CONTINGENT CLAIMS ANALYSIS AND THE INTER-SECTOR TRANSMISSION OF CREDIT RISK

Miroslav Plašil and Ivana Kubicová

The purpose of this article is to contribute to the modelling of the cross-sectional dimension of systemic risk. First, the network of financial linkages in the Czech economy is mapped and then a model of inter-sector transmission of financial contagion is presented. The model is used to quantify the results of two different risk scenarios. It is demonstrated that mutual exposures can amplify the consequences of negative shocks at times of increased financial stress. The magnitude of those consequences depends on which sector is primarily hit by the shock

1. INTRODUCTION

The financial crisis has shown that the consequences of financial turmoil can be fully quantified only in an environment in which the individual components of the system are explicitly analysed for their interrelations and interactions in addition to their financial soundness. The financial links between economic agents are a source of systemic risk commonly referred to as the *cross-sectional* dimension (for more details see Frait and Komárková, 2011). Analysis of the links between economic sectors fosters a better understanding of the process of contagion across the economy and helps to reveal potential weak spots in the system. The increasing strength of inter-sector exposures on the one hand creates the infrastructure necessary for further financial development and economic growth, but on the other hand can make the economic system more vulnerable, especially in the event of increased financial stress. In adverse conditions, inter-sector linkages generally contribute to the spread of contagion across the economy and amplify the direct impacts of risks that materialise.

This article sets out to describe the features of the Czech economy from the perspective of the cross-sectional dimension of systemic risk and to present a formalised approach to modelling inter-sector contagion via financial linkages. The model proposed in Castrén and Kavonius (2009) and extended in Silva (2010) is used to this end. This approach combines the analysis of the *network* of financial exposures with sector-level contingent claims analysis (CCA), which is used to assess credit risk. Although the model is based on several overly strong assumptions (see below), it is a useful tool for describing the propagation of the initial shock and quantifying the economic impacts on sectors hit directly or indirectly by the shock.

The article is divided into three sections. Section 2 examines the basic features of the Czech economy in terms of inter-sector financial exposures. Section 3 describes the CCA method and presents the model, which is used to simulate the impacts of various types of negative shocks. Section 4 summarises the results and briefly assesses the limitations and the power of the model.

2. INTER-SECTOR FINANCIAL LINKAGES IN THE CZECH ECONOMY

In the course of their activities, economic agents enter into financial relations with other agents and thereby form a *network* of financial linkages. To describe the structure of the network sensibly, it is first necessary to simplify it somewhat and to group agents with similar types of economic behaviour into larger units, or sectors. The network of financial linkages between sectors is fully specified if the magnitude of all the bilateral exposures between them is known. The system of interlinkages can be expressed in matrix notation as:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1S} \\ x_{21} & \ddots & & x_{2S} \\ \vdots & & \ddots & \vdots \\ x_{S1} & x_{S2} & \cdots & x_{SS} \end{bmatrix}, \quad \sum_{j=1}^{S} x_{ij} = P_i \text{ and } \sum_{j=1}^{S} x_{ij} = A_j \qquad (1)$$

where elements x_{ij} represent the magnitude of the exposures between the debtor's sector i and the creditor's sector j.[1] The row sums P_i correspond to the total liabilities of sector i to all creditor sectors (the liability side), and the column sums A_j correspond to the total financial assets of sector j regardless of the debtor's sector (the asset side). The text below considers the financial linkages between

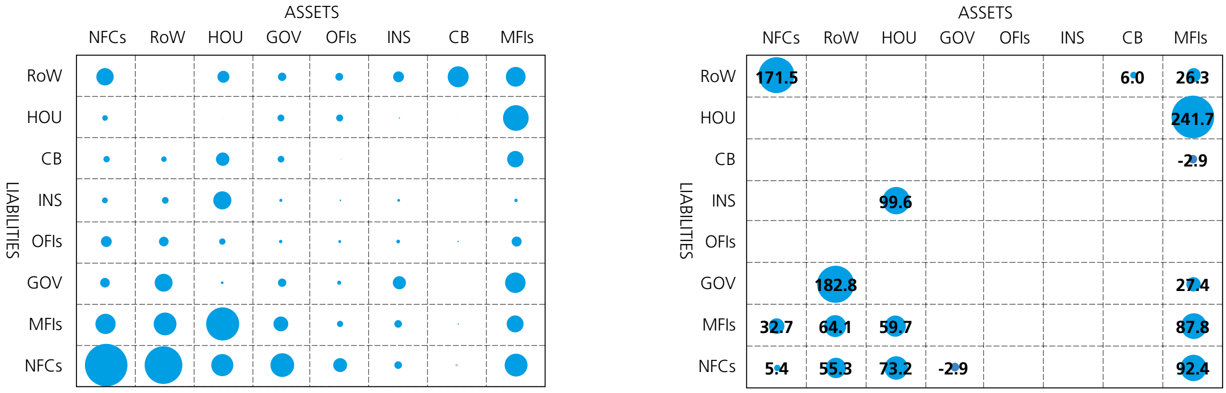
1 The relationship between the two sectors is not symmetrical with regard to financial assets and liabilities. If one sector is a major creditor of another sector, it does not mean that it is also its debtor in the same amount.

