutions during the period $[0, T]$. A credit institution's interaction with other banks is symmetric, i.e.[12],

$$j \in N(i) \Rightarrow i \in N(j),\ i \neq j, \tag{3}$$

where $N(i)$ is the collection of all remaining banks[13] that have linkages with ith, $i = 1, 2, \ldots, n$ credit institution and satisfying condition

$$|N(i)| \begin{cases} = n-1, \text{ if the interbank market is complete,} \\ \leq n-1, \text{ if the interbank market is incomplete,} \end{cases} \quad i = 1, 2, \ldots, n. \tag{4}$$

Despite the fact that the local banking sectors are highly centralized and dominated by two or three banks i.e. they have the largest parts by total assets, the big banks are not necessarily the biggest creditors and debtors in local interbank markets. In addition, they seem to be more creditors than debtors in the local interbank market, so they are more likely to be "victims" than

[10] On the other hand, Allen and Gale (2000) [1] showed that complete structures are less prone to contagion than incomplete market structures, since with complete structures, the impact of a financial crisis in one region is absorbed by a large number of regions.

[11] It is why network approach is applied to describe the interbank market: in terms of graph theory vertices mean the credit institutions and directed interlinkages berween vertices - exposures of each bank to another (loans, credit lines etc.).

[12] K. Giesecke, S. Weber: A similar contagion mechanism is also associated with non financial firms through the institution of trade credit, which link suppliers and buyers of goods through a chain of obligations. For a microeconomic model see, for example, [24].

[13] There are n such collections of counterparties in interbank market having different systemic relevance.

source of credit contagion. In the case of Lithuania, the interbank market can be divided in two groups with almost the same number of institutions: those that are systemically relevant and those that are not. Another specific feature of the Baltic interbank markets is that the lending between financial institutions is based mainly on the collateralized loans[14] and the remaining part of interbank lending without collateral is not relevant. But collateralized loans in interbank markets do not necessarily eliminate the credit risk and systemic risk and just reduces its extent. Therefore, the modeling of the systemic risk of the interbank markets caused by the default of any credit institution can be based on the modeling of following risk sources:

- (daily) liquidity shortage in the interbank market;
- risk of decreasing value of collateral.

We use the same networking methodology for these issues. To estimate the systemic relevance of each entity of interbank market in terms of quantity of linkages some centrality indices are used. In- and outdegree centrality indices of ith credit institution are defined as follows, respectively:

$$C_{in}(i) = \frac{\sum_{j \in N(i)}(j,i)}{n-1},\ C_{out}(i) = \frac{\sum_{j \in N(i)}(i,j)}{n-1},\ C_{in}(i),\ C_{out}(i) \in [0,1],\ i = 1,2,\ldots,n, \qquad (5)$$

where (i,j) denotes the financial claim of bank i to j and, reciprocally, (j,i) means the financial liabilities of bank i to j, $i,j = 1,2\ldots,n,\ i \neq j$. In the case of local interbank markets of Baltic states the values of these two indices are close to 1. In-closeness and out-closeness centralities of ith credit institution are as follows:

$$I_{in}(i) = \frac{n-1}{\sum_{j \in N(i)} d(i,j)},\ I_{out}(i) = \frac{n-1}{\sum_{j \in N(i)} d(j,i)},\ I_{in}(i), I_{out}(i) \in [0,1],\ i = 1,2,\ldots,n, \qquad (6)$$

where $d(i,j)$ is the distance between two banks, measured by the number of interbank linkages that are needed to reach ith credit institution from bank j, $i,j = 1,2,\ldots,n,\ i \neq j$, defined as in [31].[15] Since the local interbank markets consist of the small number of credit institutions and are complete then $d(i,j) = 1$ and in-closeness and out-closeness centrality indices $I_{in}(i),\ I_{out}(i)$ for ith bank are equal or close to 1, i.e. the default of any bank would have a direct impact on the whole banking sector and in the case of failure of big bank can trigger the banking crisis. In other words, the interbank markets in separate Baltic states looks as homogenous with respect only to the number of linkages despite the fact that these markets are significantly dominated by big banks.

