# Understanding Systemic Risk in the Banking Sector: A MacroFinancial Risk Assessment Framework

*Céline Gauthier and Moez Souissi, Financial Stability Department*

- The recent financial crisis highlighted the need for a better assessment of systemic risk—risk at the level of the entire financial system. Thus, models of the financial system and the complex interactions of the institutions within it have become a major priority for central banks. The development of the MacroFinancial Risk Assessment Framework (MFRAF) is an important step because it provides a framework in which the interconnections between liquidity and solvency in a financial system are modelled, and in which multiple institutions are linked through an interbank network.
- The MFRAF integrates funding liquidity risk as an endogenous outcome of the interactions between solvency risk and the liquidity profiles of banks. This approach is complementary to the new Basel III Liquidity Coverage Ratio framework for Canada.
- The primary goal of the MFRAF is to help measure risks in the Canadian banking system. The calibration exercise presented in this article highlights the vulnerability of leveraged institutions to the combination of low cash holdings and excessive dependence on short-term debt funding, a key feature of the recent global financial crisis.
- The model can also be used as a tool for policy analysis by quantifying the trade-offs among higher capital ratios for banks, increased liquid assets or fewer short-term liabilities in reducing risks in the banking system. Our results illustrate that a regulatory framework that properly controls for systemic risk should consider a bank's capital, holdings of liquid assets and short-term liabilities in a comprehensive manner.

The collective reactions of market participants during the financial crisis of 2007–09 led to mutually reinforcing solvency and liquidity problems at banks around the world. As funding liquidity evaporated, many highly capitalized financial institutions in the United States and Europe had to take significant writedowns on illiquid assets or sell them at a loss, creating uncertainty among market participants about their solvency.[1] Many institutions avoided

1 During periods of financial stress, such as the recent subprime crisis, problems with market liquidity (i.e., when there is difficulty selling assets) and funding conditions can also be mutually reinforcing, leading to downward spirals that make it difficult for banks to maintain adequate levels of liquidity. This reduced liquidity was triggered by concerns about the quality of capital at many of these highly capitalized institutions. See Gauthier and Tomura (2011).

bankruptcy only through massive public intervention. The extent of the support required in response to the crisis illustrated the need to review our approaches to monitoring and regulating the financial system. In particular, liquidity and solvency are often treated as two quite separate dimensions; however, the experience of the crisis is a reminder that they are intertwined. A framework in which these interconnections are modelled is necessary.

Models of the complex interactions among institutions within the financial system are at an early stage of development, but have become a major priority for central banks and other agencies responsible for monitoring systemic risk. This article presents the MacroFinancial Risk Assessment Framework (MFRAF), which is being developed at the Bank of Canada. The MFRAF belongs to a class of macro stress-testing models that are used to sharpen analysis of the principal vulnerabilities in national banking sectors.[2] The MFRAF goes beyond most macro stress-testing models by incorporating the impact of funding liquidity risk, credit risk and the spillover effects of interbank exposures.[3]

◀ *The MFRAF goes beyond most macro stress-testing models by incorporating the impact of funding liquidity risk, credit risk and the spillover effects of interbank exposures*

We are aware of only one other macro stress-testing model (Aikman et al. 2009) that provides such a comprehensive approach to modelling funding liquidity risk.[4] It uses exogenous rules to impose funding constraints once the balance sheets of banks deteriorate beyond certain predetermined thresholds. The MFRAF has been constructed to provide stronger analytical underpinnings for the links among solvency risk, market liquidity risk and funding liquidity risk, rather than relying on exogenous thresholds.[5] This approach is consistent with the events of the recent financial crisis: a bank's creditors refused to roll over their short-term claims if they had serious concerns about its future solvency. The introduction of such strong microeconomic foundations constitutes a major innovation in macro stress-testing models.

