Towards a Stress-Testing Model Consistent with the Macroprudential Approach

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The macroprudential approach to assessing risks to financial stability has two distinguishing features.[1] First, with this approach, the focus is on the financial system as a whole in order to limit the macroeconomic costs of episodes of financial distress. In contrast, the microprudential approach focuses on the financial strength of individual financial institutions. Second, the macroprudential perspective treats aggregate risk as being dependent on the collective behaviour of financial institutions and markets, including potential contagion channels arising from their interlinkages. Individual institutions, on the other hand, consider aggregate risk to be independent of their decisions.

The macroprudential approach has important implications for monitoring threats to financial stability using macrofinancial models, as well as for the development of prudential policy tools. In this report, we present work under way to enhance the macro stress-testing framework first used by the Bank of Canada for the exercise it conducted under the IMF's Financial Sector Assessment Program (FSAP) in 2007. In brief, that model aggregates the credit losses that would materialize at individual banks should a severe global recession occur.[2]

The recent crisis in financial markets showed how direct interlinkages among banks arising from counterparty exposures, as well as liquidity risk arising from fire sales of assets, can be important channels of contagion. This report outlines how we have integrated those two channels into the original macro stress-testing framework.[3] The results from simulations conducted to evaluate the importance of these contagion channels suggest that they can have important system-wide effects, as the recent crisis has clearly shown. Specifically, integrating these elements into the stress-testing framework tends to substantially increase the losses in the aggregate banking sector for a given macro shock, compared with the situation where we consider only "first-round" credit losses.

A Network Model of Interbank Linkages

Distress at one bank may cause distress at another if they have exposures to each other. From a macroprudential point of view, it is therefore important to consider such spillover effects. Moreover, limiting the analysis to traditional interbank lending may seriously underestimate spillover risks, since the size of off-balance-sheet exposures has increased steadily over the past decade, and other types of on-balance-sheet exposures may also be important. We therefore consider an expanded set of on-balance-sheet exposures with some off-balance-sheet interlinkages among financial institutions.[4] We integrate this channel into our core credit-risk model, which provides a distribution of banks' credit losses should a severe macroeconomic scenario materialize (see Misina, Tessier, and Dey 2007 for more details).

Following Elsinger, Lehar, and Summer (2006), we model counterparty exposures within our stylized Canadian banking system as a network of interbank obligations

1 See Borio (2003, 2009) or Gauthier and St-Amant (2005) for more details on the macroprudential approach.

2 For a summary of the objectives and results of the FSAP, see Coletti et al. (2008). For a more detailed description of the model used for this exercise, see Misina, Tessier, and Dey (2007).

3 Gauthier, Lehar, and Souissi (2009) also propose some improvements to the core credit-risk model used in the IMF FSAP exercise to take into account the granularity of the loan portfolio at individual banks.

4 See the section on exposures among Canadian banks for details on the set of exposures considered.

between the “big six” Canadian banks.[5] The analysis begins with the following representative balance-sheet identity of financial institution i,

$$\sum_j x_{ji} + a_i = k_i + L_i + \sum_j x_{ij}, \tag{1}$$

where x_{ji} represents the claims of bank i on bank j, a_i represents all other non-interbank assets, k_i represents bank i’s net worth, L_i represents bank i’s liabilities against counterparties other than banks (or outside debt holders), and x_{ij} represents the claims of other banks on bank i.

Following a shock, exposures among banks can cause distress at one bank to spread to other banks. Whenever a bank defaults, its remaining value, once outside debt holders are paid, is distributed proportionately to creditor banks.[6] Any loss by the creditor banks is absorbed by their capital. **Figure 1** illustrates a case of spillover from bank h to bank i. The macro shock pushes bank h into bankruptcy, with the value of its assets insufficient to pay all of its interbank liabilities. The same macro shock affects bank i as well, reducing the value of its assets by a fraction equal to λa_i. Bank i has sufficient capital to absorb the impact of that shock (λa_i is smaller than k_i) but is pushed into bankruptcy because of the writedown induced by the default of bank h.[7]

Figure 1: Channels of contagion

Pre-shock balance sheet of bank i	
$\sum_j x_{ji}$	k_i
	L_i
a_i	$\sum_j x_{ij}$

After-shock balance sheet of bank i	
$\sum_{j \neq h} x_{ji}$	λa_i
x_{hi}	x_{hi}
a_i	L_i
λa_i	$\sum_j x_{ij}$

Source: Bank of Canada

Integrating Asset Fire Sales into the Network

When an institution is unable to fully meet its obligations, it may be forced to sell assets at a loss—in other words, at prices well below their fair value—to achieve a quick sale. This is generally referred to as an “asset fire sale.” These sales of assets into the market cause other banks holding the same assets to incur losses as well. Because of marking to market, an initial fire sale can trigger a chain of fire sales at other institutions, as witnessed during the 2007–08 subprime crisis.

The integration of the asset-fire-sale component into the network model is an extension of the work done by Cifuentes, Ferrucci, and Shin (2005), in which banks were assumed to be equally risky. In contrast to that work, we assume a more realistic world in which banks have various risk profiles and calibrate the model such that the equilibrium market price of a bank’s illiquid assets is a decreasing function of its riskiness. This reflects the fact that riskier assets are less liquid in a crisis period.

