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Contagion Risk in the Czech Financial System: A Network Analysis and Simulation Approach

Václav Hausenblas, Ivana Kubicová and Jitka Lešanovská*

Abstract

This paper examines the potential for contagion within the Czech banking system via the channel of interbank exposures of domestic banks enriched by a liquidity channel and an asset price channel over the period March 2007 to June 2012. A computational model is used to assess the resilience of the Czech banking system to interbank contagion, taking into account the size and structure of interbank exposures as well as balance sheet and regulatory characteristics of individual banks in the network. The simulation results suggest that the potential for contagion due to credit losses on interbank exposures was rather limited. Even after the introduction of a liquidity condition into the simulations, the average contagion was below 3.8% of the remaining banking sector assets, with the exception of the period from December 2007 to September 2008. Activation of the asset price channel further increases the losses due to interbank contagion, showing that liquidity of government bonds would be essential for the stability of Czech banks in stress situations. Finally, the simulation results for both idiosyncratic and multiple bank failure shocks suggest that the potential for contagion in the Czech banking system has decreased since the onset of the global financial crisis.

JEL Codes: G01, G17, G21.

Keywords: Banking regulation, contagion, financial crisis, interbank market, market structure.

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Nontechnical Summary

This paper assesses the resilience of the Czech banking system to interbank contagion. Interbank exposures such as interbank loans and cross holdings of securities can serve as a channel for interbank contagion. Banks and their interbank exposures create a so-called interbank network, where banks represent the nodes and financial exposures create the links between those nodes. The resilience of such a network depends on both the financial soundness of individual banks and the structure of the interbank links within the network. Therefore, network analysis is employed in order to understand the structure of the Czech interbank market. The results of the interbank network analysis indicate that the network is relatively sparse and highly heterogeneous. It points to several banks important for the stability of the network whose failure could potentially have systemic consequences.

The empirical analysis is followed by a description of a computational model of interbank contagion which combines information on the stability of individual banks, bilateral interbank exposures, and the structure of the interbank network. The resilience of the system is assessed using a simulation approach where the initial shocks have the form of either individual or multiple bank failures. More specifically, we assume three potential channels of interbank contagion: a credit channel, a liquidity channel, and an asset price channel. The credit channel is active when banks in the system are defaulting due to credit losses on interbank exposures. Additionally, a bank might default when it is illiquid, i.e., when liquid assets such as cash, central bank balances, interbank lending, and domestic government bonds are not sufficient to cover short-term interbank liabilities. Finally, the asset price channel is activated in the model when government bonds are no longer considered to be highly liquid assets, hence it is not possible to exchange these bonds for cash without a price discount. The simulations incorporating the asset price channel represent a theoretical exercise where banks selling government bonds in the market face less than perfectly elastic demand for government bonds. When an unusual volume of government bonds is placed on the market, its price decreases, resulting in losses due to revaluation of these assets in the balance sheets of all banks holding government bonds.

The potential for contagion was assessed over the period from March 2007 to June 2012. The simulation results for the idiosyncratic shock suggest very low potential for interbank contagion across scenarios due to pure credit losses on interbank exposures in the Czech banking sector. The contagion amounted to 3% of the remaining banking sector assets after the initial idiosyncratic shock in the worst-case scenarios over the period in focus. After the introduction of the liquidity condition into the simulations, the average contagion was below 3.8% of the remaining banking sector assets, with the exception of the period from December 2007 to September 2008. Activation of the asset price channel further increases the losses due to interbank contagion, showing that liquidity of government bonds would be essential for the stability of Czech banks in stress situations. Finally, the simulation results for both idiosyncratic and multiple bank failure shocks suggest that the potential for contagion in the Czech banking system has decreased since the onset of the global financial crisis.

By providing a tool for assessment of systemic risk in structural dimension that better controls for heterogeneity in banking system and endogenous financial variables this work might contribute to analytical framework of a macroprudential policy authorities.

1. Introduction

The current global financial crisis has shown that the stability of individual institutions and the stability of the system as a whole do not necessarily overlap, since there are important financial linkages between individual institutions making the system more complex. The interconnectedness of financial institutions can be direct (direct exposures via loans, cross holdings of securities, etc.) or indirect (common exposures to a particular class of assets or even to the very same debtor). Both types of exposures create channels for potential contagion within the financial system.

In this paper, we narrow our focus to contagion within a banking system where the interbank market network is composed of banks (representing nodes) and financial exposures (links). In normal times, the interbank market ensures efficient liquidity redistribution from banks with surplus liquidity to banks with a shortage of liquidity and thus serves as an absorber of idiosyncratic liquidity shocks. The necessary condition is that the overall liquidity need must be lower than total amount of liquid assets in the banking sector. In turbulent times, however, interbank markets can become a channel for liquidity contagion due to liquidity hoarding by banks and/or credit risk contagion due to credit losses on interbank exposures. Interbank market contagion is more likely to occur in banking sectors that are highly dependent on wholesale financing. The credit channel and the liquidity channel can be accompanied by informal channels such as bank runs or by an asset price channel if an excessive supply of banking assets on illiquid markets results in banks incurring losses due to a decrease in the market price of those assets.

Despite the fact that the Czech banking system is characterized by favorable values of basic financial soundness indicators (CNB, 2012), especially a strong capital position, stable profitability, and liquidity, there is still heterogeneity among individual institutions (in terms of soundness indicators as well as degree of interconnectedness), leaving scope for potential credit and liquidity risk contagion in the system. Therefore, we build a computational model to assess the potential for contagion in the Czech interbank market in the period from March 2007 to June 2012. The main goal of this paper is to present an operational analytical tool that can be used to assess the systemic risk of the banking system in the Czech Republic and the potential for interbank contagion within the system over time.[1]

The structure of the paper is the following. First, we discuss the approaches and results of relevant theoretical and empirical literature dealing with the topic of interbank contagion. We continue with a description of the data used for the empirical analysis, which is followed by an analysis of the topology of the interbank market in the Czech Republic. We then describe a model of interbank contagion in the Czech Republic, which we use to simulate the effect of the credit, liquidity, and asset price channels, assuming either idiosyncratic or simultaneous failures of any of the Czech banks. The last part of the paper summarizes the main results.

[1] Similar tools are already implemented in stress-testing frameworks of several central banks. See Chapter 2 for more details.

2. Literature Review

The most common source of contagion identified in the literature is the materialization of counterparty credit risk, liquidity risk, or a combination of risks, such as a combination of counterparty credit risk and liquidity risk with market risk and common macroeconomic shocks.[2] Moreover, the structure of interbank markets is considered to be an important factor influencing the spread of contagion in financial systems. Complete interbank market structures, where banks are symmetrically linked to all other banks, should be more robust than incomplete structures, according to Allen and Galle (2000). However, contrary to these findings, Elsinger et al. (2006) find that assuming a complete market structure leads to an increase in scenarios with contagious defaults in their model and therefore conclude that simple classification into complete and incomplete structures does not reflect the full picture of the interaction between the market topology and financial fragility of the banking system. Within the incomplete structure setting, Nier et al. (2007) find the relationship between contagion and connectivity to be non-monotonic, i.e., while an increase in connectivity negatively influences the resilience of the financial system for a low level of connectivity (interbank linkages as shock transmitters), the opposite is true for highly connected financial systems (interbank linkages as shock absorbers). A specific type of incomplete network structure discussed in more recent literature is the interbank market with tiering (Upper and Worms, 2004; Craig and von Peter, 2010; Fricke and Lux, 2012; Langfield, 2012; van Lelyveld and Veld, 2012). In heavily tiered structures, a few core banks are important for the smooth functioning of the whole system.

Nier et al. (2007) and Gai and Kapadia (2010), among others, assume direct interbank linkages to be the main channel of contagion in their models. Both studies find that capital buffers are important for the stability of the financial system. A significant erosion of capital buffers can lead to a higher probability or scope of contagion via losses on interbank credit exposures. Furthermore, insufficient market liquidity can serve as an additional important contagion channel when the failed bank's external assets need to be sold.