CHART 1

INTER-SECTOR FINANCIAL LINKAGES IN THE CZECH ECONOMY

a) Inter-sector financial exposure levels
(2011 2Q)

b) Exposure dynamics 2004 Q4–2011 Q2
(in %)



CB Central bank
MFIs Monetary financial institutions
INS Ins. companies and pen. funds
OFIs Other fin. intermediaries
NFCs Non-fin. corporations
HOU Households
GOV General government
RoW Rest of the world

Source: Quarterly financial accounts (CNB), authors' calculations
Note: The size of the bubble corresponds to the strength of the financial linkage between the creditor sector in the column and the debtor sector in the row. So, for example, the figure in the last column (MFIs) and the second row (HOU) corresponds to the total amount that households owe banks (most often as loans).

the following eight sectors: the central bank, monetary financial institutions[2] (banks, money market funds and credit unions), insurance companies and pension funds, other financial intermediaries (other financial institutions not mentioned above[3]), non-financial corporations, general government (central government plus municipalities and social security funds), households (including non-profit institutions serving households) and the rest of the world.

To construct matrix X we use the quarterly financial accounts statistics,[4] which, in addition to sector-level financial balance sheets, contain a detailed breakdown of financial assets and liabilities by creditor/debtor sector. The only exception is the instrument other accounts receivable/payable, for which bilateral inter-sector linkages are not compiled in the statistics,[5] so they had to be estimated. The estimation method is based on the simple balancing algorithm described in Silva (2010).

Matrix X is depicted in graphical form in Chart 1a), where the strength of the bilateral exposures corresponds to the bubble size. For clarity, the columns and rows of the matrix have been reordered so that sectors which share a similar pattern of financial investment and funding lie next to each other.[6] This allows for a better understanding of the information contained in the data and makes it easier to answer the following questions: *i*) What is the financial linkage structure of the Czech economy? *ii*) Which sectors have a similar sector structure of financial investment and, conversely, which sectors have a similar creditor structure?

The first important observation is that the banking sector plays a key role: the strength of its exposures is very high on both sides of the balance sheet, so the banking sector – in its role as intermediary – forms the backbone of the entire system. The dominant instruments on the sector's asset side are loans to non-financial sectors (non-financial corporations and households) and investment in debt securities (rest of

2 More specifically *Other* monetary financial institutions (see the ESA95 manual). Banks account for around 98% of the financial assets of this subsector.
3 In particular leasing companies and hire purchase companies, security dealers, investment companies and financial auxiliaries (e.g. the Stock Exchange).
4 The data are available in a time series starting in 2004 Q1 (see http://www.cnb.cz/en/statistics/fin_accounts_stat/).
5 However, some linkages can be obtained from additional statistics (such as the international investment position) or can be determined on the basis of elementary economic structure assumptions. For example, the relationship between the central bank and households in the area of trade credits, which fall into the category of other accounts receivable/payable, can be expected to be negligible and can be approximated by a "statistical zero". Some sorts of linkages are ruled out by definition.
6 The optimal ordering of the rows and columns of the matrix is based on Niermann (2005).

the world and government). The main funding sources on the liability side are deposits (households and non-financial corporations) and issues of shares (held almost exclusively by non-residents). High inter-sector exposures mean that financial problems in the banking sector can spill over to the balance sheets of other sectors, while local shocks that initially only affected non-financial sectors can directly also influence the behaviour of the banking sector. This does not always involve direct losses only, but can also include other consequences such as tighter lending conditions and a freeze on new financing.[7]

Besides the strength of the linkages between the financial sector and other sectors, a fairly strong linkage can be observed between the domestic sectors and the rest of the world sector, especially as regards financial investment by foreign entities. The rest of the world asset side is dominated by investment in non-financial corporations and the banking sector in the form of shares and other equity, while the main item on the liability side is the purchase of foreign debt securities by domestic financial institutions (including holdings of international reserves by the central bank). Among other things, the size of international bilateral exposures increases the speed at which the symptoms of crisis can spread to the economy from the external environment.

The most significant debtor sector is the non-financial corporations sector, where the intra-sector exposure is particularly strong. Its strength is affected to some extent by the ownership structure of corporations, but trade credits and advances – which represent a very significant form of financing within the sector – play the biggest role here. In addition to the non-financial corporations sector itself, the banking sector and the rest of the world are major creditors. The creditor relationship of the rest of the world vis-à-vis non-financial corporations again primarily reflects the ownership structure of corporations.

In terms of the sector structure of financial investment, a slightly different investment profile can be observed for financial institutions (the four right-hand columns of Chart 1a) compared to the other sectors. By contrast, from the financing perspective a difference can be seen between the debtor profile of the two biggest debtors (non-financial corporations and MFIs), which largely use funds from non-financial sectors, and the profile of the rest of the world sector on the opposite side, where above all the investments of domestic financial institutions are channelled. Between these two extremes, sectors that are generally funded mostly by just one sector can be found in the lines in the middle of the chart. They consist mainly of households, which are linked to the banking sector via loans, and insurance companies and pension funds, which by contrast are financed by households in the form of insurance technical reserves.