Also, using the simulation approach we estimate some weighted centrality indices,[16] describing more exhaustively the positions of credit institutions in the interbank market, namely the valued indegree index measuring the proportion of ith credit institution liabilities to total

[14] The collateral depends on the amount and maturity of loan.

[15] Note that the credit values are disregarded in definitions of centrality indices.

[16] Weights are the amounts of bilateral exposures.

liabilities in interbank market and the valued outdegree index assessing the proportion of ith bank exposures to total exposures in interbank market, respectively:

$$vd_{in}(i) = \frac{\sum_{j \in N(i)} x_{ji}}{\sum_{k,l=1}^{n} x_{kl}},\ vd_{out}(i) = \frac{\sum_{j \in N(i)} x_{ij}}{\sum_{k,l=1}^{n} x_{kl}},\ vd_{in}(i), vd_{out}(i) \in [0,1],\ i = 1,2,\ldots,n, \qquad (7)$$

where x_{kl} are the exposures of kth credit institution to bank l, $k,l = 1,2,\ldots,n$, $k \neq l$. It is impossible to calculate it exactly due to the lack of information concerning bilateral exposures in interbank market. The estimates of credit institutions' weighted centrality indices and their correlation are presented in Appendix B

In the case of incomplete market the values of centrality indices are substantially different from ones estimated for complete market. Assumption that the interbank markets of separate Baltic states have a similar to incomplete market structure with two or three money centres where credit institutions are only linked to neighboring banks does not give any additional information. In this case should be possible to apply the star network approach but the problem is that big banks that serve as money centres in banking sector are not necessarily the biggest debtors and so biggest sources of credit contagion in local interbank markets.

Another factor linked to the structure of interbank network, is the banking sector concentration. Economic theory does not seem to be conclusive on the relationship between competition and stability and does not provide a clear response to the question of the impact of increasing concentration in banking sector on the stability of interbank markets, although some authors do find that such a trade-off exists in certain circumstances (for more details, see [7]). Contagion in general seems to be a larger problem in a concentrated system since the large credit institutions have fewer alternative counterparties in the interbank markets. On the other hand, we can expect that the big banks, owned by Scandinavian capital, have alternative opportunity to borrow from patronizing financial institutions.

3.2 Simulation approach

Since we have not data about the bilateral exposures in interbank market to assess the centrality of credit institutions using network approach we choose a simulation method to analyze the systemic risk in local interbank markets of the Baltic states. The network and the simulation approach are combined to assess the systemic relevance of particular financial institutions and the impact of the structure of bank relationships on the stability of the banking sector. To check the banking system's exposure to aggregate risk a default situation is simulated, which yields a measure of its inherent instability. We use an approach similar to one of Eisenberg and Noe [14] and Müller [31].

The analysis of credit contagion is based on balance sheets, which all credit institutions of Baltic states have to submit to supervising authorities and annual financial reports. We did not include some subsidiaries of foreign banks since we do not know amount of their tier 1 capital and total interbank liabilities since these data are consolidated. On the other hand, majority of

these institutions have a good credit ratings, are the branches of well known and well managed foreign financial institutions and do not seem as important sources of systemic risk.

3.2.1 Estimation of bilateral exposures

The impact of default of one of banks that seem to be systemically relevant according to the network structure and the inherent instability of these network structures as well as their resilience to bank failures is measured by the simulation approach.[17] To find the systemically relevant banks in local interbank markets we have to solve a system of n linear equations with n unknown variables:

$$r = X'r, \tag{8}$$

where $r = (r_1, \ldots, r_n)'$ is the vector of bank ranks capturing the direct links and the amounts of respective exposures which can be obtained by solving the eigenvector problem $(I - X')r = \mathbf{0}$,[18] where $\mathbf{0} = (0, \ldots, 0)'$ and the $n \times n$ matrix X describing the lending relationships in the local interbank markets is defined as follows (see, for example, [14], [34]):

$$X = \begin{pmatrix} 0 & x_{12} & \ldots & x_{1n} \\ x_{21} & 0 & \ldots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \ldots & 0 \end{pmatrix}, \tag{9}$$

where x_{ij} is gross credit exposure of bank j to the bank i, $i \neq j$, $i, j = 1, 2, \ldots, n$. Liabilities of jth bank and financial claims of ith bank in local interbank market are, respectively:

$$l_j = \sum_{i=1}^{n} x_{ij}, \; d_i = \sum_{j=1}^{n} x_{ij}. \tag{10}$$

In such way the latter constraints are known but the bilateral exposures are not. The main assumption is that banks maximize the diversification of their interbank exposures, and we need to estimate it using the procedure of maximization entropy. Without an assumption about the distribution of the bilateral exposures the matrix X can not be identified since $n^2 - 2n$ parameters are unknown. Assume that interbank loans and claims (deposits) are as equally spread over banks as possible. In fact, in further estimation procedure we use matrix of normalized bilateral

[17] Of course, exchange rate fluctuations, interest rate changes or credit defaults affect the positions on the assets and liabilities but we assume that interbank exposures are constant at the moment and we focus just on the default risk as a source of contagion.

[18] Note that r is the special case of Bonacich's measure (for more details, see [4]).

exposures

$$\tilde{X} = \begin{pmatrix} 0 & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & 0 & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \dots & 0 \end{pmatrix}, \tag{11}$$

where due to the hypothesis of the complete interbank market structure the distributions of interbank exposures, i.e. financial claims (deposits) and liabilities are independent,[19] i.e.

$$\tilde{x}_{ij} = \tilde{d}_i \tilde{l}_j, \ i, j = 1, 2 \dots, n \tag{12}$$

and normalized financial claims of ith bank and liabilities of jth bank are, respectively:

$$\tilde{d}_i = \frac{d_i}{\sum_{i=1}^n d_i}, \ \tilde{l}_j = \frac{l_j}{\sum_{j=1}^n l_j}, \ \sum_{j=1}^n \tilde{l}_j = \sum_{i=1}^n \tilde{d}_i = 1. \tag{13}$$

However solution (12) would imply that for banks that are both lender and borrower in the market they lend to themselves. In order to rule out this outcome we assume that $\tilde{x}_{ii} = x_{ii} = 0, \ i = 1, 2, \dots, n$ since banks do not incur liabilities against themselves (the assumption of independence of liabilities and claims is consistent with the work of Allen and Gale (2000)).

We use entropy maximization method that attempts to distribute the mass of the row and column totals in such a way across the cells that the sum conditions are fulfilled and that as much consistency as possible is preserved with the a priori information about the unknown cell entries. The task is to estimate bilateral exposures so that elements of matrix X^* obtained by the maximization as close as possible to the elements of matrix $\tilde{X}$. This is obtained by minimizing the cross-entropy or distance function measured by the relative entropy between matrices $\tilde{X}$ and X^*:

$$\min_{x_{ij}^*} \sum_{i,j=1}^n x_{ij}^* \log \frac{x_{ij}^*}{\tilde{x}_{ij}} \tag{14}$$

subject to constraints in interbank market

$$\begin{aligned} &\tilde{l}_j = \sum_{i=1}^n x_{ij}^*, \\ &\tilde{d}_i = \sum_{j=1}^n x_{ij}^*, \\ &x_{ij}^* \geq 0, \ i \neq j, \ x_{ij}^* = 0, \ i = j, \ i, j = 1, 2, \dots, n, \end{aligned} \tag{15}$$

[19] In fact, this assumption is the deviation from the concepts of credit correlation and contagion. However it is necessary to solve identification problem.

where $x^*_{ij},\ i,j = 1,2,\ldots,n$ are the elements of matrix X^* (by convention, $0 \log \frac{0}{0} := 0$). Since the objective function (14) is strictly concave, there is a unique solution for the structure of interbank lending X^*.