Contagion due to losses on interbank credit exposures is possible only in banking sectors that have a high share of interbank assets relative to the available capital. In the event of an initial idiosyncratic shock, i.e., the initial failure of a bank in the system, the bank's equity is wiped out and the bank is no longer able to fully repay its interbank liabilities. Depending on the relative importance of the initial shock, further rounds of solvency contagion can occur. While this channel seems to be important, for example, in Belgium (Degryse and Nguyen, 2007), Germany (Upper and Worms, 2004), Italy (Mistrulli, 2011), and the UK (Wells, 2004), it is expected to be less relevant in Hungary (Lublóy, 2004), the Netherlands (van Lelyveld and Liedorp, 2006), and Switzerland (Sheldon and Maurer, 1998).

In addition to the pure credit channel, Müller (2006) assumes that a bank can go bankrupt for illiquidity reasons. Müller (2006) strictly distinguishes between default due to insolvency and default due to illiquidity and shows that the liquidity channel is stronger in the case of the Swiss banking sector. Moreover, she shows that the existence of credit lines, which are arranged between banks to ensure provision of liquidity when needed, helps to reduce contagion only a little. Müller (2006) argues that credit lines represent an additional contagion channel, since banks

[2] An overview of the simulation approaches used in the current literature is given in Upper (2011).

rely on the possibility of drawing on these credit lines and this might not be possible in a crisis.[3] Even though such behavior seems rational from the individual perspective, it poses a systemic risk. Therefore, the simulation results call for sufficient capital as well as liquidity buffers, reflecting the idiosyncratic risk of bank failure as well as its contribution to systemic risk. Also, a lender of last resort could significantly mitigate the spill-over effects resulting from a bank's illiquidity and its inability to draw on credit lines at times of financial distress.

Alternatively, in financial systems heavily dependent on interbank market lending, the contagion via liquidity channel might stem from hoarding of liquidity by banks which can significantly contribute to the freeze of interbank markets (Gai et al., 2011). Gai et al. (2011) conclude that resilience of the system to liquidity contagion can be achieved by, among other measures, requiring sufficient holdings of liquid assets and stricter regulation of systemically important financial institutions (SIFIs), since more concentrated markets are more vulnerable to shocks affecting SIFIs.

Adrian and Shin (2008) point out that the simple domino model is unlikely to explain financial contagion in a modern, market-based financial system, where any unusual volumes of trading in financial assets directly influence the market value of these assets and consequently the net worth of financial institutions. The standard liquidity and credit channels might therefore be accompanied by other risks that intensify the effect of contagion, e.g., a downward spiral in asset prices due to fire sales, the effect of a common macroeconomic shock on the banking sector, or bank runs due to information asymmetries. While the former two risks are captured in a number of studies, the latter is usually excluded from the analysis even though this shifts the model further away from reality.[4]

Cifuentes et al. (2005) and Bluhm and Krahnen (2011) assume that the contagion might be spread in the system via losses on direct exposures as well as via the asset price channel. When a bank's capitalization is impaired by the initial shock, the bank tries to sell assets that have a non-zero risk weight in the capital requirement calculation in order to increase their capital adequacy ratio. If the market demand is less than perfectly elastic, the fire sale depresses the market prices of those assets. Such a price decline feeds back to the balance sheet of all other banks with a positive net exposure to these assets. If the bank is not able to fulfill the capital requirement even after the sale of the assets, it defaults and its liabilities might not be repaid in full. Hence, contagion can spread in the banking system via both the credit channel due to losses on direct interbank exposures as well as the asset price channel due to exposure of banks to the same class of illiquid assets.

In addition to the analysis of idiosyncratic shocks, Elsinger et al. (2006) highlight the possibility of a common macroeconomic shock, which may cause simultaneous multiple bank defaults at the initial stage. A stronger initial shock might therefore also intensify the resulting contagion via interbank linkages. They assume various sources of macroeconomic shocks in the form of market risk (interest rate shock, exchange rate shock, stock market changes) or a credit risk event such as

[3] A major part of the credit lines might be blocked when the counterparty banks are already insolvent and/or illiquid.

[4] Iyer and Peydro-Alcalde (2010) empirically analyze the contagion via interbank linkages resulting from the failure of a large bank in the Indian banking sector. They find that banks with higher exposures to the failed bank experienced higher deposit withdrawals, confirming the potential for a bank run after a significant negative event even in the case of an idiosyncratic shock.

a downturn in the business cycle. Their findings suggest that the systemic risk resulting from the correlated exposures of banks is far more important than contagion itself due to defaults of other banks in the system and that contagion is a low-probability/high-impact event. Interbank contagion is also partially incorporated into the macro stress tests of the Czech banking system (Geršl and Seidler, 2012).

3. Data

The contagion analysis presented later in this paper is based on quarterly individual balance sheet and regulatory data taken from the CNB internal database. The dataset contains 22 periods within the time span Q1 2007–Q2 2012, where the data are reported as of the end of each quarter. The balance sheet data provide information on the simplified structure of banks' balance sheets, while the regulatory data concern regulatory capital and risk-weighted assets. Furthermore, we use a unique dataset on bilateral exposures between domestic banks, including direct interbank exposures in the form of interbank loans[5] as well as cross holdings of securities (shares and bonds issued by domestic banks, excluding mortgage bonds[6]). The data on interbank loans provide neither information on the maturity and seniority of interbank claims, nor a distinction between collateralized and uncollateralized lending. However, the survey by the CNB on daily interbank turnovers shows that most of the interbank lending is on an uncollateralized basis with up to one month maturity (Table 1).[7]

Off-balance sheet items such as derivatives and credit lines are not included in the interbank exposures due to a lack of data on a bilateral basis. Neglecting the off-balance sheet items, nevertheless, might not cause significant bias in the empirical results regarding the scope of interbank contagion in this case. Firstly, Czech banks are active in interest rate swaps and foreign exchange derivatives, but they do not trade in risky derivatives such as credit derivatives, hence the potential loss is represented by the small percentage of the nominal value of derivative contracts resulting from interest rate and exchange rate movements. Moreover, mutual netting of claims and liabilities from derivatives with any particular counterparty bank often applies, further decreasing the potential losses on derivatives transactions.[8] Secondly, the total credit lines received by domestic banks make up less than 1% of the banking sector balance sheet, indicating low dependence of the Czech banking sector on this source of liquidity.

[5] The data on interbank loans are assembled from quarterly reporting by domestic banks of the 15 largest loans to, and the 15 largest liabilities from, counterparty banks.

[6] The mortgage bonds issued by banks are considered to be well-secured liabilities which do not represent a potentially strong channel of interbank contagion. It would be reasonable to assume that mortgage bonds are an effective contagion channel when a shock to the mortgage segment is modeled. There might be some additional decrease in the value of mortgage bonds in the case of an inefficient bankruptcy and resolution procedure for failed banks issuing mortgage bonds.

[7] The Czech National Bank surveys average daily turnovers on the interbank market four times a year (in January, April, July, and October). The survey always lasts one week and covers interbank transactions in CZK only. Banks and branches of foreign banks having a banking licence in the Czech Republic and operating on the Czech interbank market take part in the survey.

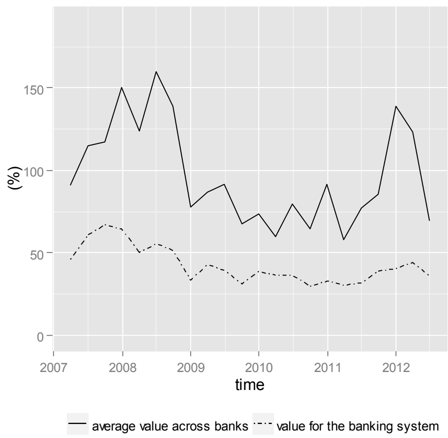
[8] The application of so-called master netting agreements.

Table 1: Turnover on the Interbank Market

Period	Uncollateralized		Collateralized	
	[O/N, 1M]	(1M, 12M]	[O/N, 1M]	(1M, 12M]
April 2008	74,761	2,407	0	0
April 2009	65,271	240	44	0
April 2010	42,068	785	3,728	287
April 2011	56,922	256	1,299	1,126
April 2012	52,424	412	5,435	430

Note: The table shows the average daily turnovers on the interbank market in CZK millions vis-à-vis both residents and non-residents.
Source: CNB

Figure 1: Domestic Interbank Exposures to Regulatory Capital



Note: The chart excludes branches of foreign banks since there is no capital in their balance sheets.
Source: Authors' computations.

The analysis in this paper is focused solely on the domestic interbank market. In order to model the impact of failure of foreign banks we would need data not only on the exposures of domestic banks to foreign banks, but also on the linkages between foreign banks. This information was not available.