The financial exposures undergo dynamic changes over time (see Chart 1b[8]), signalling the growing financial interconnectedness of sectors and an increasing susceptibility to inter-sector transmission of credit risk. It is evident that the banking sector's significance as an intermediary of the flow of funds from sectors with free liquidity to those with financing needs increased sharply in the period under review. The dynamic growth in loans to households outpaces even the high growth in the banking sector's financial assets and liabilities.

The globalisation of the inflow of funds is giving rise to growth in the exposures between the domestic sectors and the rest of the world sector. A new feature is the increasing share of foreign investors in the rising government debt linked with deficit financing in recent years. Among the other linkages it is worth emphasising the growing financial investment by households in insurance companies and pension funds, which for historical reasons was very low in the past. At present, therefore, we are seeing a partial restructuring of households' portfolio and some (albeit still relatively slow) convergence towards the investment strategy typical of Western European countries.

3. BALANCE-SHEET SHOCK AND CREDIT RISK TRANSMISSION MODEL

In contrast to other sorts of assets, a financial asset is simultaneously a liability of another entity, so its existence implies a linkage between the two entities' balance sheets. If the debtor has repayment problems, the mutual exposures can serve as risk transmission channels. It is

7 These consequences are not directly observable from financial account data, nor are they captured by our model. However, they based on economic theory and were confirmed by the recent financial crisis.

8 To reduce the information noise, the chart only contains data on growth in linkages that are significant in the economy. The assessment of significance is rather arbitrary – in our case the percentage increases are depicted for linkages having shares of more than 2% in total financial assets in the economy.

on this concept that the simple model of inter-sector propagation of balance-sheet shocks is based.[9] The main assumption of the model is the use of mark-to-market balance sheet valuation, where losses caused by a shock show up directly in the affected entity's accounts via its profit-and-loss account. The loss will affect its equity and therefore also the market price of its shares.

Mark-to-market loss valuation and its impact on share prices is the basic inter-sector shock transmission mechanism in this model. Besides the sector primarily affected, shareholders from other sectors also suffer losses due to a fall in the value of their shareholdings. These losses, in turn, pass through to their balance sheets (shareholder equity positions) via accounting adjustments for the shares and again trigger a fall in the market prices of the shares, which, in the next round, shows up in the balance sheets of the relevant owners. This process continues until the primary shock has been fully absorbed by the entities in the system and no longer generates new losses in the next round. Full absorption of the shock is usually ensured thanks to the existence of sectors which do not issue shares (households and general government) and absorb the shock without spreading it further into the system. The role of these sectors is thus linked solely with losses due to shareholdings in other sectors. The role of the rest of the world is debatable in this respect, as foreign creditors do not necessarily correspond to foreign debtors and so any shock will not necessarily be transmitted back into the economy in its entirety.[10]

The assumption of mark-to-market valuation is connected with the rate at which losses propagate through the economic system. If loss valuation takes place quickly enough or immediately, the shock also transmits immediately to other sectors and the individual rounds of financial contagion will then take place (almost) simultaneously. In normal conditions, however, the mark-to-market assumption is usually not fully satisfied. Moreover, the time needed for reporting losses can vary significantly from sector to sector. Consequently, the time duration of inter-sector shock transmission is quite difficult to determine, hence the model helps us to uncover the shock propagation channels rather than to determine the specific time path of inter-sector contagion.

Another limitation of the model is that it abstracts from the accumulation of credit risk and the formation of risky exposures. Castrén and Kavonius (2009) therefore proposed to combine the said framework with sector-level credit risk indicators and enriched the inter-sector contagion model with a risk factor (the „risk channel"). The contingent claims analysis (CCA) approach is used to determine sector-level risk measures. Specifically, CCA can be used to determine a sector's probability of default and, using that probability, to estimate approximately[11] the riskiness of bilateral exposures. The larger is the probability of default, the greater is the risk that the debtor sector will not be able to honour its commitments to other sectors.

The algorithm of the credit-risk-enriched model can then be described as follows (Silva, 2010). In the first round, a shock occurs in one of the sectors. As in the previous model, this shock leads to an impact on equity via the profit-and-loss account and to a reduction in the market value of shares. However, the changes in the balance sheet of the sector concerned additionally trigger a change in its risk profile and there is a potential rise in the probability of default (or fall in the distance to distress – see below). If the probability of default becomes non-zero, the likelihood of bilateral obligations being honoured drops below 100%. In such conditions, losses are incurred not only by sectors that hold shares in firms from the shock-hit sector, but also by all sectors that are in a creditor position vis-à-vis that sector, because, under market pricing, if the repayment probability is not equal to one they have to adjust their claims for the amount which will probably not be paid back.[12] In the next round, on the basis of the same mechanism, all sectors incurring a loss in the previous round will again see a fall in the market prices of their shares and a potential change in their probability of default. In addition to the losses arising from the fall in the market prices of shares, this change can again lead to further losses arising from the decrease in the probability of repayment of obligations and from the need to

9 The idea of the model used in Castrén and Kavonius (2009) is based on earlier literature on credit chains and balance-sheet risk transmission (see Shin, 2008, and Kiyotaki and Moore, 2002).