3.2.2 Estimation of contagion in the absence of safety net

The simulation of credit contagion is based on assumption that there are no independent defaults of credit institution during the period of financial crisis $[0,T]$. The default of jth bank triggers the default of ith credit institution if the loss of ith credit institution from the claims in jth bank exceeds its capital endowment, i.e. tier-1 capital c_i:

$$\theta_j(i)x_{ij} \geq c_i,\ i,j = 1,2,\ldots,n,\ i \neq j. \tag{16}$$

On the other hand, the default of a single credit institution triggers a whole chain of subsequent defaults even if the initial impact is relatively weak. In this case it can cause the default of kth financial institution if

$$\sum_{j \in N(i)} \theta_j(i)x_{ij} \geq c_i,\ i = 1,2,\ldots,n. \tag{17}$$

This formula captures all impacts of previously failed credit institutions. The simulation is iterated to verify if defaulting credit institutions after the first iteration make other banks fail as well. The initial default is assumed to cause an additional failure when the exposure of one bank to defaulted banks is large enough to offset its tier-1 capital. At each iteration those banks which defaulted in the previous one are dropped from the set of banks which may be affected by credit contagion. The simulation continues until at least a bank default occurs, i.e. the contagion stops when banks that failed during the last round do not cause any additional defaults, i.e. when the system is again stable (for more details, see Appendix A). A credit institution that defaults in the first round of the fictitious default algorithm is taken to be fundamentally insolvent. Other failures in consecutive rounds can be considered as contagious defaults. Assume that ith credit institution defaults first. Then the path of contagion after the default of ith credit institution for any $i = 1,2,\ldots,n$ can be described as follows.

Defaulted banks

$$\begin{cases} F^0(i) = \{i\}, \\ F^t(i) = \left\{k \in S^{t-1}(i) : c_k^t(i) = c_k^{t-1}(i) - \sum_{j \in F^{t-1}(i)} \theta_j(i)x_{kj} \leq 0\right\},\ t = 1,2,\ldots,T-1 \\ F^T(i) = \{\emptyset\}. \end{cases} \tag{18}$$

Survived banks

$$\begin{cases} S^0(i) = N(i), \\ S^t(i) = \left\{k \in S^{t-1}(i) : c_k^t(i) = c_k^{t-1}(i) - \sum_{j \in F^{t-1}(i)} \theta_j(i)x_{kj} > 0\right\},\ t = 1,2,\ldots,T, \end{cases} \tag{19}$$

where time $t = 1, 2, \ldots, T$ means the step of iteration. Note that the sequences $\{F^t(i),\ t = 1, 2, \ldots, T\}$ and $\{S^t(i),\ t = 1, 2, \ldots, T\}$ are non-increasing and $F^t(i) \subset S^{t-1}(i)$ and the sequence $\{c_k^t(i),\ t = 1, 2, \ldots, T\}$ describes the dynamics of tier-1 capital of kth bank in the period of credit contagion $[0, T]$ for any $i = 1, 2, \ldots, n$. $\{\theta_j(i),\ j = 1, 2, \ldots, n\ j \neq i\}$ is the sequence of loss given default ratios for any initially defaulted credit institution $i = 1, 2, \ldots, n$.[20] If $S^T(i) = \emptyset$ the banking sector is non-resistant to the default of ith credit institution and, vice versa, if $F^1(i) = \emptyset$, the default of ith bank has no significant impact to the whole interbank market. Of course, it depends on the relevance and centrality of ith credit institution, $i = 1, 2, \ldots, n$.

4 Contagion in the common Baltic states interbank market

In this section we analyze the more general case of financial contagion presented in Definition 2.4. Based on the estimated matrix of bilateral exposures we measure simulations successively study the impact of the failure of each of credit institution for a given loss given default θ.

Since the systemically relevant credit institutions in the Baltic states are owned by Scandinavian banks and get separately loans, i.e. are its net debtors, there are no "pure" credit contagion risk source from patronizing financial institution. Therefore the big banks in the Baltic states are more likely to be the source of contagion than "victims" of regional financial contagion and "victims" are, of course, patronizing institutions. In such case the banking sectors in separate Baltic states are quite isolated. On the other hand, this fact also enhances the big banks' strong dependence on the liquidity risk that meet patronizing institutions. In addition, the contagion may occur as a result of information effect. For example, when clients of one of big banks get to know that the bank with the same brand defaulted in neighbor Baltic country start panic and take their money away in their local market. As a result banks with the same brand in other Baltic states can become illiquid. The remaining part of credit institutions seems to play only a limited role in the Baltic interbank market. Therefore for further analysis, we focus just on the structure of interlinkage in the interbank markets and treat the contagion induced by the default of one of big financial institution. In 2007 year, the shares by total assets of separate banking sectors in Baltic market were as in Table 3.