Since some of the domestic banks in the Czech banking system are in a parent-subsidiary relationship, we assume that these banks do not operate independently, similarly to Wells (2004) and Mistrulli (2011). Therefore, we rely on the consolidated balance sheets of those parent banks rather than on balance sheets on solo basis from now on.[9] The consolidation leads to a decrease in the total number of banks from 44 to 40 as of June 2012 (Appendix A). The mutual exposures between the domestic parent bank and its domestic subsidiary are also cancelled out. The balance sheet consolidation implicitly embeds the assumption that credit risk losses are borne by the banking group as a whole and liquidity management is also undertaken on a group basis.[10]

The consolidation of the data leads to a significant decrease in the total value of domestic interbank lending, meaning that a significant part of the interbank lending comprises contracts between domestic parent banks and their domestic subsidiaries.[11] Total domestic interbank

[9] Balance sheet consolidation was applied to those banks in a parent-subsidiary relationship where the domestic parent bank holds more than 50% of the registered capital and more than 50% of the voting rights of the domestic subsidiary. Banks in such a relationship are supposed to have high incentives not to operate independently when a significant shock occurs. An alternative approach would be to apply consolidation also to all other domestic banks belonging to the same international financial group, which also creates an implicit relation between those domestic banks.

[10] All banks subjected to consolidation also create so-called regulated consolidated entities which have no limits on their mutual exposures according to the Czech banking regulation (Decree No. 123/2007 Coll.) supporting the reasonableness of the assumption of free liquidity management on a group basis.

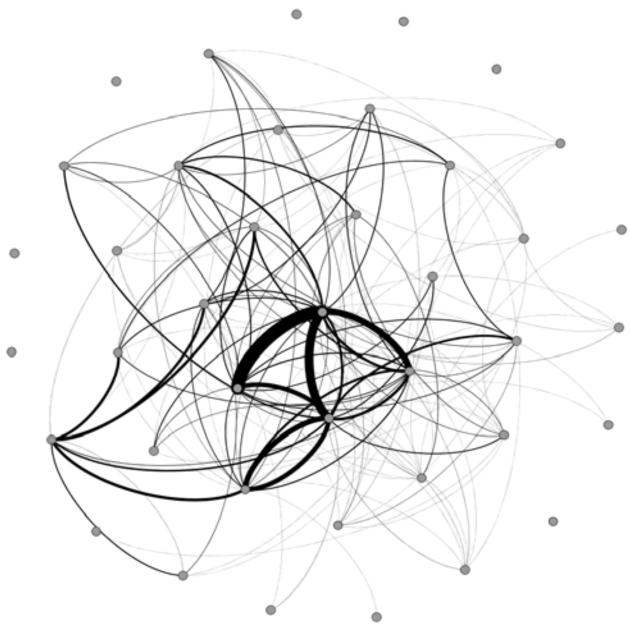
[11] The share of domestic interbank exposures in total banking sector assets is 2.7% on a consolidated basis and 6.4% on an unconsolidated basis.

exposures made up 36% of the regulatory capital of the banking sector on an aggregate consolidated basis as of June 2012 (Figure 1). They consisted mainly of interbank loans (83%) and less of cross holdings of securities (17%). Although the share of domestic interbank exposures of the banking sector is smaller than regulatory capital, the average ratio of interbank exposures to regulatory capital across banks exceeded 100% in some periods, leaving room for potential interbank contagion via credit channel.

4. Topology of the Czech Interbank Network

The aim of this chapter is to characterize the structure of the Czech interbank network and to describe its basic properties. The motivation to explore the interbank market topology stems from the recognition in the literature that the structure of the interbank market can significantly influence the probability and scope of contagion in the financial sector. Besides the network structure there are other factors, such as banks' balance sheet characteristics and regulatory "soundness", which are important with respect to contagion. Therefore, the structure of the interbank market can have different contagion consequences in different banking sectors. Nevertheless, network analysis is a useful tool for orienting oneself within interbank financial linkages, discovering the importance of individual banks, and acquiring a better understanding of the financial system per se.

Figure 2: Network Structure of the Czech banking system



Note: Network structure as of Q2 2012. The thickness of the link represents the absolute value of the interbank exposure. The grey dots are individual banks.
Source: Authors' computations

Theoretical studies usually deal with three types of networks, i.e., complete networks, incomplete networks, and a special type of incomplete networks with tiering. In the real world, complete structures are rather rare. Empirical studies often report that interbank networks have a scale-free topology (e.g., Boss et al, 2004; Cont et al., 2009). This is associated with the existence of very few banks with numerous interbank linkages in the network on the one hand, and many banks with few or no linkages on the other hand. Scale-free networks are vulnerable to disruptions affecting institutions that are central to the network, i.e., high-degree nodes are typically important and comprise large commercial banks highly connected within the network (Callaway et al., 2000). Identifying these central players can be important from the point of view of a macroprudential policy authority.

4.1. Structure of the Czech Banking Network

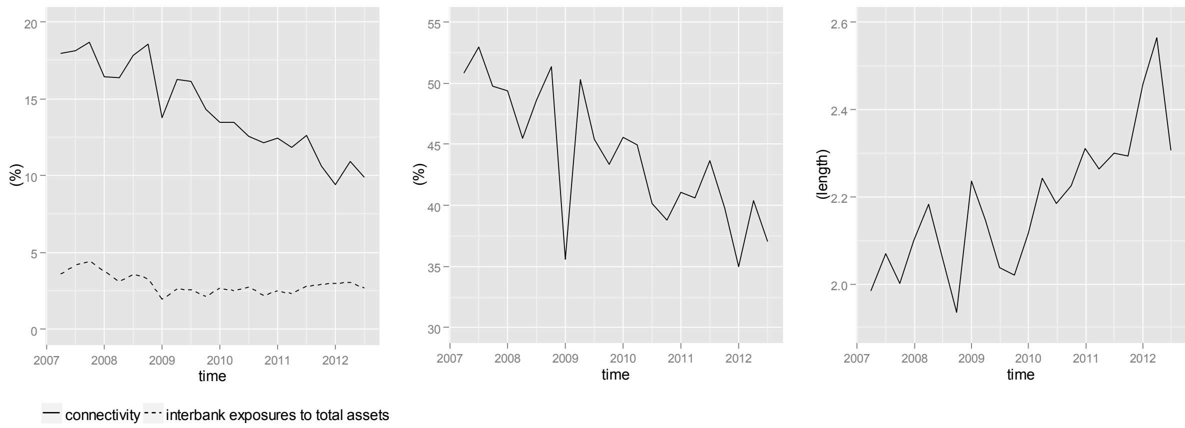
The structure of the interbank market can be examined with the aid of basic descriptive statistics used in the network analysis literature (connectivity, clustering coefficient, and average path length) as well as centrality measures (degree, betweenness, and eigenvector). The definitions and methods of calculation of these measures are described in Appendix B.

The number of nodes in the Czech interbank network varies between 31 and 40 banks (nodes) on a consolidated basis, which are connected via 152 links on average (Figure 2). The connectivity of the Czech interbank network is rather low – only 10% of all the potential links between banks had been created by the end of June 2012 (Figure 3a). The connectivity has been steadily decreasing over time, reflecting the onset of the global financial crisis, with a particularly significant drop at the end of 2008. Despite the continuing fall in interbank connectivity, the ratio of interbank exposures to total assets has been quite stable, suggesting increasing strength of the remaining interbank links (Figure 3a).

The clustering coefficient (*C*) follows similar pattern as connectivity, decreasing from its pre-crisis level of above 52% to 37% in June 2012, with a significant drop in September 2008 (Figure 3b). Clustering is approximately three times higher in the Czech banking system than in the Austrian interbank network (*C* = 12%; Boss et al., 2004).