Assets held by the banks are subject to a minimum capital ratio, which stipulates that the ratio of the bank’s Tier 1 capital to the mark-to-market value of its assets must be above some prespecified minimum, r^*. When a bank violates this constraint, we assume that it has to sell assets to reduce the size of its balance sheet.[8] We use s_i to denote the units of illiquid assets sold by bank i.[9] Whereas Cifuentes, Ferrucci, and Shin (2005) used a simple (non-risk-weighted) leverage ratio, our constraint is closer in spirit to the Basel II Accord, in which banks have to hold capital commensurate with the risk on their balance sheets. This is given by:

$$\frac{p_i e_i + c_i + \sum_j x_{ji} - \sum_j x_{ij} - L_i}{w_i p_i (e_i - s_i)} \geq r^*. \tag{2}$$

Here, bank i’s stock of non-interbank assets, a_i in Figure 1, is divided into liquid and illiquid assets. Bank i’s stock of liquid assets is given by c_i and includes cash holdings, government securities, and insured mortgages.[10] For simplicity, interbank assets are also assumed to be liquid. The remainder of the bank’s assets, e_i, are considered illiquid. The price, p_i, of the illiquid assets of bank i is determined in equilibrium, while the liquid assets have a constant price of 1. The average risk weight of bank i’s illiquid assets is represented by w_i.

5 The holdings of the big six Canadian banks represent approximately 90 per cent of the total assets of the Canadian banking sector. A useful extension would be to expand the network to include the large Canadian insurance companies and some foreign institutions with significant linkages with Canadian financial institutions.

6 The residual worth is distributed proportionately to the creditor’s share of the debtor’s total interbank liabilities. For simplicity, this calculation is omitted from the notation.

7 Eisenberg and Noe (2001) show that, following an initial default, there is a unique vector of payments between banks that clears the obligations of all parties.

8 We do not consider the possibility of raising fresh capital or the need to sell assets because of a loss of funding. The consequences of the latter would be similar to those described here, assuming that the assets would have to be sold at a discount (see the April 2009 *Global Financial Stability Report* for an example).

9 Selling liquid assets does not help to reduce the size of the balance sheet because of their zero risk weight. Note, however, that holding more liquid assets reduces the size of the balance sheet ex ante.

10 We consider insured mortgages to be liquid because they also carry a zero risk weight.

The numerator is the equity value of the bank, where the interbank claims and liabilities are calculated in terms of the realized payments. The denominator is the mark-to-market risk-weighted value of the bank's assets after the sale of s_i units of the illiquid assets. The underlying assumption is that assets are sold for cash, and cash does not require capital. Thus, if the bank sells s_i units of the illiquid assets, the value of the numerator is unchanged, since this involves only a transformation of assets into cash. However, the value of the denominator is decreased, since cash has a zero risk weight, whereas the illiquid assets sold carry a positive risk weight. Thus, by selling some illiquid assets, the bank can reduce the size of its balance sheet and increase its capital-to-assets ratio.

An equilibrium of the model is represented by a combination of interbank payments, individual sales of illiquid assets, and their prices, such that:

(i) equity holders have limited liability and debt holders have priority over interbank liabilities;[11]

(ii) either the bank is liquidated altogether, or its sales of illiquid assets reduce its assets sufficiently to comply with the capital-adequacy ratio; and

(iii) the price of the illiquid assets is determined by the intersection of a downward demand curve and the aggregate supply curve.

Data on Exposures Among Major Canadian Banks

As in previous studies of systemic risk in foreign banking systems, our data cover exposures among banks that arise from traditional lending (unsecured loans and deposits).[12] We expand the set of exposures among banks to also cover those arising from other on-balance-sheet items, such as cross-shareholdings (in terms of common shares), and from off-balance-sheet instruments, such as exposures related to derivatives.[13] Of course, there are other types of exposures among banks—most notably, those arising from intraday payments and settlements, from bank holdings of preferred shares (and other forms of capital), and from holdings of debt instruments issued by banks, such as debentures and subordinated debt. Owing to data limitations, however, they are not considered here.

Data on these exposures were collected on a consolidated basis and were drawn from various sources, as described below. Available data were collected for May 2008 (except for exposures related to derivatives, which are as of April 2008). We present descriptive statistics for these data in **Table 1**.