	2004	2005	2006	2007	2008	2009
Estonia	30.33	29.29	27.83	27.27	27.00	27.18
Latvia	39.68	38.55	41.15	41.50	40.91	40.70
Lithuania	29.99	32.16	31.02	31.22	32.09	32.12

Table 2: The dynamics of shares of local banking sectors in the Baltic states by total assets, %

[20] Due to the lack of data and for the sake of simplicity we assume that as mentioned in subsection 3.1 loss given default ratio θ is constant over all credit institutions.

Systemically all banking sectors in the Baltic States are almost equally relevant during the last years. Therefore the initial source of contagion from any of Baltic states has approximately the same impact on other banking sectors through common creditor channel.[21] In addition, despite the fact that the probability that five patronizing financial institutions from Scandinavia representing common creditor for the Baltic states will withdraw their investments at the same time is very small there exists such risk.

Default risk and liquidity risk of patronizing financial institutions. The problem in Baltic states can occur just due to the sudden liquidity shortage in patronizing financial institutions and liquidity shortage in Scandinavian interbank markets. Therefore the Baltic banking sector strongly depends on the Scandinavian monetary policy, state of interbank markets and supervision of financial institutions.

Common creditor risk. Scandinavian banks are the major sources of financing for the banking sector of the Baltic states and also one of the most volatile ones. The so called "common creditor channel" assumes that some countries or regions that depend on a common creditors are vulnerable to spillovers through this linkage.[22] Spillovers result from interlinkages between the affected countries. Spillovers through financial market interlinkages emerge from shifts in investors portfolios. The common creditors channel belongs in this category. There are several mechanisms how lending centres can cause cross-border spillovers (for more details, see [6], [25], [33]). Losses in one country could lead banks to sell off assets in other countries in an attempt to restore their capital adequacy ratios. Also, there are some medium banks residing in one if the Baltic states which also has their subsidiaries in other Baltic states. The underlying presumption is that common creditors exposures in Baltic states affected by the primary financial crisis were relatively large, implying substantial potential losses, and hence the need to restore capital asset ratios, meet margin calls, or readjust risk exposures, thus accounting for the common bank lender effect. The common creditor channel presupposes that financial institutions' responses to unexpected losses are fairly mechanistic. Patronizing financial institutions' needs to rebalance their portfolios following losses in the primary crisis country (not necessarily in the Baltic states) lead to an instantaneous reduction of lending to other countries in which they hold positions (for more details, see [33]). In addition, the risk of short term liquidity exists in the case if owning financial institution should not give any credit more.

[21] In fact, there exists also the same risk from other emergent financial markets as Ukraine, Russia where the Scandinavian banks (i.e. common creditor) have their branches.

[22] In addition, it means that the Scandinavian patronizing banks look as money centres in larger regional extent of interbank market.

5 Conclusion

We explained and distinguished more strictly the notions of financial contagion and correlated defaults. Also, we presented the structure of the local interbank markets as the source and channel of financial contagion through the interbank linkages. In addition, we treated the risk of "common creditor channel" as specifical channel of financial contagion in the Baltic region not only due to the crisis in particular country but also due to the shortage of liquidity of foreign financial institutions. We find that the bankruptcy of one of the large financial institutions will put a considerable burden on the other financial institutions, but will not lead to a complete collapse of the interbank market. The contagion effects of the failure of a smaller bank are limited.

We estimated the systemic risk without having exhausted data concerning the bilateral exposures and the information of the interbank market structure. Due to the complete interbank market structure the weighted and unweighted centrality indices are uncorrelated.

In addition, the financial stability of banking sector in the Baltic states strongly depends on the supervision and financial stability in Scandinavian banking sector.