Figure 3: Properties of the Interbank Network over Time

a) Connectivity of the network **b) Clustering coefficient** **c) Average path length**

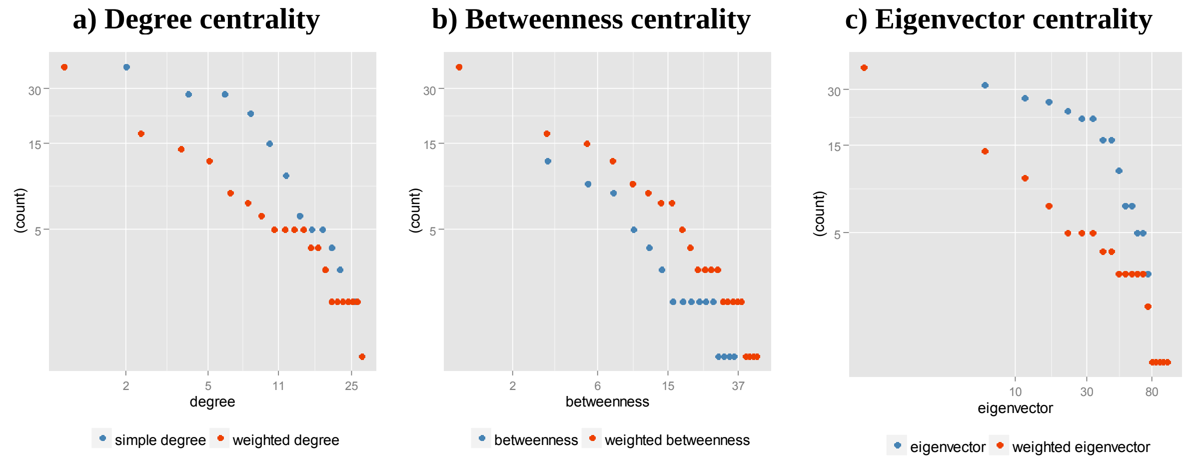


Source: Authors' computations

According to Figure 3c the average shortest path length (*APL*) has varied between 1.9 and 2.6. This result resembles the findings from empirical studies of the Austrian interbank network, where *APL* = 2.59 (Boss et al., 2004). A market structure with central institutions and peripheral institutions apparently leads to short interbank distances via the upper tier of the banking system. This so-called small-world property indicates that the network is structured such that the effective interconnectedness is relatively high despite the low number of links.

Network analysis includes tools to analyze the system from the micro-level point of view as well. The centrality measures refer to the importance of nodes or links in the network. These indices can help with identification of banks that qualify as banks posing a systemic risk to the system on their own. The centrality measures – degree, betweenness, and eigenvector centralities – have also been calculated in a weighted variant to reflect the strength of the links (values of exposures).

Figure 4: Cumulative Distribution of Interbank Network Centralities (Q2 2012)



Note: For scale-free networks $P(k) \approx c \cdot k^{-\alpha}$, i.e., centrality k is exponentially distributed. In a logarithmic plot of the cumulative distribution the observations should form an approximately straight line. Both axes have a logarithmic scale and the weighted alternatives were normalized to fit in the chart area.

Source: Authors' computations

The network analysis results reveal a highly heterogeneous interbank network, with several nodes being central throughout the period and many nodes being mostly on the periphery (Figure 2). The distribution of the centralities in the Czech interbank market network roughly follows power-law relationship with a time-varying exponent and can thus be referred to as a scale-free network (Figure 4).[12] Moreover, the four most interconnected banks in the network are often connected with each other, but unlike money center banks, they do not create full cycles.

Since network analysis does not control for many basic financial variables (such as solvency and liquidity indicators) there might be other important banks that have the potential to jeopardize the stability of the whole system. The findings above are thus further analyzed in the context of the results of more complex tools in Section 6.

[12] Since the number of observations is not sufficient for statistical estimation of the power-law coefficient, the scale-free property was derived from graphical representation of the cumulative degree distribution (Figure 4).

5. Model of Interbank Contagion

The resilience of the Czech banking system to interbank contagion is assessed within a model which takes into account the size and structure of interbank links as well as balance sheet and regulatory characteristics of each bank in the network. In general, the model comprises a population of n banks excluding the central bank.

The balance sheet structure of the banks is rather simplified. The assets comprise *cash and central bank balances (m)*, interbank exposures, *domestic government bonds (b)*, and *other external assets (s)*. The interbank exposures comprise *interbank loans (e)* and *cross holdings of securities (h)*, i.e. bonds and shares, excluding mortgage bonds issued by banks. The liability side is divided into *interbank liabilities (l)*, *capital (c)*, and *other liabilities (o)*. The banks can only incur losses from interbank exposures to resident banks. With respect to capital we operate in terms of regulatory capital rather than own capital. The analysis is based on three types of model corresponding to the three contagion channels assumed in the simulations, i.e., a *benchmark model* (credit channel), an *extended model A* (credit and liquidity channel), and an *extended model B* (credit, liquidity, and asset price channel).

In the *benchmark model*, we assume solely the credit contagion channel, where banks default due to credit losses on interbank exposures. In this setting, credit losses from interbank exposures are first absorbed by the current-year profit of the bank, and if that is not sufficient then the losses are deducted from the regulatory capital of the bank. A bank defaults whenever its capital adequacy ratio, defined as $\frac{capital}{risk\ weighted\ assets}$, falls below 1/3 of the regulatory minimum of 8%.[13] This condition is set according to the current regulatory framework in the Czech Republic. Furthermore, the model is based on the following assumptions:

- Interbank contagion occurs in the short run rather than in the long run. Since contagion can spread rapidly within the banking system, banks are unlikely to alter their behavior before they are affected, hence the network remains static within the monitored period. After being affected, banks are not allowed to raise additional capital in order to increase their capital adequacy ratio.

- LGD on interbank exposures is 100%. The reason for this extreme setting is threefold. Firstly, the interbank lending is mostly in the form of uncollateralized transactions. Secondly, the resolution procedure can take several months, influencing the time value of the interbank claim; bankruptcy costs also reduce the remaining value of the claim for creditors. Thirdly, we prefer to model the worst-case scenario in order to assess the resilience to less probable but plausible shocks.

- Netting of interbank exposures and interbank liabilities is not allowed in the model.

[13] The risk weight applied to interbank loans is 20%, which is consistent with the standardized approach to the calculation of capital requirements according to Decree No. 123/2007 Coll. Since bonds and shares do not account for a high proportion of total interbank exposures, we do not distinguish between these two types of assets with respect to the risk weight setting, and a common 50% risk weight is applied to both bonds and shares for simplification.

- Branches of foreign banks can serve as a source of shocks, but they are never shock transmitters in the model since they cannot fail for solvency reasons (as they do not have their own capital) or due to illiquidity.[14]

In the *extended model A*, the failure of a bank in the system is possible for both solvency and liquidity reasons, similarly to Müller (2006). The solvency condition is unchanged from the *benchmark model*. The bank *i* is assumed to be illiquid when $(m_i + (1 - k_i)e_i + b_i) < l_i$, where k_i represents the fraction of total interbank claims of bank *i* which are impaired, i.e., some of the counterparties of bank *i* failed to repay their interbank liabilities. This condition does not include other expected cash inflows and outflows connected to balance sheet items other than interbank claims and liabilities in the short run. Moreover, government bonds are assumed to be high-quality and liquid assets that can be exchanged for cash without any price discount.[15] This setting describes the situation where the Czech government bond market is highly liquid and/or Czech government bonds are eligible collateral in liquidity-providing repo operations with the Czech National Bank.[16] Also, the current Basel II regulation assigns domestic government bonds a 0% risk weight in the capital requirement calculation according to the standardized approach, which is normally used for high-quality and liquid assets.[17]

Instead, in the *extended model B* we assume that government bonds are no longer liquid assets. This assumption reduces the liquidity buffers held by banks. Moreover, bonds cannot be exchanged for cash without a price discount in the market. Instead, banks selling government bonds in the market face inelastic demand for government bonds, leading to a decrease in government bond prices depending on the amount of such bonds being sold in the market. The inelasticity of the demand can be associated with insufficient liquidity of the government bond market in any stress conditions. Such a setting is a theoretical exercise showing how the interbank contagion would change if government bonds were no longer liquid assets due to market illiquidity and/or central bank collateral policy and is inspired by the following facts:

- Czech banks have non-negligible exposure to domestic government securities. This exposure increased significantly during the crisis, from 9% in September 2008 to 16% in June 2012. Effects such as flight to quality and home bias might have contributed to this increase, as might the search for alternative investment opportunities due to the decrease in demand for credit from the real economy.

- The preferential treatment of Czech government bonds under Basel II (the 0% risk weight) might underestimate the credit risk of domestic government securities.

[14] The advantages to a foreign bank of setting up a branch instead of a subsidiary in the Czech Republic include free liquidity management at the banking group level.

[15] Mortgage bonds, although assumed to be assets of good quality, are not included in the liquidity buffer of Czech banks, as the liquidity of the mortgage bond market is rather low.