Table 1: Summary statistics on exposures among Canadian banks

	Aggregate exposure (Can$ billions)	Exposure as a percentage of Tier 1 capital		
		Minimum	Average	Maximum
Traditional lending	12.7	5.25	16.3	38.6
Derivatives exposures	5.4	0.0	5.9	21.1
Cross-shareholdings	3.5	0.3	4.1	8.8
Total	21.6		26.3	

Source: Authors' calculations

Data on deposits and unsecured loans were taken from the banks' monthly balance-sheet reports to the Office of the Superintendent of Financial Institutions (OSFI).[14] Data on exposures related to over-the-counter (OTC) derivatives were obtained from a survey initiated by OSFI at the end of 2007. In that survey, banks were asked to report their 100 largest mark-to-market counterparty exposures that were greater than $25 million. These exposures were related to both OTC and exchange-traded derivatives and were reported after netting and before collateral and guarantees.[15] The reported data were used to construct a matrix of the bilateral exposures of the big six banks. Data on cross-shareholdings were collected from the Bank of Canada's quarterly securities returns.[16]

The aggregate size of interbank exposures was approximately $21.6 billion for the big six Canadian banks. As summarized in Table 1, total exposures among banks accounted for more than 26 per cent of bank capital, on average. The available data suggest that exposures related to traditional lending (deposits and unsecured loans) and derivatives were more important than exposures related to cross-shareholdings.[17]

11 In reality, the legal situation might be more complicated, and the seniority structure might differ from the simple procedure we employ here.

12 See Upper (2007) for a survey.

13 Zero risk exposures were excluded, despite their large size. These exposures, consisting mainly of repo-style transactions, accounted for more than half of total exposures among the big six Canadian banks in the second quarter of 2008.

14 For deposits (unsecured loans), we combined the information contained in the banks' L4 and M4 (L4 and A2) reports to estimate the total exposures of each of the big six banks to the other five banks in the group.

15 The derivatives exposures reported may be biased upward, since they were reported before collateral and guarantees. In particular, anecdotal evidence suggests that the major Canadian banks often rely on high-quality collateral to mitigate their exposures to OTC derivatives.

16 A thorough description of the linkages among Canadian banks requires a complete matrix of the bilateral exposures. Such a complete matrix was available only for exposures related to derivatives. Unavailable bilateral exposures were estimated under the assumption that banks spread their lending and borrowing as widely as possible across all other banks. This is called *entropy maximization*. A difficulty with this solution is that it assumes that all lending and borrowing activities among banks are completely diversified.

17 Including repos and excluding exposures related to derivatives and cross-shareholdings (not available for other countries), these exposures make up a comparable proportion of banks' balance sheets in Canada, the United States, and the United Kingdom.

An Overview of the Simulation Results

To assess the importance of the two risk-propagation channels described above, we first simulate the macro stress-testing framework under a severe recession scenario without allowing for any second-round effects.[18] In such an environment, where only credit risk is taken into account, the default risk of individual banks is extremely low. This is consistent with the strength of the balance sheets of Canadian banks and the objective of the regulatory framework to limit risk at individual institutions.

The introduction of the network of interbank linkages has only a slight impact on risk at individual banks and on systemic risk, even with the expanded set of exposures.[19] However, these results might change if the exposures to foreign financial institutions were included. This is left for future research. Once asset fire sales are considered, default probabilities increase significantly, and even more so when the expanded set of exposures is included.[20] This speaks further to the importance of accurately capturing the interlinkages among banks.

Some caveats should be noted, however. First, all default probabilities are under the assumption of a severe macro stress scenario, which is a rare event. Thus, while our analysis explores the financial stability of Canadian banks in a severe economic downturn, the overall probability of a systemic crisis remains low. Second, the default probabilities resulting from the asset-fire-sales channel depend crucially on assumptions about the specification of the demand function that determines the price impact of asset fire sales. While there is anecdotal evidence, for example, that prices for mortgage-related securities fell as banks unloaded their holdings during the recent crisis, it is hard to differentiate price declines caused by excessive supply from those caused by the release of new information to the market. Therefore, our model, like others in the literature, must rely on assumptions about the specification of the demand function (Aikman et al. 2009). Third, the available information on exposures among banks is incomplete and forces us to make simplifying assumptions, which may affect our results.

Conclusion

The work reported here represents a first step in incorporating elements of interlinkages and network effects into our macrofinancial model. Our results suggest that these elements can have important system-wide effects, as the recent crisis has clearly shown.

Without second-round effects, the Canadian banking system is very stable. For the system to incur significant losses, relatively unrealistic macroeconomic contractions would have to occur. When a network of direct bank balance-sheet interlinkages is added to the credit-risk model, the impact of a shock remains small, even when a broader set of interlinkages that includes some off-balance-sheet exposures is considered. But, of the two potential risk-propagation channels discussed in this report, the asset-fire-sale channel is the one that could seriously increase the likelihood of bank defaults. These results imply that the risk to the system as a whole can be seriously underestimated if we ignore second-round effects and take into account only the direct impact of a macro shock on individual financial institutions.

The model could be expanded in many directions and used for different purposes. For example, additional financial institutions (both domestic and foreign), as well as other non-financial sectors, could be added to the network. We could also consider different types of exposures among banks, such as holdings of other forms of capital and debt instruments issued by financial institutions.

18 Consistent with the severity of the macro stress scenario, simulated probabilities of sectoral default are, on average, 50 per cent higher than the observed sectoral default rates over the 1988–2006 period.

19 It would be interesting to do a similar exercise with the major banking centres of the world, in which OTC derivatives exposures probably represent a larger share of bank assets than they do in Canada.

20 Detailed results can be found in Gauthier, Lehar, and Souissi (2009).

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