Quantifying Contagion Risk in Funding Markets: A Model-Based Stress-Testing Approach

K Anand[*] C Gauthier[†] M Souissi[‡]

[*]Deutsche Bundesbank [†]Université du Québec en Outaouais
[‡]International Monetary Fund

“Bad news”

- The subprime crisis was put in motion on Aug 9th, 2007
  - BNP Paribas announced it had suspended withdrawals from three investment funds exposed to U.S. subprime mortgages
- News triggered general market anxiety about the extent of other banks’ exposures to sub-prime mortgages and solvency
  - Exacerbated by the opacity of banks’ balance sheets
- Funding conditions deteriorated for all banks

"Good news"

- Flip side – good news can have a positive market impact
- The Supervisory Capital Assessment Program (SCAP)
  - Stress-tests conducted by the Federal Reserve on U.S. banks
  - First conducted in 2009 – midst of the crisis
  - Yielded credible results for prospective losses for banks
  - Helped restore confidence in the banking system

Information contagion and stress testing

- **Information contagion** – key driver in financial crises
- Modeling / quantifying contagion is crucial for **stress testing**
  - Identify vulnerabilities within financial systems
  - Support crisis management and resolution

Our contribution

- **We present a model-based stress-testing framework**
  - Banks' solvency risks, funding liquidity risks and market risks are intertwined due to information contagion
- Frictions
  - Coordination failure
  - Asymmetric information
- Used by the BoC in regular stress-testing of banks (MFRAF)

◂ Related Literature

Outline of Presentation

Overview

Our model

- Solvency risks
  - Exogenous
  - Stress-test scenario
- Funding liquidity risks
  - Endogenous
  - Coordination failures between a banks creditors
  - Global games (Morris and Shin, 2009)

Our model

- Market risks
  - Collateral haircuts – influences banks' recourse to liquidity
  - Macro-economy $= \begin{cases} \text{“Good”} \rightarrow \text{low haircuts} \\ \text{“Bad”} \rightarrow \text{large haircuts} \end{cases}$
  - Investors entertain prior beliefs on the macro-economy
  - Bank failure $\rightarrow$ Beliefs updated $\rightarrow$ “Bad” state more probable

Our results

- **Vicious illiquidity:** Investors' pessimism over the macro-economy hampers the bank's recourse to liquidity
  - Influences the incidence of bank runs
  - Investors turn more pessimistic
  - Driving down other banks' recourse to liquidity
- **Virtuous liquidity:** Investors' are optimistic to start with
  - Banks are more likely to survive solvency shocks
  - Investors turn more optimistic over asset quality
  - Other banks' recourse to liquidity improves

Our results

- **Haircut spread:** An increase in the haircut-spread heightens the illiquidity channel
  - Larger spread $\rightarrow$ greater uncertainty over macro-economy
  - Investors are more inclined to believe that banks fail because the macro-economy is in the “bad” state
- **Convergence:** For a system of $N \geq 2$ banks, a unique equilibrium is always reached after, at most, N iterations
  - Simple induction argument

MODEL

Agents and environment

- Three dates $t = 0, 1, 2$, and no time discounting
  - Map to an annual time-horizon
- $N = 2$ banks, $b \in \{1, 2\}$
- Two groups of risk-neutral agents
  - Banks' creditors; can consume in $t = 1$ or $t = 2$
  - Outside deep-pocketed investors; consume at $t = 2$
- Interim date $t = 1$ is divided into two rounds

Balance sheet in period 2

Risky Investments $Y^b - S_1^b - S_2^b$	**“Short-term” Debt** ST^b
	“Long-term” Debt LT^b
Liquid Assets M^b	**Capital** $\underbrace{E^b}_{=\mathrm{CET1}+\mathrm{In}-\mathrm{Div}} - S_1^b - S_2^b$

Insolvency

- Bank b is insolvent in period 2 whenever $E^b - S_1^b - S_2^b < 0$
- However, illiquidity in period 1 can also trigger insolvency

Recourse to liquidity in period 1 (round 1)

- Banks repo risky assets with investors for liquidity
  - Reversed in period 2
- **Pro-cyclical haircuts:** depend on the macro-economy
  - "Good" $(m = 1)$ – small haircut; $\psi_H < 1$ of liquidity
  - "Bad" $(m = 0)$ – large haircut; only $\psi_L < \psi_H$ of liquidity

Recourse to liquidity in period 1 (round 1)

- State m realized in period 2 – **no one knows the state**
  - Investors do not observe banks' shocks
  - Prior belief: $w_1 = \mathrm{Prob}(m = 1)$
- Bank b's recourse to liquidity is

$$M^b + \underbrace{\{w_1\, \psi_H + (1 - w_1)\psi_L\}}_{= \overline{\psi}^1} (Y - S_1^b)$$

Rollover risk in period 1 (round 1)

- The rollover decisions of bank b's "short-term" creditors at round 1 modeled as a binary-action simultaneous move game

	Solvent	Insolvent
Not to withdraw	$1+r^b$	0
Withdraw	1	1

Rollover risk in period 1 (round 1)