[16] Czech government securities such as short-term Treasury notes and government bonds are currently eligible collateral accepted by the Czech National Bank. The liquidity-providing operations were introduced in reaction to the global financial crisis and have been active since October 2008. Until then, the Czech National Bank only performed liquidity-absorbing open market operations due to excess liquidity in the Czech banking system.

[17] The preferential 0% risk weight on Czech government bonds is applicable since Czech banks use CZK to finance these assets. Normally, a 20% risk weight should be applied given the current rating of Czech government debt.

- The government debt is held mainly by domestic financial institutions, which reduces the potential number of counterparties in the government bond market (CNB, 2012).

- The relative shallowness of the domestic bond market was demonstrated in the crisis (CNB, 2012).

Banks enter the government bond market whenever they face liquidity problems, i.e., when $(m_i + (1 - k_i)e_i) < l_i$. If there are sufficiently large sales of government bonds by domestic bank(s) in the market, the market price of government bonds is likely to decrease. This would have the following consequences. Firstly, it would cause revaluation of government debt securities in the balance sheets of those banks exposed to government debt.[18] The scope of the revaluation depends on the intensity of the market stress. Secondly, the inelastic demand reduces the probability that banks in liquidity problems will fulfil the liquidity condition after the sale of government bonds.

The market prices of government bonds are assumed to be determined by an inverse demand function in the form[19]

$$p = e^{\left(-\varepsilon \sum_{i=1}^{l} s_i\right)} \tag{1}$$

where l is the number of banks supplying bonds at a given moment, s_i stands for the supply of individual banks, and ε denotes the elasticity parameter. The elasticity of demand is set arbitrarily so that bond prices will decrease by half if 10% of the total government bond holdings of the whole banking system are sold on the market. Market prices converge in a tâtonnement process to a new equilibrium reflecting the demand for these assets, which is assumed to be less than perfectly elastic ($\varepsilon > 0$).[20]

If the amount of cash raised by banks via the sale of government bonds is not sufficient to fulfill the liquidity condition, the banks default for liquidity reasons. They can also fail due to losses from revaluation of government bonds in their balance sheets. The important feature of the model is that the revaluation losses influence all banks with exposures to government bonds, not only those facing liquidity problems.

In our analysis, we assume both *idiosyncratic shocks*, i.e., the failure of individual banks, and a distribution of losses resulting from *multiple bank failures*. We do not assign probabilities to the individual scenarios, since we aim to explore the characteristics of the interbank network with respect to the propensity to spread contagion and not to assess the likelihood of particular

[18] Mark-to-market accounting is applied to the government bond portfolios in bank balance sheets, resulting in revaluation of these assets according to market movements. Such an approach is in line with the economic value of these assets rather than with their accounting value, which seems to be more conservative.

[19] The demand function in this form is commonly used for modeling the asset price channel (e.g., Cifuentes et al., 2005; Nier et al., 2007; Bluhm and Krahnen, 2011).

[20] Consistent with the existing literature (Cifuentes et al., 2005; Bluhm and Krahnen, 2011), the term elasticity of demand in this context relates to quantity (derived from the inverse demand function above) and should not be confused with price elasticity, i.e., inelastic demand means that a large price discount is needed to increase the quantity demanded. The role of the elasticity parameter ε is crucial in the contagion analysis. In our case the setting of the parameter is rather conservative, i.e., rather more intensive stress on the government bond market is assumed.

scenarios. This was motivated by the nature of our analysis, which involves stress testing rather than estimating the most probable cases.

Although it would be more realistic to assume additional symptoms of systemic distress, such as bank runs and other informal channels of contagion, we do not include these channels in the analysis in order to keep the model parsimonious.

The model is quantified in an iterative computational simulation where any bank can default due to contagion as a result of counterparty credit losses, balance sheet illiquidity or losses from revaluation of government bonds. There are two input parameters in the simulation. First, a vector of banks that are arbitrarily assumed to fail at the start of the simulation determines the severity of the initial shock to the banking system. The whole space of initial shocks consists of 2^n vectors – the number of all possible combinations of banks under consideration. Second, the elasticity parameter ε determines how important the asset price channel is. The less elastic the demand for government bonds, the lower the resulting equilibrium price every time banks enter the bond market.

If we define

S as the set of banks hit by the initial shock,

R as the set of surviving banks,

N as all the banks in the network,

a_i as the total assets of bank i,

then the initial arbitrary shock can be expressed as

$$shock = \frac{\sum_{i \in S} a_i}{\sum_{i \in N} a_i}$$

and the *contagion* is defined as the ratio of the losses due to the initial shock to the value of the total assets remaining after the initial shock, while the losses due to the initial shock are computed as the difference between the total assets remaining after the initial shock and the total assets after the contagion simulation:

$$contagion = \frac{\sum_{i \in N} a_i - \sum_{i \in S} a_i - \sum_{i \in R} a_i}{\sum_{i \in N} a_i - \sum_{i \in S} a_i} .$$

The modelled banking system is classified as stable when no bank fails in the two subsequent iterations and there is no bank in liquidity stress at the same time. Details of a single iteration within the simulation procedure can be found in Appendix C.

6. Results and Discussion

This chapter presents the results of simulations aiming at detecting the potential for contagion in the Czech banking system and shows its evolution over time. The analysis incorporates three contagion channels, i.e., a credit channel, a liquidity channel, and an asset price channel. The discussion of the results is divided into two separate parts. Firstly, we focus on contagion due to idiosyncratic shocks. Secondly, we assume failures of multiple banks.

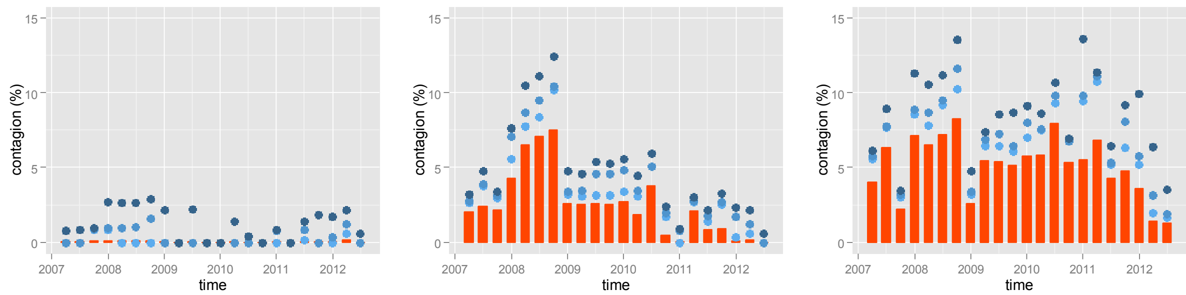
6.1 Simulation of the Idiosyncratic Shock

The simulation of the impact of the idiosyncratic shock was performed for every quarter separately over the period Q1 2007–Q2 2012. The overall results are plotted in Figure 5 and Figure 6, where the average contagion and the three worst-case scenarios for each period are presented.

Benchmark model: In the *benchmark model* only the credit channel is considered. The Czech banking system is resilient to contagion via mutual interbank credit exposures. The contagion resulting from the initial shock is smaller than 3% even in the worst-case scenarios and has decreased over time. Up to two banks failed due to interbank contagion via the credit channel. The higher resilience of the system has been driven by an increase in the regulatory capital of the Czech banking system in recent years.