10 We assume in the model that only one-fifth of the losses suffered by the rest of the world are transmitted back into the economy. This roughly corresponds to the ratio of residents' shares abroad to non-residents' shares in the Czech economy.

11 The riskiness of bilateral exposures can be roughly approximated by the probability of default. In practice, this can overstate the true risk, because even given default a creditor will usually get part of his claim back, i.e. the loss given default (LGD) is not equal to 100% in reality. It is also true that in the event of increased financial stress the debtor sector will not honour its commitments to other sectors in the same way (for example, a troubled debtor may prefer to make payments to a bank than pay premiums to an insurance company).

12 This can be calculated as the amount of the bilateral obligation to the affected sector multiplied by the probability of default.

write off a further portion of risky assets vis-à-vis the debtor sector. The inter-sector shock and credit risk transmission algorithm goes through further rounds until the shock has been fully absorbed by the system or until it becomes clear that without another positive shock the sectors are no longer capable of absorbing the original negative shock and the system heads towards complete collapse.

It should be emphasised that this model implies higher losses than the model that excludes credit risk. This is because sectors, besides incurring losses as a result of a fall in the market prices of their shareholdings (the "equity channel"), incur losses due to risky bilateral exposures (the "risk channel"). What is more, the two channels act in synergy, because in any given round of the algorithm the market price of shares is reduced by both types of losses, and the equity channel is thus amplified in the next round by the effect of the risk channel from the previous round. The existence of the risk channel better describes the formation of credit risk over time and enables the impacts of the initial shock to be distributed more realistically, since these impacts can directly influence not only the shareholder sectors, but also, as a result of the existence of credit risk, other sectors with bilateral exposures to the affected sector.

In order to apply the model to the Czech data it is first necessary to calculate the sector-level risk measure using contingent claims analysis (CCA). The CCA method is based on Merton's model (Merton, 1974), which extends the option pricing theory described in Black and Scholes (1973). Although this model is applied more often at the microeconomic level, where it is used to determine the probability of default of a firm, it has also been used successfully to analyse economic sectors (see, for example, Gray et al., 2007, and Gray and Malone, 2008). CCA is based on three main principles: (*i*) the value of liabilities is derived from the value of assets; (*ii*) liabilities are divided into two "classes" with different settlement priorities, where debt ("senior claims", B) has precedence over shareholders' claims ("junior claims", J); (*iii*) the value of assets is determined by a stochastic process that reflects market dynamics.

If the total value of the assets in a particular sector falls, the sector's debt becomes more risky for creditors owing to a decrease in the funds available for paying it back. The uncertainty regarding the value of assets at time t can be described by a probability distribution. At the end of period t, the asset value should ideally be above the "barrier" constituted by the debt repayments. If this does not happen and the asset value falls below this barrier, the debt can no longer be covered and default occurs. The degree of uncertainty associated with this happening is given by the probability of default (PD). This probability is non-zero if part of the asset value probability distribution lies below the barrier constituted by the value of the debt plus related interest. The distance to default (DD) is then determined by the difference (distance) between the implied market value of the assets and the default barrier. This distance is related (scaled) to the asset volatility.

The distance to default, DD, and the probability of default, PD, are the main outputs of CCA. Using Merton's model they can be expressed by the following relations:[13]

$$\mathrm{DD} = \frac{\ln(A_0 / B_t) + (\mu_A - \sigma_A^2 / 2)t}{\sigma_A \sqrt{t}}, \tag{2}$$

$$\mathrm{PD} = P(A_t < B_t) = F(-\mathrm{DD}), \tag{3}$$

where[14] A_0 is the implied market value of assets at time $t=0$, B_t is the book value of the debt (default barrier), $\mu_A = r^*\lambda\sigma_A$ is the expected rate of growth of the sector's assets, σ_A is the asset volatility, defined as the standard deviation of the return, r is the risk-free interest rate, t is the length of the time period (usually equal to one), λ is the market price of risk, $P(.)$ denotes probability and $F(.)$ denotes the cumulative distribution function of a standard normal distribution.

The asset volatility σ_A is not generally known but can be estimated from its relationship to the volatility of junior claims σ_J, which also ensues from Merton's model:

$$\sigma_J = \frac{F(\mathrm{DD} + \sigma_A \sqrt{t})A}{J} \sigma_A . \tag{4}$$

It can be derived (see Castrén and Kavonius, 2009) that the distance to default is decreasing (and the level of risk increasing) in asset volatility and/or leverage (B/A). The relationships between the variables are non-linear,

13 A detailed derivation of the relationships and their economic rationale can be found, for example, in Gapen et al. (2008) and Seidler (2008). The equations in the text indicate which variables enter the CCA. The construction of the variables on the basis of sector-level data is analysed in the subsequent text.
14 The solution to the resulting system of equations is found using iterative optimisation techniques. Our calculations were performed using Excel Solver.

and credit risk is particularly sensitive to changes in asset volatility when leverage is high.