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Appendix A. Approximation of matrix X

To approximate matrix X we solve the problem defined in formulas (14)-(15). The Lagrangian for this problem is

$$\mathcal{L}(X^*, \lambda, \mu, N) = \sum_{i,j=1}^{n} x_{ij}^* \log \frac{x_{ij}^*}{\tilde{x}_{ij}} \tag{A.1}$$
$$- \sum_{j=1}^{n} \lambda_j \left(l_j - \sum_{i=1}^{n} x_{ij}^* \right) - \sum_{i=1}^{n} \mu_i \left(d_i - \sum_{j=1}^{n} x_{ij}^* \right) - \sum_{i,j=1}^{n} \eta_{ij} x_{ij}^*,$$

where $\lambda = (\lambda_1, \ldots, \lambda_n)$, $\mu = (\mu_1, \ldots, \mu_n)$ and $N = \{\eta_{ij},\ i, j = 1, 2, \ldots, n\}$. The Kuhn-Tucker conditions for this problem are as follows:

$$\begin{aligned}
&\frac{\partial \mathcal{L}}{\partial x^*_{ij}} = 1 + \log \frac{x^*_{ij}}{\tilde{x}_{ij}} + \sum_{j=1}^{n} \lambda_j + \sum_{i=1}^{n} \mu_i - \eta_{ij} = 0,\ i, j = 1, 2, \ldots, n \\
&\lambda_j \left(\sum_{i=1}^{n} x^*_{ij} - \tilde{l}_j \right) = 0,\ j = 1, 2, \ldots, n \\
&\mu_i \left(\sum_{j=1}^{n} x^*_{ij} - \tilde{d}_i \right) = 0,\ i = 1, 2, \ldots, n \\
&\eta_{ij} x^*_{ij} = 0,\ i, j = 1, 2, \ldots, n.
\end{aligned} \tag{A.2}$$

Finally, we apply the RAS algorithm which is a special case of the entropy projection method. We use the iterative procedure

$$x^{*,t+1}_{ij} = \frac{x^{*,t}_{ij} \tilde{l}_j}{\sum_{i=1}^{n} x^{*,t}_{ij}} \text{ and } x^{*,t+1}_{ij} = \frac{x^{*,t}_{ij} \tilde{d}_j}{\sum_{j=1}^{n} x^{*,t}_{ij}}. \tag{A.3}$$

Appendix B. Estimated weighted centrality indices

The values of weighted In- and outdegree indices for each country are presented in following tables:

Credit institution	Type	Indegree 2007	Indegree 2008	Indegree 2009
EST1	Big	0.263824	0.969255	0.986530
EST2	Big	0.562910	0.004605	0.004590
EST3	Small	0.007411	0.015623	0.001945
EST4	Medium	0.162792	0.000000	0.000000
EST5	Small	0.000000	0.000000	0.000000
EST6	Small	0.000000	0.000000	0.000000
EST7	Small	0.001739	0.000403	0.000373
EST8	Small	0.001324	0.007221	0.004671
EST9	Small	0.000000	0.002893	0.001891
EST10	Small	–	0.000000	0.000000

Table 3: Estonian interbank market, 2007, 2008 and 2009 years.

Credit institution	Type	Outdegree 2007	Outdegree 2008	Outdegree 2009
EST1	Big	0.048656	0.189344	0.042898
EST2	Big	0.313145	0.664587	0.299965
EST3	Small	0.014897	0.057849	0.019079
EST4	Medium	0.013227	0.000000	0.000000
EST5	Small	0.000000	0.000000	0.000000
EST6	Small	0.000000	0.000000	0.000000
EST7	Small	0.602821	0.004671	0.623629
EST8	Small	0.000109	0.001507	0.000565
EST9	Small	0.007145	0.081756	0.011298
EST10	Small	–	0.000285	0.002567

Table 4: Estonian interbank market, 2007, 2008 and 2009 years.

Note that in the case of complete market weighted centrality indices are uncorrelated with those unweighted.

Credit institution	Type	Indegree 2007	Indegree 2008	Indegree 2009
LIT1	Big	0.051482	0.644541	0.318269
LIT2	Big	0.320207	0.052003	0.063309
LIT3	Big	0.339243	0.090460	0.077874
LIT4	Medium	0.064115	0.091640	0.009956
LIT5	Medium	0.011769	0.041865	0.007444
LIT6	Small	0.008308	0.077555	0.000065
LIT7	Medium	0.060823	0.000592	0.078662
LIT8	Medium	0.055487	0.000237	0.121794
LIT9	Small	0.029433	0.000318	0.044944
LIT10	Small	0.008194	0.000049	0.009730
LIT11	Small	0.050937	0.000739	0.267952

Table 5: Lithuanian interbank market, 2007, 2008 and 2009 years.