Figure 5: Contagion Losses Relative to Potential Losses

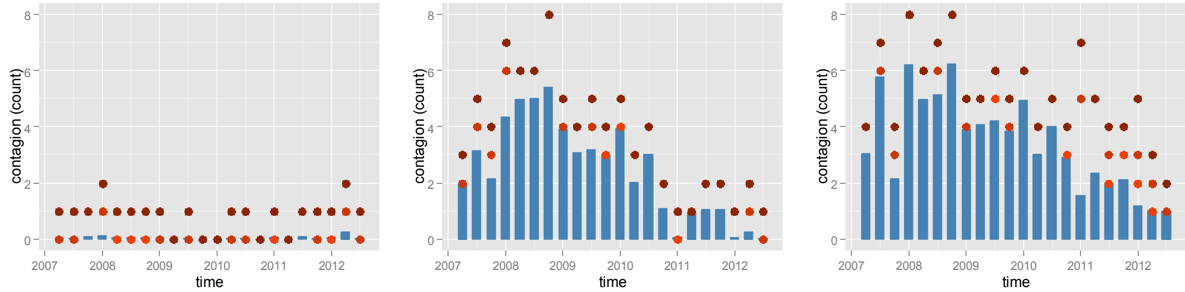
Benchmark model	**Extended model A**	**Extended model B**
Credit channel	**Credit and liquidity channel** (elastic demand function)	**Credit and liquidity channel** (inelastic demand function)



Note: The red bars represent the average contagion and the blue dots are the three worst-case scenarios, i.e., the scenarios with the worst contagion impact (y-axis).
Source: Authors' computations

Figure 6: Number of Failed Banks due to Contagion

Benchmark model	**Extended model A**	**Extended model B**
Credit channel	**Credit and liquidity channel** (elastic demand function)	**Credit and liquidity channel** (inelastic demand function)



Note: The blue bars represent the average contagion and the red dots are the three worst-case scenarios, i.e., the scenarios with the worst contagion impact (y-axis).
Source: Authors' computations

The relationship between the market topology and the potential for contagion losses is expected to be close. Banks that are "central" to the network are supposed to cause higher losses than banks on the periphery. The propensity to spread contagion can be best approximated by eigenvector centrality given its correlation with contagion losses of 0.42 for the pre-crisis period, although the values for other centralities are similar (Table 2). The crisis period is characterized by rather low correlations of contagion losses regarding all types of centralities, as the potential for contagion is negligible in that period compared to the already low pre-crisis values.

Table 2: Correlation of Centralities with Contagion Losses

	Degree	**In-degree**	**Betweenness**	**Eigenvector**
Contagion losses (Q1 2007–Q3 2008)	0.39	0.37	0.41	0.42
Contagion losses (Q1 2009–Q2 2012)	0.23	0.34	0.21	0.23

Note: The centralities were considered in weighted form, where the weights are the interbank exposures of each bank included in the simulation. In-degree measures the importance of a bank as a borrower.
Source: Authors' computations

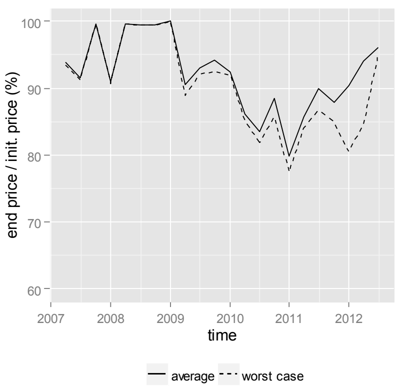
Extended model A: In comparison to the *benchmark model*, the *extended model A* supplements the credit channel with a liquidity channel. In this setting we assume that government bonds are high-quality and liquid assets that can be exchanged for cash without any price discount.

The introduction of the liquidity condition resulted in an increase in contagion losses. The effect of contagion increased in the pre-crisis period, peaking in Q3 2008. This peak was characterized by the number of banks not fulfilling the liquidity condition, with eight banks – accounting for 12.5% of the remaining banking sector assets – failing due to contagion in the worst-case scenario. In the crisis period, the potential for interbank contagion remained stable, with the average losses up to 3.8% and the worst-case losses up to 6%. The observations for recent years show a significant decline in contagion risk. This is supported by the fact that Czech banks improved their liquidity position by increasing their holdings of government bonds, which are considered to be highly liquid assets in this model setting.

Extended model B: In addition to the credit risk and liquidity channel, an asset price channel is included in the simulations in the *extended model B*, where domestic government bonds are no longer assumed to be liquid assets. Banks have the opportunity to sell domestic government bonds on the market when facing liquidity problems. However, they face less than perfectly elastic demand for domestic government bonds.

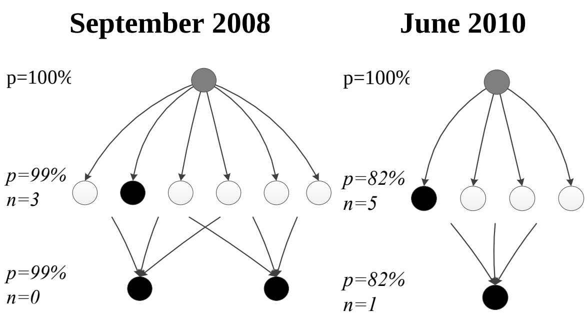
As expected, adding the asset price channel increased the interconnectedness of the banking sector via common exposures to government bonds and contributed to the intensification of contagion losses in some periods. Up to five banks used the option to sell government bonds to improve their own liquidity position in the simulations. Their perfectly rational individual actions depressed the market price of government bonds and thus indirectly affected other banks' assets. The biggest price drop was observed in Q4 2010, when the price of government bonds decreased by more than 20 pp (Figure 7).

Figure 7: Stress on the Domestic Government Bond Market



Note: End price represents the new market price of government bonds after all rounds of contagion for the average as well as the worst-case scenario. The new market price is expressed as a percentage of the initial government bond price as initially taken from banks' balance sheets.
Source: Authors' computations

Figure 8: Illustration of Contagion in the Extended Model B



Note: Black points represent banks that failed in given iteration for solvency reasons, while white points indicate failure to meet the liquidity condition. p stands for the resulting market price after the sale of government bonds by n banks in a given iteration.
Source: Authors' computations

Figure 8 shows detailed information about the simulations in two periods with non-negligible contagion, i.e., September 2008 and June 2010. The evolution of contagion in these two periods differs. The contagion in the worst-case scenario in September 2008 occurred within two iterations, with six banks failing in the first iteration and two banks in the second one (Figure 8, left). A total of three banks were selling government bonds in the simulation. In contrast to September 2008, only five banks failed in the worst-case scenario in June 2010 (Figure 8, right). In this period, five banks had to place part of their government bond holdings on the market, and one of them entered the market repeatedly. This caused the market price to drop by 18 pp, a significantly larger decline than that observed in September 2008 (less than 1 pp).

6.2 Simulation of Multiple Bank Failures

Instead of assuming an individual bank failure, we move to scenarios where multiple banks were assumed to fail in the first step. For each analyzed period, a random sample of 5,000 shocks[21] was processed in simulations which produced the distribution of the potential losses in that period. For the purposes of this paper, we narrow our focus to two particular periods – September 2008 and June 2010 – in order to decrease the number of output charts. The period choice was based on the previous analysis of idiosyncratic shocks. September 2008 was revealed as the most contagious period, and June 2010 was identified as a period with a significant recent contagion effect.

Figure 9 presents the results in four dimensions: the initial shock in terms of the total assets of banks failing in the first step (x-axis); the initial shock in terms of the number of failed banks (colour of bubbles); *contagion* (y-axis); and the end price on the government bond market (radius of bubbles). The area toward the upper left corner of the charts in Figure 9 represents the most severe scenarios posing a threat to the resilience of the Czech banking sector. Within this area, large contagion losses (upper on the vertical axis) would be caused by relatively small shocks in terms of initially failed assets (left on the horizontal axis). Moreover, the light blue dots upper in the chart represent results where the failure of one or very few banks would have caused significant contagious losses.[22] The dark blue dots represent scenarios with a large number of initial defaults and hence rather less likely scenarios.

In the setting of the *benchmark model*, the contagion losses were significantly lower on average in June 2010 compared to September 2008. Even an extremely large initial shock did not wipe out all the remaining banking assets in June 2010 in comparison to September 2008. The inclusion of the liquidity condition in the *extended model A* increased the contagion losses and moved the whole distribution of contagion losses up and to the left. Hence, the contagion losses increased in both periods, but higher potential for contagion was observed again in September 2008.

In most of the scenarios, the Czech banking system was noticeably more prone to contagion when the asset price channel started to be active in the *extended model B*, especially during the crisis period. Due to sales of government bonds on the illiquid market, the initial shock caused the model to converge to a new set of solutions in June 2010 (dashed ellipse). The separate cluster of observations toward the upper left corner represents model solutions where government prices iteratively decreased by up to 20 pp, which resulted in higher contagion losses. Such distinct model solutions emerged in a few other periods as well. To reach 50% *contagion*, in general at least 75% of total banking sector assets must have been hit by the initial shock (Figure 9).