At the sector level it can be difficult to find suitable data to fill equations (2)–(4) and it is often necessary to adopt somewhat simplified definitions. In line with earlier studies[15] junior claims are defined as the sum of equity and net financial assets.[16] The default barrier is set equal to the sum of short-term liabilities plus 50% of long-term liabilities. The risk-free interest rate is approximated by one-year interest-rate swaps. Parameter λ is fixed at 0.45, which corresponds to the long-term average as calculated by Moody's.[17] The volatility of junior claims for individual sectors can generally be obtained from stock indexes. Because the historical index volatility does not necessarily match the present volatility, forward-looking (implied) volatility measures, which are commonly available for economies with developed capital markets, tend to be preferred. However, they are not available for the Czech Republic, nor – owing to a shallow capital market – are stock sub-indexes available for individual (sub)sectors for the calculation of historical volatility.

The volatility of the junior claims of non-financial corporations is therefore approximated by the historical (time-varying) volatility of the PX 50 index as calculated by the exponentially weighted moving average (EWMA) method used by RiskMetrics (RiskMetrics, 1996). The same method was used to calculate the volatilities for the other sectors, although the weighted average of the stock price of domestic banks and the Eurostoxx bank sub-index was used for the monetary financial institutions sector. The relevant Eurostoxx sub-indexes were used for the other financial subsectors, and the aggregate Eurostoxx 50 index was used for the rest of the world. For the government and household sectors the volatility of junior claims is given by the historical volatility of ten-year government bond yields.

4. RESULTS AND SIMULATION OF INTER-SECTOR SHOCK TRANSMISSION

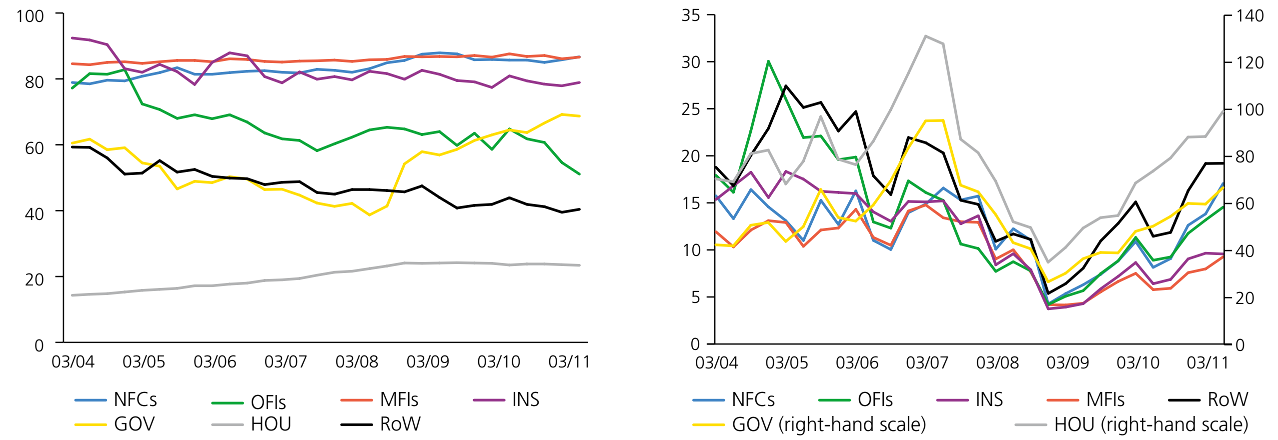
In the text below, the CCA outputs are first presented and, on the basis of those results, a simulation of two negative scenarios is performed using the model described in section 3.

Chart 2

SELECTED CCA OUTPUTS

a) Implicit leverage (B/A)
(in %)

b) Distance to default
(in standard deviations of asset volatility)



Source: Authors' calculations

Source: Authors' calculations

15 See Gray et al. (2007), Castrén and Kavonius (2009) and Silva (2010). These papers also give a more detailed economic rationale for the definitions adopted, as well as alternative suggestions. However, their use (e.g. for the household sector) in the Czech case is prevented by a lack of the necessary data.

16 With the exception of the general government sector, which does not issue equity and whose net financial assets are negative in some periods. For general government, junior claims are therefore defined as the sum of government bonds and net financial assets (see Castrén and Kavonius, 2009).

17 For the Czech economy this choice may be rather subjective. However, the simulation does not indicate high sensitivity to changes in the parameter close to the value used.