- If a fraction $\ell_1^b \in [0,1]$ creditors withdraw, bank b is illiquid if

$$\ell_1^b > \lambda^b\left(S_1^b; \overline{\psi}^1\right) \equiv \frac{M^b + \overline{\psi}^1\left[Y^b - S_1^b\right]}{ST^b}$$

- We refer to λ^b as the **balance sheet liquidity** for bank b

Rollover risk in period 1 (round 2)

- Indicator $\eta_1^b \in \{0, 1\}$ for the outcome of bank b after round 1
- End of round 1, bank b is $\begin{cases} \text{liquid} & \rightarrow \eta_1^b = 0 \\ \text{illiquid} & \rightarrow \eta_1^b = 1 \end{cases}$
- Investors update their belief $w_2 = \text{Prob}\left(m = 1 | \eta_1^1, \eta_1^2\right)$

Rollover risk in period 1 (round 2)

- Change to liquid bank(s) recourse to liquidity ("margin call")

$$\overline{\psi}^2 = w_2\,\psi_H + (1 - w_2)\psi_L$$

- Creditors of liquid bank(s) decide to withdraw in round 2
    - Payoffs same as in round 1

- If a fraction $\ell_2^b \in [0, 1]$ of "short-term" creditors from (liquid) bank b withdraw, then bank b is illiquid if

$$\ell_2^b > \lambda^b\left(S_1^b; \overline{\psi}^2\right)$$

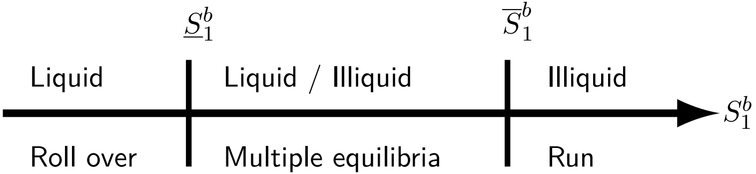
Model timeline

$t = 0$	$t = 1$ (round 1)	$t = 1$ (round 2)	$t = 2$
1. Initial balance sheet	1. Interim shock	1. Belief updated	1. Final shock
	2. Private signals	2. “Margin calls”	2. Incomes accrued
	3. ST debt withdrawals	3. New private signals	3. Dividends paid
		4. ST debt withdrawals	4. State m realized

EQUILIBRIUM

Tripartite classification of shock

- With common knowledge about the shock, in each round



- Solve for the Bayes-Nash equilibrium in each round
  - Creditors of bank b receive a noisy signal on S^b
  - The noise is i.i.d across creditors and rounds

Critical illiquidity threshold

In the limit of vanishing private noise, there exists a unique equilibrium in threshold strategies, S_d^{b*}*, where bank* b *is illiquid if and only if* $S_1^b > S_d^{b*}$*.*

The threshold is implicitly defined by the indifference condition for the expected payoff to a creditor between rolling over and withdrawing:

$$F_2^b(E^b - S_d^{b*})\,\lambda^b(S_d^{b*};\overline{\psi}^d) = \frac{1}{1+r^b}.$$

Virtuous liquidity

If both banks are liquid at the end of round 1, then $w_2 > w_1$*. Consequently, both banks remain liquid at the end of round 2*

Vicious illiquidity

Suppose bank i is liquid and bank j is illiquid after round 1. The investors become more pessimistic, $w_2 < w_1$, whenever:

$$\frac{\mathrm{Prob}\left(\eta_1^i = 0 \,|\, m = 1\right)}{\mathrm{Prob}\left(\eta_1^i = 0 \,|\, m = 0\right)} < \frac{\mathrm{Prob}\left(\eta_1^j = 1 \,|\, m = 0\right)}{\mathrm{Prob}\left(\eta_1^j = 1 \,|\, m = 1\right)}.$$

If the downward revision of the belief is large enough, then bank i will also become illiquid at the end of round 2

Price and spread effects

For a given initial belief, w^1*, and "bad" state haircut,* ψ_L*, an increase in the "good" state haircut,* ψ_H*, increases the spread,* $\Delta = \psi_H - \psi_L$*. This, in turn, strengthens the pessimism condition and increases the range of parameters where the investor's belief is revised downwards.*

On the other hand, for a given "good" state haircut, ψ_H*, an increase in the "bad",* ψ_L*, leads to a decrease in the spread. This weakens the pessimism condition and reduces the range of parameters where the investor's belief is revised downwards.*

Convergence

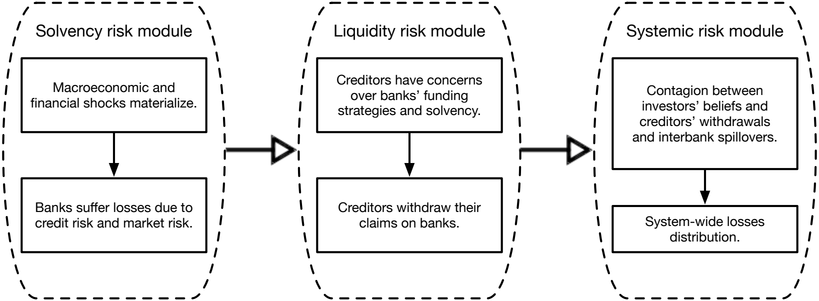
In a game involving $N \geq 2$ banks, the cycles of Bayesian updating by investors and withdrawal by creditors terminates after, at most, N rounds.