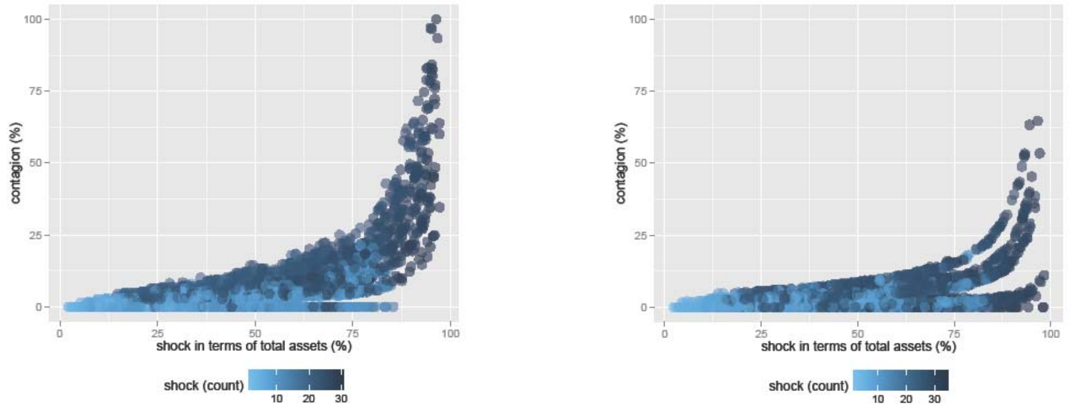
[21] In total, there are 2^N possible combinations of bank failures. For technical reasons we considered all branches of foreign banks to fail together, which allowed us to reduce N to approximately 20.

[22] Note that the sample of 5,000 out of 2^N simulations, where N is about 20, may not include all relevant shocks important for finding systemically important (groups of) banks, i.e., scenarios with the failure of a small number of banks that may have significant contagious potential. Such simulations can be processed separately.

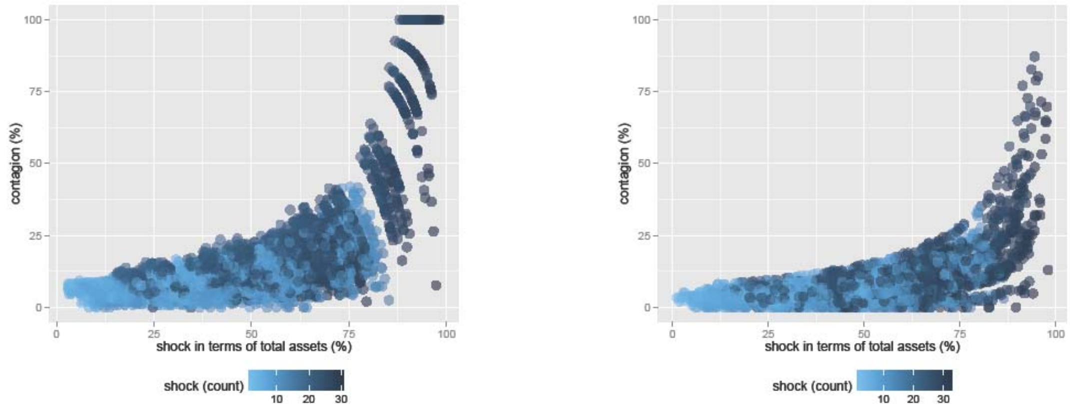
Figure 9: Distribution of Contagious Losses Caused by Multiple Bank Failures

September 2008 **June 2010**

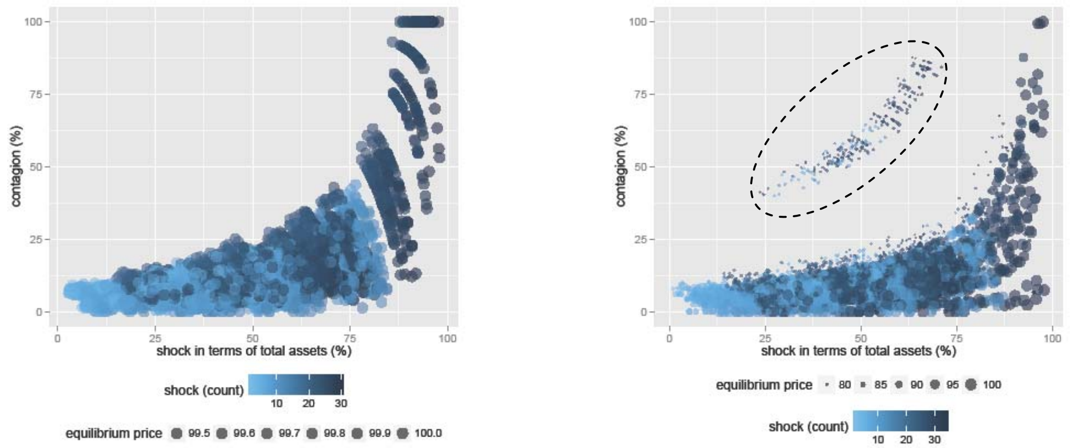
Benchmark model: Credit channel



Extended model A: Credit and liquidity channel (elastic demand function)



Extended model B: Credit and liquidity channel (inelastic demand function)



Note: The x-axis represents the initial shock to the total assets of the banking system due to the failure of randomly selected banks. The resulting contagion losses are depicted on the y-axis. A lighter blue means that the initial shock was caused by a smaller number of banks, while a darker colour indicates an increasing number of defaulted banks in the initial shock. The smaller is the size of a bubble, the lower are government bond prices at the end of the simulation, i.e., the more intensive is the stress on the government bond market. The plots are based on results from a random sample of 5,000 simulations.

Source: Authors' computations

7. Conclusion

Our analysis of interbank contagion within the Czech banking system examined the systemic risk associated with the financial interconnectedness of Czech banks. The period in focus starts in March 2007, i.e., prior to the onset of the global financial crisis, and ends in June 2012. We made use of two standard techniques to assess the resilience of the Czech banking system to contagion.

Firstly, network analysis explores the sparse and heterogeneous structure of the Czech interbank market. The connectivity of banks has been decreasing, while the share of interbank exposures relative to the total balance sheet of Czech banks has been relatively stable over time. Centrality measures used as proxies for individual bank importance in the network, i.e., degree, betweenness, and eigenvector, show that there are a few bigger banks that are important for the system and many relatively small banks on the periphery of the system.

Knowledge of the network structure is not sufficient to assess the vulnerability of the banking system to contagion, since it does not allow us to control for other important features of the banking sector, such as its capitalization and liquidity. Hence, a simulation approach was employed to address these financial issues.

Secondly, using three alternative versions of the model which successively introduce individual contagion channels, i.e., a credit channel, a liquidity channel, and an asset price channel, we simulate failures of individual as well as multiple banks. The simulation results of the initial idiosyncratic shock indicate that contagion due to solely credit losses on interbank exposures was very low over the period in focus. This contagion was smaller than 3% of the remaining banking sector assets and affected no more than two banks even in the worst-case scenarios. Introducing the liquidity condition into the model increases the contagion impact. The average contagion affected less than 3.8% of the remaining banking sector assets, with the exception of the period from December 2007 to September 2008. Furthermore, the simulation results for both idiosyncratic and initial multiple bank failure shocks suggest that the potential for contagion in the Czech banking system has decreased since the onset of the global financial crisis.

Moreover, we focused on scenarios where government bonds – otherwise assumed to be high-quality and liquid assets – would no longer be perfectly liquid assets. This theoretical exercise is inspired by the fact that the exposure of Czech banks to government debt is significant and that the relative shallowness of the domestic bond market was demonstrated in the crisis. In this setting, the potential for contagion significantly increases in the Czech banking system. The results suggest that activation of the asset price channel further increases the losses due to interbank contagion, showing that liquidity of government bonds would be essential for the stability of Czech banks in stress situations.

Based on the results of our model simulations, we conclude that systemic risk in the form of interbank contagion is rather limited in the Czech banking system. Nevertheless, there might be additional complementary channels, such as bank runs and other informal channels, intensifying the risks and losses from contagion which were not captured in the analysis.