4.1 CCA outputs

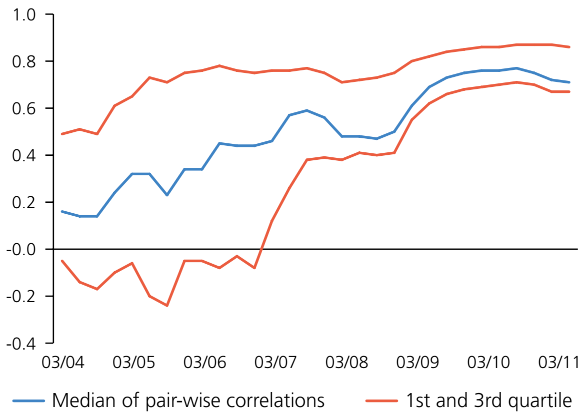
The evolution of leverage (Chart 2a), i.e. the ratio of the debt barrier to the implicit market value of assets calculated using the model (risk-adjusted assets), reveals that the household sector has the lowest leverage while banks and non-financial corporations currently have the highest. With regard to the dynamics it is interesting to note the relatively sharp growth in the government sector's leverage since 2008 Q2. This rise was fostered by increased issuance of government bonds and the sector's deficits and by a simultaneous decline in the market prices of its asset holdings.

Until mid-2007, the distance to default – documenting the evolution of credit risk (Chart 2b) – was relatively high[18] in all sectors. However, following the outbreak of the financial crisis it started to fall in aggregate terms, reaching its minimum (the highest credit risk) in late 2008/early 2009. This mainly reflects increased asset volatility during the crisis. A gradual recovery then started and the distance to default rose to its pre-crisis level. The highest credit risk during the crisis period was recorded by the most leveraged sectors (monetary financial institutions, non-financial corporations, and insurance companies and pension funds). This demonstrates the aforementioned (non-linear) property of the CCA model, as more leveraged sectors are significantly more sensitive to the materialisation of credit risk when asset volatility is high.

As part of the credit risk transmission analysis, it is interesting to look at the pair-wise correlations between the sector-level distances to default and their evolution over time (see Chart 3).[19] The fact that there was a noticeable rise in the correlations between all DDs in the period under review suggests an increased possibility of inter-sector credit risk transmission, as a deterioration in DD in one sector is highly likely to lead to an increase in risk in all other sectors if the correlations are high. It is important to emphasise, however, that this was caused mainly by increased correlation between stock index volatilities during the financial crisis. A slight decline in the overall correlation can be observed in recent quarters, as the closest links between DDs were seen during and immediately after the crisis.

Chart 3

PAIR-WISE CORRELATIONS BETWEEN SECTOR LEVEL DISTANCES TO DEFAULT
(descriptive statistics)



Source: Authors' calculations

4.2. Simulation of negative shocks

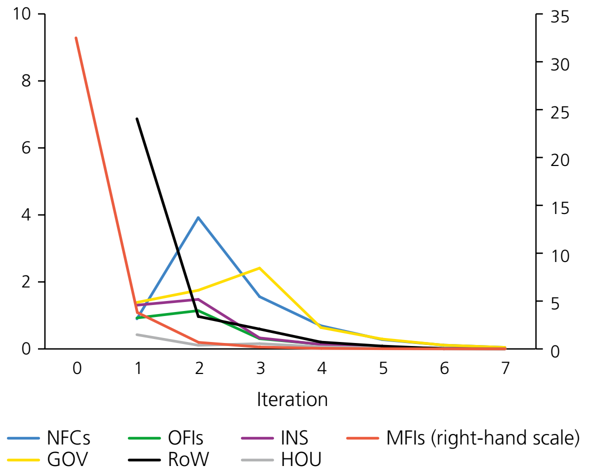
This section contains a simulation of two negative shocks, each primarily hitting a different sector. Both scenarios represent strong stresses intended to assess the economic system's ability to absorb very implausible and extreme shocks. The starting period for the simulation is 2011 Q2, but to increase the stress to the system it is also assumed that the shock was accompanied by an increase in the volatility of junior claims (and therefore also assets) to the level of 2008 Q4, when the volatility of the stock (sub) indexes peaked in the time period under review.

The first scenario assumes an unrecoverable loss of 15% in loans granted by monetary financial institutions to households ("*MFI shock*"), while the second stress scenario assumes problems in client-supplier relations within the non-financial corporations sector caused by a dramatic deterioration in economic conditions ("*NFC shock*"). These problems lead to insolvency and an unrecoverable loss of 10% in inter-company trade credits (or other accounts receivable/payable). In both scenarios, the magnitude of the primary shock is determined simultaneously by the change in the volatility of junior claims and by the loss incurred. Seven post-shock iterations are performed using the inter-sector transmission model.[20]

18 If the indicator takes a value of three, the probability of default is approximately 10%; a value of four represents a virtually zero probability of default.
19 The time-varying correlations were again estimated using the EWMA method.
20 The number of iterations is the same for both scenarios. The number cannot be increased owing to a fall in junior claims below zero in non-financial corporations in the second scenario.