To demonstrate how the model works, and highlight the vulnerability of leveraged institutions to the combination of low cash holdings and excessive short-term debt, we first assess risks in a generic banking system in which the leverage and liquidity profiles of banks are similar to those of the banks that were bailed out during the financial crisis.[6] We then show how the model can be used as a tool for policy analysis by quantifying the trade-offs among higher bank capital ratios, increased liquid assets or fewer short-term liabilities that are required to reduce risks in the banking system. Other potential policy applications include helping to gauge the impact of central bank liquidity facilities during crisis periods or determining the relative contributions of individual banks to systemic risk.[7]

In this article, we first describe the structure of the MFRAF and then present the results from two applications of the framework. In our conclusion, we highlight areas where the framework could be extended.

2 Macro stress testing is conducted simultaneously at many banks, using the same scenario and assessment methodology, which allows for a comparison of results (Foglia 2009). It complements the bottom-up risk assessment that is the cornerstone of most risk-management frameworks at major banks.

3 Funding liquidity risk is the risk of loss arising from an inability to roll over existing funding or obtain new funding without incurring a large cost. Credit risk is the risk of loss stemming from a borrower's failure to repay a loan or otherwise meet a contractual obligation. Spillover effects occur when a bank with a serious capital shortfall is unable to fulfill its obligations toward other banks, causing counterparty credit losses that can lead to their potential default.

4 Other studies focusing on the measurement of systemic risk include Huang, Zhou and Zhu (2010) and Gauthier, Lehar and Souissi (2012).

5 Solvency risk, also known as bankruptcy risk, is the risk that a firm will be unable to repay its debts.

6 Leverage is defined as the ratio of total assets to capital.

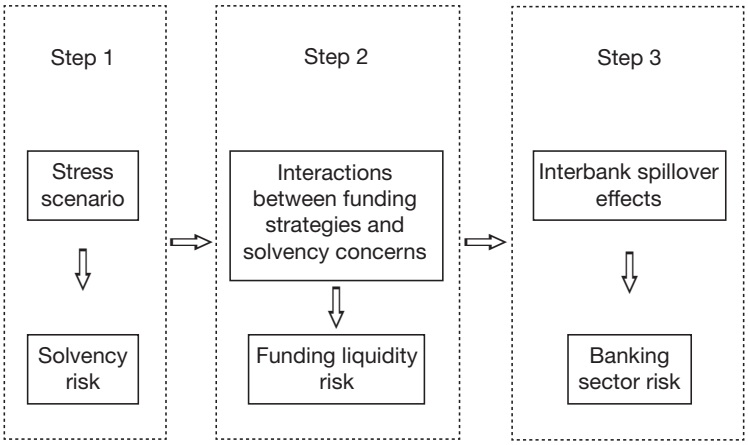
7 Gauthier et al. (forthcoming) use the MFRAF to identify the determinants of systemic importance in various hypothetical banking systems. Another approach to measuring systemic importance is based on market data, as described in Gravelle and Li (2011).

## How the MFRAF Works

Drawing on data from bank balance sheets, the MFRAF takes into account solvency risk, reflecting potential losses associated with bank assets (such as credit risk) and funding liquidity risk, as well as network interactions among banks. **Figure 1** illustrates the basic structure of the framework, tracing the steps from the macroeconomic shock of the stress scenario to banking sector risk.

The framework involves a three-step process. First, banks are subjected to common adverse macroeconomic shocks that provoke asset losses over a one-year horizon.[8] These losses are due to the decline in the credit quality of the banks' loans, since expected defaults increase as macroeconomic conditions deteriorate. The second step introduces funding liquidity risk. As initial losses reduce bank capital, concerns about the future solvency of the banks mount, causing short-term lenders to refrain from rolling over their claims and thus generating an increase in funding liquidity risk. In the third step, failure or distress at one bank—due to solvency risk or funding liquidity problems—can spill over to other banks through interbank exposures. We will now describe each step in more detail.