STRESS TESTING

Macro Stress Tests in Canada

- Annual exercise involving Canadian D-SIBS
- **Objective**: Assess the resilience of the financial system to extreme but plausible shocks
- MST scenario development
- Bottom-up exercise
  - Banks apply MST scenario to their balance sheets
  - Focus on solvency risk only
- Top-down exercise
  - The Macro Financial Risk Assessment Framework (MFRAF)

The MFRAF: Structure



The MFRAF: Calibration

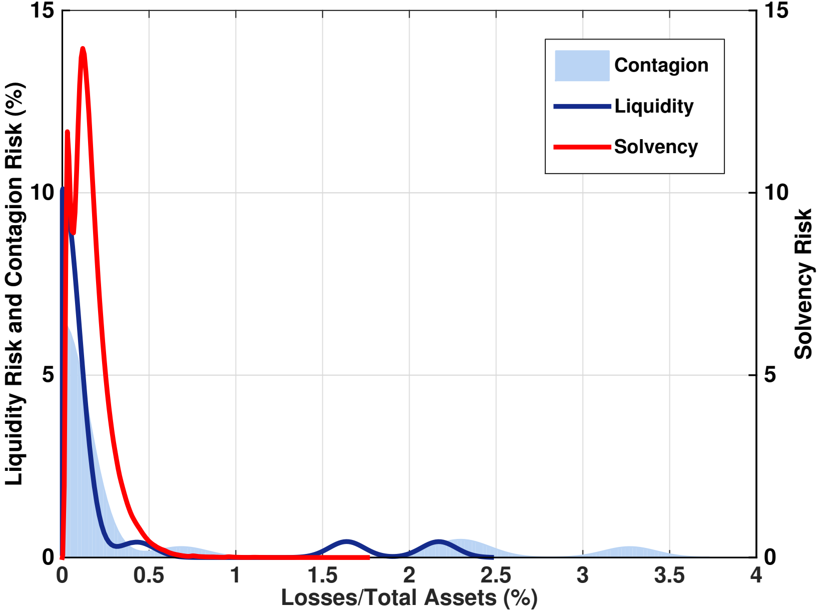
- Macroeconomic scenario draws on Canada's 2013 FSAP
- Canadian D-SIBs' balance sheet – 2013Q1
  - Average CET1 ratio – 8.9%
  - Liabilities maturity within 6 months – 35% of all liabilities
- Front-load income onto bank's capital
- "Insolvency" if capital falls below 7% CET1 capital
- Baseline
  - Identical asset portfolios and losses
  - Banks differ in their liability structures
  - Market liquidity parameters: $\psi_H = 0.3$ and $\psi_L = 0.2$

The MFRAF: Results

- Average balance sheet liquidity $= 1.08$

	Risks			
Bank	Solvency	Liquidity	Contagion	Total
1	47.0	22.9	0.0	69.9
2	47.0	0.0	0.0	47.0
3	47.0	23.0	0.6	70.6
4	47.0	0.0	19.2	66.2
5	47.0	0.0	0.0	47.0
6	47.0	22.2	0.8	70.0

The MFRAF: System-wide loss distribution



Conclusion

- We offer a model-based stress-testing framework
  - Information contagion amplifies banks' funding liquidity risks
  - Use Global games to solve for unique equilibrium
- Uses in policy
  - Consistency check for bottom-up results
  - Considers impact of second-round effects over and above the (solvency only) bottom-up stress-test
  - Quantifies liquidity assistance required to avoid runs

Thank you!

Related literature

- Chen (1999) – Heterogenous information amongst depositors are responsible for runs
- Acharya and Yorulmazer (2008) – Ex-post information contagion leads to ex-ante herding, with banks undertaking correlated investments
- Li and Ma (2013) – Most similar to our paper; coordination failure and adverse selection mutually reinforce each other, leading to bank runs and fire-sales
- Many models of stress-testing, e.g., Elsinger et al. (2006), Alessandri et al. (2009), and Gauthier et al. (2012)

Return

References

Acharya, V. and T. Yorulmazer (2008). Information contagion and bank herding. *Journal of Money, Credit and Banking 40*(1), 215–231.

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.

Chen, Y.-N. (1999). Banking panics: The role of the first-come, first-served rule and information externalities. *Journal of Political Economy 107*(5), 946–968.

Elsinger, H., A. Lehar, and M. Summer (2006). Risk assessment for banking systems. *Management Science 52*(9), 1301–1314.

Gauthier, C., A. Lehar, and M. Souissi (2012). Macroprudential capital requirements and systemic risk. *Journal of Financial Intermediation 21*(4), 594–618.

Li, Z. and K. Ma (2013). Self-fulfilling fire-sales, bank runs and contagion: Implications for bank capital and regulatory transparency. Mimeo Warwick Business School.

Morris, S. and H. S. Shin (2009). Illiquidity component of credit risk. Mimeo Princeton University.