CHART 4A

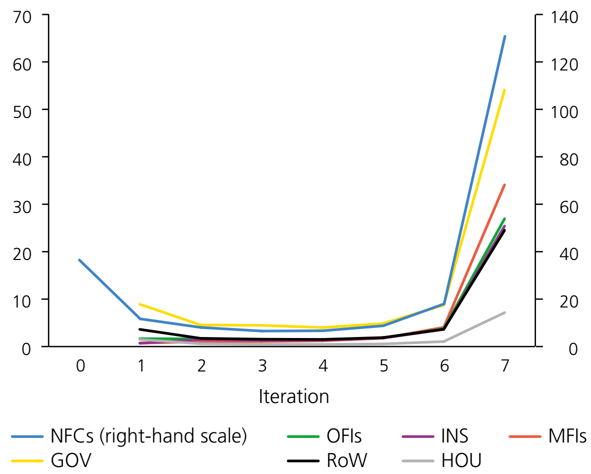
LOSSES IN EACH ITERATION, MFI SHOCK
(in % of junior claims in 2011 Q2)



Source: Authors' calculations

CHART 4B

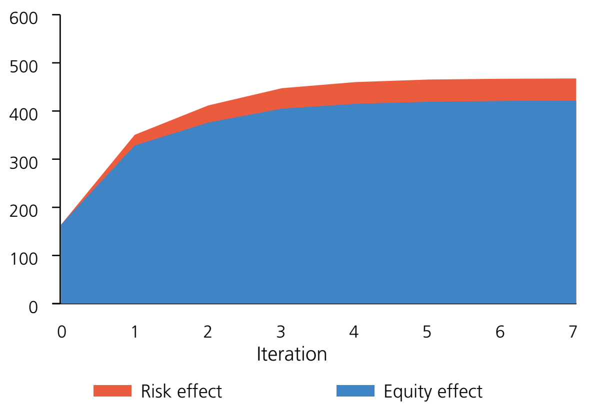
LOSSES IN EACH ITERATION, NFC SHOCK
(in % of junior claims in 2011 Q2)



Source: Authors' calculations

CHART 4C

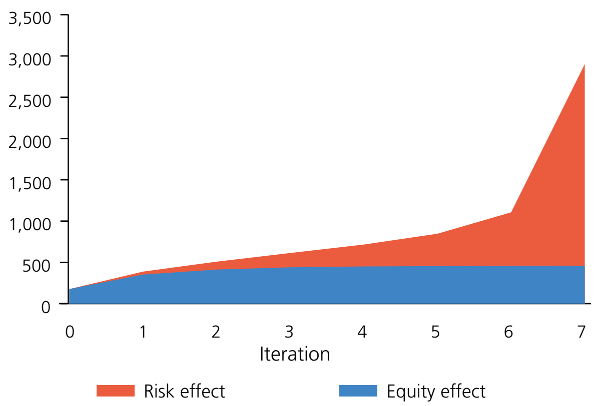
ACCUMULATED LOSSES IN SYSTEM, MFI SHOCK
(in CZK billions)



Source: Authors' calculations

CHART 4D

ACCUMULATED LOSSES IN SYSTEM, NFC SHOCK
(in CZK billions)



Source: Authors' calculations

The simulations (see Chart 4) indicate that given an initial shock of the same magnitude the ultimate effects on the financial system can be completely different depending on which sector is primarily affected and what exposures it has to other sectors. While in the first scenario the banking sector showed a high degree of resilience and was able to cope with the shock even amid increased financial stress (increased volatility + loss), in the second scenario in the case of non-financial corporations the losses initially accumulate within the sector and are subsequently also transmitted increasingly to other sectors up to the point where the entire system heads towards collapse (see Chart 4a–d).

In addition to general financial soundness, the different shock profiles are due mainly to the different natures of the bilateral exposures and ownership relations. In the case of a shock to the banking sector, it is foreign shareholders that incur the biggest losses in the first round. Owing to the high resilience of the banking sector, however, bilateral exposures are not significantly threatened. The size of the losses in subsequent rounds therefore depends primarily on the transmission of losses caused by the fall in market prices of shares, with shareholders of sectors hit in the previous round gradually suffering losses. The overall magnitude of the risk effect[21] is low relative to the equity effect and it is evident (see Chart 4c) that the shock is gradually absorbed by the system in the subsequent iterations. Nevertheless, the total accumulated loss is almost three times as large as the primary shock.

By contrast, the sizeable intra-sector linkages in the non-financial corporations sector contribute to the accumulation of losses (both equity and risk) within the sector in the event of a extreme shock, leading to spiralling growth in credit risk. When a certain threshold is crossed, the accumulated risk quickly spills over to other sectors. The model indicates the government sector[22] and the banking sector (a key provider of funds to firms) as being the most strongly affected. In contrast to the first simulation, the importance of the credit risk effect in the second scenario increases gradually over time before suddenly becoming totally dominant in the final round. This suggests significant non-linearity in the propagation of credit risk – once a certain tipping point is crossed, the network of bilateral linkages, instead of being a shock absorber, becomes a massive propagator of the accumulated risk to all sectors (see Silva, 2010, and Haldane, 2009).