**Figure 1: Basic structure of the MacroFinancial Risk Assessment Framework**




### Step 1: Solvency risk

In Step 1, the asset losses at individual banks stem from exposures to non-bank borrowers.[9] A key input in estimating future loan losses is the default rates in different sectors of the economy. To estimate default rates in the business sector, we use an updated version of the empirical model originally developed by Misina and Tessier (2007). We also use the model described in Djoudad (2009) to estimate default rates on loans within the household

8 An obvious criticism of this approach is that the 2007–09 crisis was triggered by a financial shock generated by losses on subprime loans. This shock was amplified into a banking crisis and eventually a recession (and not the reverse). The framework can accommodate any type of initial shock, however, as long as the impact of that shock is mapped into an impact on bank capital.

9 Work is under way to map the process from initial shock to losses resulting from interest rate risk and market risk. The yield-curve model developed by Yang (2008) can be used to assess the extent of interest rate risk in the loan portfolios of banks, depending on the macro scenario.

sector. Within this framework, structural differences across banks, based on their balance sheets, are taken into account, since the larger a bank's exposure to stressed sectors, the larger its credit loss would be.

## Step 2: Funding liquidity risk

The MFRAF introduces funding liquidity risk by adapting recent theoretical advances proposed by Morris and Shin (2009), who note that solvency risk and liquidity risk are intertwined. This observation is consistent with the experience of the recent financial crisis.

The MFRAF divides the one-year horizon into three periods: the beginning of the year, when only expected first-round losses are known; the interim period, six months after the start, when some loan losses are realized, which could lead to a run on the bank by wholesale funding markets; and the end of the year, when total credit losses are observed.[10]

Funding liquidity risk materializes during the interim period, when the bank's short-term creditors have observed any credit losses incurred, are aware of the distribution of losses likely to occur in the next six months, and must decide whether or not to roll over their claims.[11] This decision also depends on their assumptions regarding the proportion of rollovers by other short-term creditors. The more pessimistic the short-term creditors are (i.e., the larger the share of creditors they expect to withdraw), the higher the likelihood of a run on an individual bank. These assumptions are influenced by the bank's ability to use its capital to absorb realized and expected credit losses, its funding structure, and the liquidity of its assets. Better-capitalized banks will be less prone to runs, and banks with lower reliance on wholesale short-term funding markets will be less vulnerable to changes in market sentiment. Moreover, runs become less likely if the bank holds a high level of liquid assets, which are the first defence against funding withdrawal. Market liquidity also plays an important role in creditors' decisions to renew their loans. If banks lack sufficient liquid assets to cover their funding needs and are forced to sell illiquid assets, they will be even more vulnerable to rollover risks, as the expected discount on these assets increases.

This approach to modelling funding liquidity risk in the banking sector is complementary to Basel III's new Liquidity Coverage Ratio (LCR) framework for Canada. While the LCR was designed using exogenous assumptions for withdrawal rates (on short-term liabilities) and drawdowns (on credit lines), the MFRAF assesses the endogenous likelihood of a run on each bank, consistent with market perceptions of the health of that bank.[12]

10 A run occurs when a bank's short-term creditors attempt to withdraw their claims simultaneously (or decide not to roll over their credit at maturity, as they would under normal circumstances) and the bank's liquid holdings are not sufficient to cover the withdrawals (i.e., the institution becomes illiquid). The time frame of the model can be changed by moving the interim date toward the beginning (end) of the scenario. This can have a significant impact on the results, since the amount of funding liabilities to be rolled over at the interim date decreases (increases), and so does funding liquidity risk. See Gauthier, He and Souissi (2010).

11 The greater the uncertainty around potential losses is, the larger the likelihood of a run by short-term creditors.

12 To reduce liquidity risk as well as solvency risk, Basel III will supplement the capital standards with the LCR, which aims to make banks more resilient to the risks associated with short-term funding. See BCBS (2010) for more details.

### Step 3: Banking sector risk

The MFRAF incorporates network externalities caused by defaults by counterparties.[13] A defaulting bank (or a bank with a serious capital shortfall) will not be able to fulfill its obligations in the interbank market, causing counterparty credit losses in the system and leading to the potential default of other banks. The size of a counterparty's interbank exposures, as well as factors that heighten insolvency and funding liquidity risk, increase the likelihood of spillover effects generated by counterparty defaults.