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Appendix A: List of Banks Included in the Analysis

BANIS	Name	Q1 2007	Q2 2007	Q3 2007	Q4 2007	Q1 2008	Q2 2008	Q3 2008	Q4 2008	Q1 2009	Q2 2009	Q3 2009	Q4 2009	Q1 2010	Q2 2010	Q3 2010	Q4 2010	Q1 2011	Q2 2011	Q3 2011	Q4 2011	Q1 2012	Q2 2012
100	Komerční banka																						
300	ČSOB																						
400	Živnostenská banka																						
600	GE Money Bank																						
800	Česká spořitelna																						
2010	Fio banka																						
2020	Bank of Tokyo-Mitsubishi																						
2100	Hypoteční banka																						
2210	Evropsko-ruská banka																						
2230	AXA Bank Europe																						
2310	ZUNO BANK AG																						
2240	Poštová banka																						
2400	eBanka																						
2600	Citibank Europe																						
2700	UniCredit Bank																						
3030	Air Bank																						
3500	ING Bank																						
4000	LBBW Bank CZ																						
4300	Čm. záruční a rozvojová banka																						
5000	Credit Agricole S.A.																						
5400	The Royal Bank of Scotland N.V.																						
5500	Raiffeisenbank																						
5800	J&T Banka																						
6000	PPF banka																						
6100	Equa bank																						
6200	COMMERZBANK																						
6210	BRE Bank																						
6300	Fortis Bank																						
6700	Všeobecná úvěrová banka																						
6800	Volksbank																						
7910	Deutsche Bank																						
7940	Waldviertler Sparkasse																						
7950	Raiffeisen stav. spořitelna																						
7960	Čm. stav. spořitelna																						
7970	Wüstenrot stav. spořitelna																						
7980	Wüstenrot hypoteční banka																						
7990	Modrá pyramida stavební spořitelna																						
8030	Raiffeisenbank im Stiftland																						
8040	Oberbank																						
8060	Stav. spořitelna ČS																						
8070	HYPO-stav. spořitelna																						
8090	Česká exportní banka																						
8150	HSBC Bank																						
8200	PRIVAT BANK AG																						
8211	Saxo Bank A/S																						
8221	Volksbank Löbau-Zittau																						
8231	Bank Gutmann																						
	Total number of banks (unconsolidated)	**37**	**37**	**37**	**37**	**37**	**37**	**36**	**35**	**36**	**36**	**36**	**38**	**39**	**40**	**40**	**40**	**40**	**41**	**43**	**44**	**44**	**44**
	Total number of banks (consolidated)	**32**	**32**	**32**	**32**	**33**	**33**	**32**	**31**	**32**	**32**	**32**	**34**	**35**	**36**	**36**	**36**	**36**	**37**	**39**	**40**	**40**	**40**

banks subjected to consolidation

other banks included in the analysis

Note: Balance sheet consolidation was applied to those banks in a parent-subsidiary relationship where the domestic parent bank holds more than 50% of the registered capital and more than 50% of the voting rights of the domestic subsidiary. Banks are identified primarily by their BANIS code. The bank names are as of June 2012.

Appendix B: Selected Indicators from Network Analysis

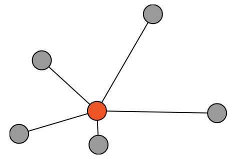
Basic properties of the network

The network is defined by an *adjacency matrix,* a square matrix $A = a_{ij}$, where a_{ij} represents the link (exposure) from node *i* to node *j*. The diagonal of the matrix is assumed to be a zero vector.

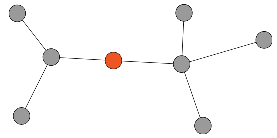
- **Connectivity (density)** represents the unconditional probability that two banks have a link between each other and describes the density relative to the potential complete network. The connectivity is calculated as the ratio of actual links to all potential links and thus ranges between zero and one (Freeman, 1978).
- **Clustering coefficient (transitivity**) represents the probability that two banks having a link to a third bank also have a link to each other (Watts and Strogatz, 1998).
- **Shortest path (distance)** is solved by an algorithm searching for the optimal solution of the minimum path between banks. For weighted networks the length of the path is equal to the sum of the inverse values of the links on the path (Dijkstra, 1959; Freeman, 1978).

Centrality measures

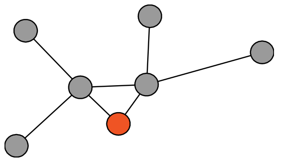
1. **Degree centrality**, σ_D, counts the number of links coming into or out of a node (in-degree, out-degree). Degree centrality takes into account only the local structure around the node (Freeman, 1978).

	$\sigma_D(x) = \sum_{i=1}^{n} (1 \; if \; (a_{ix} \neq 0))$	

2. **Betweenness centrality**, σ_B, measures the number of shortest paths in a network that go through the node. The node is more central if a higher number of paths go through the node (Freeman, 1978).

	$\sigma_B(x) = \sum_{i=1, i \neq x}^{n} \sum_{j=1, j<i, j \neq x}^{n} \frac{g_{ij}(x)}{g_{ij}}$	g_{ij} represents the number of shortest paths from node i to node j. $g_{ij}(x)$ describes the number of those paths that go through node x.

3. **Eigenvector centrality,** σ_E, is based on the fact that a relationship to a more interconnected node contributes to the own centrality to a greater extent than a relationship to a less interconnected node (Bonacich and Lloyd, 2001). The advantage of eigenvectors lies in taking into account the environment of the whole network.

	$\sigma_E(x) = v_x = \frac{1}{\lambda_{\max}(A)} \cdot \sum_{j=1}^{n} a_{jx} \cdot v_j$	$v = (v_{1,\ldots\ldots,} v_n)^T$ refers to the eigenvector for the maximum eigenvalue $\lambda_{\max}(A)$ of the adjacency matrix A.

Appendix C: Iterations of the Simulation Procedure

Benchmark model

STEP 0: Arbitrarily chosen bank(s) is/are classified as insolvent.

STEP 1: SINGLE ITERATION
STEP 2: Losses from exposures to bank(s) that failed in steps 0 or 4 are recognized by exposed banks.
STEP 3: The new capital adequacy ratio is calculated. Regulatory capital and risk-weighted assets are adjusted for losses resulting from interbank exposures.
STEP 4: A bank with CAR < 8/3 is classified as insolvent and defaults due to insolvency.
STEP 5: If the number of insolvent banks has changed since the previous iteration go to STEP 1, otherwise end.

Extended model A

STEP 0: Arbitrarily chosen bank(s) is/are classified as insolvent.

STEP 1: SINGLE ITERATION
STEP 2: Losses from exposures to bank(s) that failed in steps 0, 4 or 6 are recognized by exposed banks.
STEP 3: The liquidity condition $(m_i + (1-k_i)e_i + b_i) < l_i$ is evaluated and the liquidity gap, i.e., the gap between current liquidity $(m_i + (1-k_i)e_i + b_i)$ and needed liquidity l_i is calculated.
STEP 4: If the bank does not satisfy the liquidity condition it is classified as illiquid and defaults due to illiquidity.
STEP 5: The new capital adequacy ratio is calculated. Regulatory capital and risk-weighted assets are adjusted for losses resulting from interbank exposures.
STEP 6: A bank with CAR < 8/3 is classified as insolvent and defaults due to insolvency.
STEP 7: If the number of insolvent banks has changed since the previous iteration or any solvent bank does not satisfy the liquidity condition go to STEP 1, otherwise end.

Extended model B

STEP 0: Arbitrarily chosen bank(s) is/are classified as insolvent.

STEP 1: SINGLE ITERATION
STEP 2: Losses from exposures to bank(s) that failed in steps 0, 7 or 10 are recognized by exposed banks.
STEP 3: The new capital adequacy ratio is calculated. Regulatory capital and risk-weighted assets are adjusted for losses resulting from interbank exposures.
STEP 4: A bank with CAR < 8/3 is classified as insolvent and defaults due to insolvency.
STEP 5: The liquidity condition $\left(m_i + (1-k_i)e_i\right) < l_i$ is evaluated and the liquidity gap, i.e., the gap between current liquidity $\left(m_i + (1-k_i)e_i\right)$ and needed liquidity l_i is calculated.
STEP 6: If the condition is not satisfied the illiquid but solvent bank enters the market and tries to sell government bonds in order to close the liquidity gap.
STEP 7: If the bank still does not satisfy the liquidity condition it is classified as illiquid and defaults due to illiquidity.
STEP 8: All banks in the system revalue the government bonds in their balance sheets according to current market prices of government bonds.
STEP 9: The new capital adequacy ratio is calculated. Regulatory capital and risk-weighted assets are adjusted for losses resulting from holdings of government bonds.
STEP 10: A bank with CAR < 8/3 is classified as insolvent and defaults due to insolvency.
STEP 11: If the number of insolvent banks has changed since the previous iteration or any solvent bank does not satisfy the liquidity condition go to STEP 1, otherwise end.

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