Credit institution	Type	Outdegree 2007	Outdegree 2008	Outdegree 2009
LIT1	Big	0.224521	0.149656	0.373851
LIT2	Big	0.201570	0.201396	0.165060
LIT3	Big	0.054093	0.034981	0.039364
LIT4	Medium	0.014246	0.106559	0.021648
LIT5	Medium	0.120962	0.111255	0.117161
LIT6	Small	0.003441	0.081548	0.008700
LIT7	Medium	0.199839	0.219806	0.143084
LIT8	Medium	0.128176	0.017125	0.079901
LIT9	Small	0.019789	0.009758	0.004782
LIT10	Small	0.016796	0.023707	0.005856
LIT11	Small	0.016568	0.044210	0.040592

Table 6: Lithuanian interbank market, 2007, 2008 and 2009 years.

Credit institution	Type	Indegree 2007	Indegree 2008	Indegree 2009
LAT1	Big	0.242495	0.017315	0.256807
LAT2	Big	0.430765	0.430766	0.490155
LAT3	Medium	0.006846	0.006082	0.011611
LAT4	Small	0.000000	0.002920	0.000000
LAT5	Medium	0.000000	0.000000	0.000000
LAT6	Big	0.139954	0.011916	0.121953
LAT7	Medium	0.004814	0.004006	0.003498
LAT8	Medium	0.028797	0.000513	0.018707
LAT9	Medium	0.001010	0.028081	0.000219
LAT10	Small	0.000566	0.000469	0.000570
LAT11	Small	0.000079	0.000079	0.000093
LAT12	Small	0.000271	0.000590	0.000011
LAT13	Small	0.016662	0.001257	0.003498
LAT14	Small	0.004646	0.000253	0.002287
LAT15	Small	0.088220	0.001056	0.080803
LAT16	Small	0.000018	0.000292	0.000135
LAT17	Small	0.001990	0.000000	0.000906
LAT18	Small	0.016110	0.000023	0.003423
LAT19	Small	0.002254	0.000734	0.000358
LAT20	Small	0.002989	0.000325	0.000456
LAT21	Medium	0.009522	0.008938	0.004508
LAT22	Small	0.001990	0.000039	0.000000

Table 7: Latvian interbank market, 2007, 2008 and 2009 years.

Credit institution	Type	Outdegree 2007	Outdegree 2008	Outdegree 2009
LAT1	Big	0.080785	0.058888	0.101803
LAT2	Big	0.111730	0.121246	0.199065
LAT3	Medium	0.005063	0.001297	0.003581
LAT4	Small	0.000000	0.000000	0.000000
LAT5	Medium	0.000000	0.000000	0.000000
LAT6	Big	0.177690	0.222814	0.140397
LAT7	Medium	0.000000	0.098520	0.044048
LAT8	Medium	0.137528	0.106032	0.129223
LAT9	Medium	0.076078	0.078028	0.087692
LAT10	Small	0.016984	0.039923	0.045658
LAT11	Small	0.003840	0.005047	0.004866
LAT12	Small	0.014125	0.016607	0.014262
LAT13	Small	0.064230	0.018203	0.031752
LAT14	Small	0.017280	0.014467	0.001892
LAT15	Small	0.035584	0.029191	0.015198
LAT16	Small	0.183591	0.106301	0.023760
LAT17	Small	0.000053	0.000178	0.008684
LAT18	Small	0.008021	0.022815	0.034882
LAT19	Small	0.005713	0.015194	0.017348
LAT20	Small	0.053468	0.025163	0.052185
LAT21	Medium	0.005108	0.015974	0.043703
LAT22	Small	0.003129	0.004112	0.000000

Table 8: Latvian interbank market, 2007, 2008 and 2009 years.

Corr $\{vd_{in}(\cdot), vd_{out}(\cdot)\}$	2007	2008	2009
Estonia	0.219568	0.153786	-0.097071
Latvia	0.433949	0.330360	0.759965
Lithuania	0.256960	0.288748	0.634082

Table 9: The data used covers 2007, 2008 and 2009 years.