**Table 1** summarizes the impact (positive or negative) of increases in the degree of various factors affecting the size of interbank spillover effects, as well as the extent of solvency risk and funding liquidity risk. A higher level of capital, for example, would decrease solvency risk, while less reliance on short-term funding would reduce funding liquidity risk.

**Table 1: Impact of an increase in the intensity of key factors affecting risks considered in the MFRAF**

| | Solvency risk | Funding liquidity risk | Interbank spillover risk | Banking sector risk |
|---|---|---|---|---|
| Macroeconomic shocks | + | + | + | + |
| Reliance on short-term funding | | + | + | + |
| Discount on illiquid assets | | + | + | + |
| Size of interbank exposures | | | + | + |
| Holdings of liquid assets | | - | - | - |
| Capital | - | - | - | - |

Note: The + (-) sign represents an increase (decrease) in risk.

## Applications of the Framework

In this section, we present two different applications of the MFRAF. We first assess the risks in a hypothetical banking system affected by a macroeconomic stress scenario, and then demonstrate how the framework can be used as a tool for policy analysis.

### Application 1: Funding liquidity risk and network spillover effects

Canadian banks have been recognized for their resilience during the 2007–09 financial crisis because of lower leverage and lower reliance on wholesale short-term funding markets relative to many of their global peers. In our first application of the model, we illustrate how the Canadian banking system could have been affected had Canadian banks been more leveraged and hence more vulnerable to a liquidity shortfall. We create a hypothetical banking system consisting of six major banks whose main balance-sheet parameters (capital ratio level, reliance on short-term funding and holdings of liquid assets) are in line with those observed in 2007 for banks that were bailed out during the crisis. We calibrate the parameters of each bank as follows: Tier 1 capital ratio at 6 per cent, short-term liabilities (coming to maturity within six months) at 50 per cent of total liabilities and liquid-asset holdings at 10 per cent of total assets. This calibration compares with a 9.5 per cent Tier 1 capital ratio, short-term liabilities at 30 per cent of total liabilities and liquid assets at 12 per cent of total assets, on average, for Canadian banks in late 2007. We set all other balance-sheet parameters at the values for Canadian banks at the second quarter of 2008.

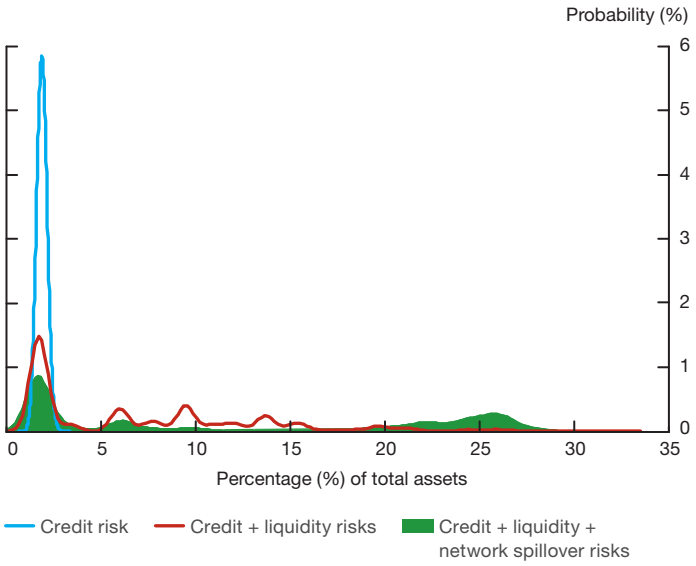
13 An externality is a cost or benefit incurred or enjoyed by a party that was not responsible for the cost or benefit.