This fact is confirmed by Table 1, which shows the change in the distance to default between the initial moment and the situation after the primary shock as well as the change between the situation immediately after the primary shock and the final round of the algorithm. In the first scenario, the DDs decrease in all sectors because of increased junior claim volatility and in the banking sector also because of loan losses. Subsequently, however, the changes in DD are minimal. In the second scenario, by contrast, the DDs continue to decline in all sectors as a result of inter-balance sheet exposures, owing mainly to the accumulation of credit risk in the non-financial corporations sector.

The shock transmission model presented above is not limited to non-recurring shocks to a single sector. The impacts of full-blown scenarios where various types of risks crystallise in different sectors simultaneously can also be tested. These can be linked to macro-scenarios calculated in other models.

TABLE 1A

CHANGE IN DISTANCE TO DEFAULT DUE TO SHOCK
(Scenario: MFI shock)

2011 Q2		Primary shock		End of algorithm	
sector	**DD**	**DD**	**ΔDD(%)**	**DD**	**ΔDD(%)**
NFCs	17.1	3.5	79.7	3.5	0.2
MFIs	9.3	2.6	71.8	2.6	1.1
OFIs	14.5	4.2	71.2	4.2	0.4
INS	9.6	3.2	66.4	3.2	0.0
GOV	66.7	23.5	64.8	23.4	0.4
HOU	99.1	34.7	65.0	34.6	0.2
RoW	19.2	5.4	71.9	5.2	3.3

TABLE 1B

CHANGE IN DISTANCE TO DEFAULT DUE TO SHOCK
(Scenario: NFC shock)

2011 Q2		Primary shock		End of algorithm	
sector	**DD**	**DD**	**ΔDD(%)**	**DD**	**ΔDD(%)**
NFCs	17.1	2.7	84.4	0.2	92.6
MFIs	9.3	3.3	64.6	2.5	23.7
OFIs	14.5	4.2	71.2	3.3	21.8
INS	9.6	3.2	66.4	2.6	18.7
GOV	66.7	23.5	64.8	5.6	75.9
HOU	99.1	34.7	65.0	33.2	4.5
RoW	19.2	5.4	71.9	4.3	20.8

NFCs Non-financial corporations
MFIs Monetary financial institutions
GOV General government
HOU Households
OFIs Other financial intermediaries
INS Ins. companies and pen. funds
ROW Rest of the world

Source: Authors' calculations

21 As the equity and risk channels cannot be entirely separated owing to their mutual synergy, the risk effect is calculated as the difference between the losses in the model including credit risk and those in the accounting model excluding risk.

22 The government acts as a shareholder of non-financial corporations, but the losses also reflect the risk of non-payment with regard to other claims on non-financial corporations (loans and tax arrears).

On the other hand, the model has some limitations, since it abstracts from liquidity risk and from the possibility of rebalancing a sector's balance sheet by selling a proportion of its assets. The sale of assets and the settlement of short-term liabilities from the proceeds can lead the real losses caused by a shock to follow a different – often less pessimistic – trajectory. The simulations should therefore be viewed as overstated with respect to the true degree of contagion. Also linked with the high-stress nature of the model is the comparatively strong assumption of a 100% loss given default (LGD), i.e. the worst-case scenario of default on the entire debt. More sophisticated models allowing dynamic measurement of LGD across sectors over time or incorporating late payments have yet to be theoretically elaborated and provide an incentive for further development of the study of inter-sector linkages. Finally, it is necessary to take into consideration that the model only examines the amplification of primary shocks via the existing network of financial exposures and does not analyse their causes in any further detail. Likewise, the model is not capable of working with such shocks until they show up in a change in biliateral exposures. For this reason, the study of inter-sector contagion should be embedded in a wider analytical framework.

5. CONCLUSION

This article set out to map the network of inter-sector financial linkages in the Czech economy and to contribute to the study of the cross-sectional dimension of systemic risk. The article analyses whether inter-sector balance-sheet linkages can act as amplifiers of shocks and transmitters of contagion in the event of financial stress. A model that extends inter-sector shock transmission to include a description of credit risk based on contingent claims analysis was used to this end. Despite the simplicity of this approach, a need to study inter-sector linkages was demonstrated and their role in the transmission of contagion across the economy was identified.

The simulations indicated that the transmission of a primary shock differs depending on its sector of origin. From the financial stability perspective, it is significant that the results revealed strongly non-linear risk transmission. Once a tipping point is crossed, the gradual accumulation of risks can suddenly and dramatically switch into a situation that implies a significant stress for the system and – in the extreme worst case – collapse of the system. However, the simulations also demonstrated that the banking sector is strongly resilient to adverse shocks and indicated that it is capable of assisting in the complete absorption of shocks.

The CCA analysis also yielded interesting information as a separate output. It was demonstrated that the correlations between the sector-level measures of credit risk increased significantly in the period under review, peaking during and immediately after the financial crisis. This suggests an increased probability of inter-sector credit risk transmission in this period.

A promising avenue of future research would be to integrate the model described above with the suite of models used at the Czech National Bank. This would allow for the creation of consistent macro-scenarios and quantification of their impacts on systemic risk or its cross-sectional dimension. Alongside this there is a need to continue working on a subtler version of the model to eliminate some of the overly strong assumptions.

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