Following Gauthier, Lehar and Souissi (2012), we use a severe but plausible macroeconomic scenario with a recession that is about 20 per cent larger than the one experienced in late 2008. The discount on illiquid assets is set at 75 per cent for the average bank.[14] To calibrate the network of exposures among the six banks in the hypothetical banking system, we use actual exposures among the Big Six Canadian banks as of the second quarter of 2008. This includes a set of exposures that exceeds those covered in related literature, which are generally limited to traditional lending, to include interbank exposures arising from cross-shareholdings, as well as exchange-traded and over-the-counter derivatives. The total size of the individual inter-bank exposures was approximately Can$21.6 billion, or about 25 per cent of individual bank capital, on average.

**Chart 1** shows the impact of the various risks analyzed in the MFRAF on the distribution of aggregated losses, as a percentage of total assets, in this hypothetical banking system. When only the direct impact of credit risk is considered (represented by the blue line), maximum system-wide losses are 3 per cent of total assets and average losses amount to less than 2 per cent of total assets. The extreme in the loss distribution (the tail) is, however, significantly affected by adding funding liquidity risk to credit risk (the red line). In this scenario, the negative tail outcomes of potential runs by short-term creditors are much more adverse and more likely to occur. Indeed, when factoring in liquidity risk, the likelihood of the banking system suffering losses larger than 10 per cent of its total assets increases markedly.

The inclusion of interbank network spillover risks on the system-wide loss distribution leads to multiple peaks (the shaded green area). One peak is associated with the average direct outcome of credit losses, while the peak in the right-hand tail captures the combined impact of network spillover

**Chart 1: Loss distributions of a hypothetical banking system for various groups of risks**




Source: Authors' calculations

**14** Loans and derivatives are assumed to be totally illiquid, i.e., with a 100 per cent discount.

risks and runs based on liquidity.[15] Our results demonstrate that a failure to account for either liquidity risk or network spillover effects could cause a significant underestimation of the extent of systemic risk in an under-capitalized banking system that relies extensively on the short-term funding market. Both liquidity risk and network externalities are virtually zero when the balance-sheet parameters are set to either the pre-crisis or current values for Canadian banks. Replicating the vulnerability of banks that got into trouble during the crisis, while also showing the robustness of Canadian banks, provides confidence in the ability of the MFRAF to assess risks.

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Our results also highlight the importance of obtaining timely information on exposures among banks and suggest that current initiatives under the Basel III framework to promote greater use of central counterparties could be useful in mitigating this risk.

## Application 2: Trade-offs between capital and liquidity

As illustrated in **Chart 1**, for institutions with low capital ratio levels (a 6 per cent capital ratio in this simulation), the presence of liquidity risk amplifies systemic risk. The MFRAF can contribute to the current work to reform liquidity regulation by measuring the trade-offs between higher levels of capital and a more-secure funding structure in reducing systemic risk. To illustrate this, we set the parameters for capital and funding liquidity at the same values for all banks in our hypothetical system. We then let short-term liabilities (S) vary uniformly between 25 per cent and 75 per cent of total liabilities and allow holdings of liquid assets (M) to vary between 5 per cent and 25 per cent of total assets, for two different levels of bank capitalization.[16]

*The MFRAF can measure the trade-offs between higher levels of capital and a more-secure funding structure in reducing systemic risk*

**Chart 2** plots systemic risk—measured as the probability of having at least one bank default—as a function of M and S for capital ratio levels of 6 per cent (a) and 8 per cent (b). As expected, systemic risk generally decreases as the capital ratio increases from 6 per cent to 8 per cent. For a given capital ratio, systemic risk rises as holdings of liquid assets decrease and short-term liabilities increase.

The distributions in **Chart 2** (a and b) show the relationship between systemic risk and the two dimensions of liquidity—short-term funding and holdings of liquid assets. In particular, the positive relationship between systemic risk and reliance on short-term funding is much steeper when banks have fewer liquid-asset holdings, for both levels of capital. This means that an illiquid bank is more sensitive to disruptions in short-term funding markets. Similarly, the negative relationship between systemic risk and holdings of liquid assets is more significant when banks have a greater reliance on short-term funding. Consequently, our framework allows us to assess the degree to which an increase in liquid-asset holdings would offset the negative effect on systemic risk arising from increases in short-term liabilities. These results support the new Basel III liquidity standards, demonstrating that both holdings of liquid assets and the structure of funding are relevant for the containment of liquidity risk at individual banks.[17] Limiting liquidity risk would in turn reduce the extent of systemic risk.

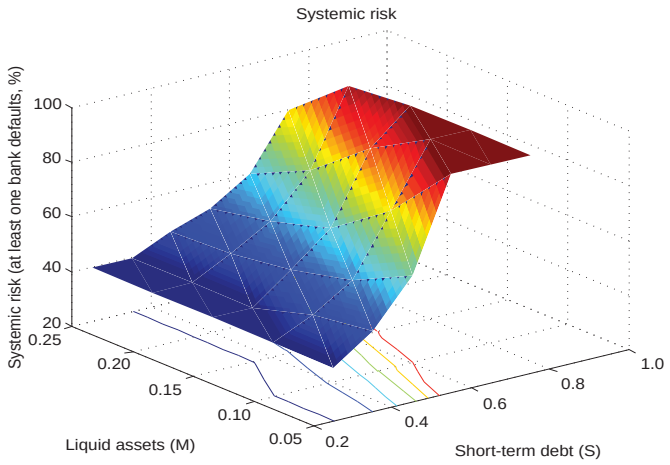
15 Alessandri et al. (2009) also obtain a system loss distribution with multiple peaks that takes into account the effects of network spillover risks and asset-price feedback. When the effects of network spillover risks and liquidity risks are considered, some banks may fail. The multiple modes are driven mainly by calibrated bankruptcy costs.

16 In recent years, Canadian banks, on average, have relied on unsecured short-term funding (holdings of liquid assets) at levels close to the lower (upper) bound of our simulated values.

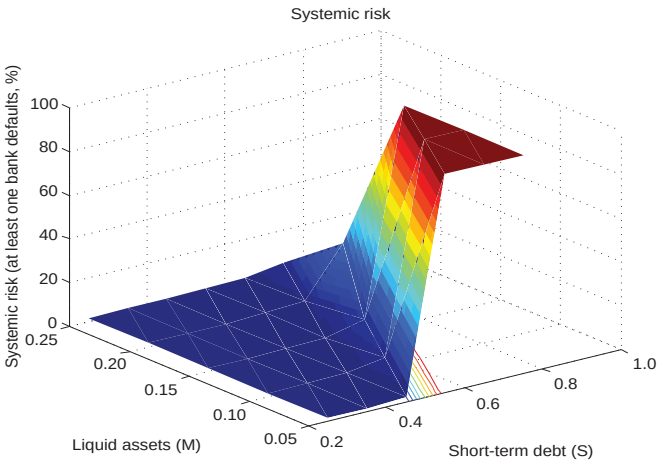
17 For details on the calibration of the LCR, see Gomes and Khan (2011).

**Chart 2: Systemic risk for different capital ratios under the assumed severe recession**

a. Capital ratio of 6 per cent




b. Capital ratio of 8 per cent




Source: Authors' calculations

Our results also suggest that a regulatory framework that takes systemic risk into account should consider capital, holdings of liquid assets and short-term liabilities in a comprehensive manner. For example, we find that an increase in the capital ratio from 6 per cent to 8 per cent would completely eliminate systemic risk for short-term funding below 40 per cent, and consequently make more liquidity unnecessary. This result is highly sensitive to the assumed capital threshold below which funding problems and network effects occur (zero in this simulation). If these effects were triggered much earlier (for capital close to the minimum requirements, for example), much more capital and liquidity would be required to eliminate systemic risk.

◂ *A regulatory framework that takes systemic risk into account should consider capital, holdings of liquid assets and short-term liabilities in a comprehensive manner*

## Concluding Remarks

The MFRAF is a tool for assessing systemic risk in the Canadian banking system. By using it to integrate funding liquidity risk as an endogenous outcome of the interactions among market liquidity risk, solvency risk and the structure of banks' balance sheets, we find that the failure to account for network effects and liquidity risk would cause a significant underestimation of the extent of systemic risk in the financial system.

In its current form, the MFRAF could be used to address various policy questions, such as the impact of central bank interventions on systemic risk during periods of financial stress. Central bank liquidity facilities could reduce the discount on illiquid assets, which would in turn reduce funding liquidity risk and systemic risk. Other potential policy topics include the measurement of the relative cost of regular and contingent capital, and whether bank size is an ideal determinant of a capital surcharge for systemically important financial institutions (see Gauthier et al. forthcoming).

The framework can also be extended in different directions. Work is under way to map the initial shock into losses arising from interest rate risk and market risk, and to introduce the potential for contagion among banks in short-term funding markets owing to, for example, negative information about one of them or about other non-regulated financial institutions.

Another important extension of the model would be to include any negative feedback that could occur between heightened risks to the banking system and the real economy.

## Literature Cited

Aikman, D., P. Alessandri, B. Eklund, P. Gai, S. Kapadia, E. Martin, N. Mora, G. Sterne and M. Willison. 2009. "Funding Liquidity Risk in a Quantitative Model of Systemic Stability." Bank of England Working Paper No. 372.

Alessandri, P., P. Gai, S. Kapadia, N. Mora and C. Puhr. 2009. "Towards a Framework for Quantifying Systemic Stability." *International Journal of Central Banking* 5 (3): 47–81.

Basel Committee on Banking Supervision (BCBS). 2010. "Basel III: International Framework for Liquidity Risk Measurement, Standards and Monitoring." Bank for International Settlements. Available at <http://www.bis.org/publ/bcbs188.pdf>.

Djoudad, R. 2009. "Simulations du ratio du service de la dette des consommateurs en utilisant des données micro." Bank of Canada Working Paper No. 2009-18.

Foglia, A. 2009. "Stress Testing Credit Risk: A Survey of Authorities' Approaches." *International Journal of Central Banking* 5 (3): 9–45.

Gauthier, C., T. Gravelle, X. Liu and M. Souissi. "What Matters in Determining Capital Surcharges for Systemically Important Financial Institutions?" In *Simulation in Computational Finance and Economics: Tools and Emerging Applications*. IGI Global (forthcoming).

Gauthier, C., Z. He and M. Souissi. 2010. "Understanding Systemic Risk: The Trade-Offs Between Capital, Short-Term Funding and Liquid Asset Holdings." Bank of Canada Working Paper No. 2010-29.

Gauthier, C., A. Lehar and M. Souissi. 2012. "Macroprudential Capital Requirements and Systemic Risk." *Journal of Financial Intermediation*. Available at <http://dx.doi.org/10.1016/j.jfi.2012.01.005>.

Gauthier, C. and H. Tomura. 2011. "Understanding and Measuring Liquidity Risk: A Selection of Recent Research." *Bank of Canada Review* (Spring): 3–11.

Gomes, T. and N. Khan. 2011. "Strengthening Bank Management of Liquidity Risk: The Basel III Liquidity Standards." Bank of Canada *Financial System Review* (December): 35–42.

Gravelle, T. and F. Li. 2011. "Measuring Systemic Importance of Financial Institutions: An Extreme Value Theory Approach." Bank of Canada Working Paper No. 2011-19.

Huang, X., H. Zhou and H. Zhu. 2010. "Assessing the Systemic Risk of a Heterogeneous Portfolio of Banks During the Recent Financial Crisis." Bank for International Settlements Working Paper No. 296.

Misina, M. and D. Tessier. 2007. "Sectoral Default Rates Under Stress: The Importance of Non-Linearities." Bank of Canada *Financial System Review* (June): 49–54.

Morris, S. and H. S. Shin. 2009. "Illiquidity Component of Credit Risk." Princeton University. Photocopy.

Yang, J. 2008. "Macroeconomic Determinants of the Term Structure of Corporate Spreads." Bank of Canada Working Paper No. 2008-29.