Stressed but not helpless: strategic behavior of banks under adverse market conditions

Grzegorz Hałaj and Sofia Priazhkina

EBA Workshop 2019
Paris, November 28, 2019

The views and findings of this paper are those of the authors and do not necessarily represent the views of the Bank of Canada.

www.bank-banque-canada.ca
Motivation

- Banks take actions during stress that amplify/mitigate systemic risk
Research Contribution

- First bank stress test model capturing banks’ strategic behavior
  - Detailed balance sheets
  - Analytical solution (existence/uniqueness)
  - Banks sensitive to changes in expectations, risk, and externalities that they impose on each other
  - Basel III (role of regulation in stress propagation, interactions of leverage, capital, liquidity requirements)

- Model calibrated to historical data for Canadian D-SIBs
  - Most difficult part
Key results

- **Theory of management actions:**
  Unique equilibrium of actions with market externalities

- **Application:**
  Management actions help D-SIBs withstand the scenario
  - Banks broadly *maintain their capital ratios*
  - But at a cost of *reducing lending* to real economy
  - However strategic interactions *limit the reduction* of loans
New Dynamic Balance Sheet (DBS) model

- **Objectives**: banks maximize expected return to shareholders, subject to Basel III requirements (capital + leverage + liquidity)

- **Management actions**:
  - Banks rebalance their portfolios of assets
  - Given elasticity of funding costs and risk/return of each asset

- **Externalities** that banks impose on each other: Nash game (banks factor in other banks expected actions into their actions)

“Not a black box”: analytical solution exists and is unique
Application: one-period models run sequentially

Stress horizon:
2018Q4 (no stress)
2019Q1 (start stress)
2019Q4 (peak stress)
2020Q4 (end scenario)
Calibration strategy: estimation of elasticities

Two-step structural approach based on equilibrium equations

1) Sensitivity of funding cost to changes in leverage ratio

2) Sensitivity of prices to changes in transacted volumes

<table>
<thead>
<tr>
<th>balance sheet item</th>
<th>q¹</th>
<th>median</th>
<th>q³</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0</td>
<td>0.00000026</td>
<td>0.00000040</td>
<td>0.00000079</td>
</tr>
<tr>
<td>L1</td>
<td>0.00000044</td>
<td>0.00000076</td>
<td>0.00000150</td>
</tr>
<tr>
<td>L2</td>
<td>0.000000095</td>
<td>0.000000137</td>
<td>0.00000209</td>
</tr>
<tr>
<td>L3</td>
<td>0.00000056</td>
<td>0.00000073</td>
<td>0.00000138</td>
</tr>
<tr>
<td>L4</td>
<td>0.00000081</td>
<td>0.00000138</td>
<td>0.00000211</td>
</tr>
<tr>
<td>L5</td>
<td>0.00000164</td>
<td>0.00000490</td>
<td>0.00001253</td>
</tr>
<tr>
<td>L6</td>
<td>0.00001623</td>
<td>0.00002518</td>
<td>0.00009995</td>
</tr>
<tr>
<td>L7</td>
<td>0.00000579</td>
<td>0.00000813</td>
<td>0.00188304</td>
</tr>
<tr>
<td>S0</td>
<td>0.00000021</td>
<td>0.00000025</td>
<td>0.00000033</td>
</tr>
<tr>
<td>S1</td>
<td>0.000000601</td>
<td>0.00001345</td>
<td>0.00002124</td>
</tr>
<tr>
<td>S2</td>
<td>0.00000094</td>
<td>0.00000188</td>
<td>0.00000270</td>
</tr>
<tr>
<td>S3</td>
<td>0.00000001</td>
<td>0.00000004</td>
<td>0.00000012</td>
</tr>
</tbody>
</table>

+10 CAD bn (Δ volume) => -95 bps (Δ return)
Stress scenario applied to six Canadian D-SIBs

We use confidential supervisory data for individual banks

Macro scenario

<table>
<thead>
<tr>
<th></th>
<th>Historical stress periods</th>
<th>Pre-stress periods</th>
<th>Adverse Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real GDP growth</td>
<td>-3.4</td>
<td>-4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>(annual rate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-year government</td>
<td>9.8</td>
<td>3.0</td>
<td>1.9</td>
</tr>
<tr>
<td>bond yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-month government</td>
<td>10.0</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>bond yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House price (2017=100)</td>
<td>0.5</td>
<td>0.8</td>
<td>100</td>
</tr>
<tr>
<td>Equity price (2017=100)</td>
<td>0.2</td>
<td>0.7</td>
<td>100</td>
</tr>
<tr>
<td>Unites States</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real GDP growth</td>
<td>-0.9</td>
<td>-3.0</td>
<td>2.2</td>
</tr>
<tr>
<td>(annual rate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-year government</td>
<td>8.0</td>
<td>2.8</td>
<td>2.3</td>
</tr>
<tr>
<td>bond yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House price (2017=100)</td>
<td>0.4</td>
<td>0.8</td>
<td>100</td>
</tr>
<tr>
<td>Equity price (2017=100)</td>
<td>0.2</td>
<td>0.5</td>
<td>100</td>
</tr>
</tbody>
</table>
Assets shrink: substitute away risky business lending

Lower exposures to:
- Less profitable corporate loans (L0)
- Less profitable treasury bonds and cash (S0)

More exposures to:
- Relatively more profitable mortgages (L3 and L4)
Financial ratios under stress: mostly non-binding

- **Capital ratio non-binding**: First decline then rebuild
- **Leverage ratio non-binding**: Balance sheets shrink so leverage ratios improve
- **A few banks may be liquidity constrained**
Strategic interactions reduce the credit crunch

No strategic interactions:
Banks optimise in isolation (no game)

With strategic interactions:
Banks take actions of others into account (game)

-16% of business loans
-24% of business loans
DBS mechanics: Nash game

Δexposure

BANK A

rate

Δrate

reoptimise

Impact on loan profitability

BANK B

reoptimise

Impact on loan profitability

equilibrium

no game volume for comparison

Impact on loan profitability

reoptimise

Impact on loan profitability

Δexposure
Sensitivity analysis: risk aversion and LCR requirement

Change in average CAR from baseline:

<table>
<thead>
<tr>
<th></th>
<th>ΔCAR (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCR ↘ 60%</td>
<td>2.5</td>
</tr>
<tr>
<td>risk aversion ↗ 5</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Less liquidity constraint and more risk aversion mean more room to improve capital position

Changes of business loans from baseline:

<table>
<thead>
<tr>
<th></th>
<th>Δ business loans (in pp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCR ↘ 60%</td>
<td>0.1</td>
</tr>
<tr>
<td>risk aversion ↗ 5</td>
<td>-1.7</td>
</tr>
</tbody>
</table>

More risk averse banks cut more risky assets

baseline parameters: LCR=100, risk aversion=2
Robustness analysis: LCR

Sensitivities of prices to transacted volumes sampled from estimated distribution

Distribution of LCR well approximated by the mean projection (solid black line)...

...although for two bank (5,6) more dispersion
Conclusions

- First model of banks strategic behaviors where expected prices reflect banks’ decisions on credit/securities
  - We find that banks try to preserve their equity but cut on lending

- Several purposes:
  1. Enhance stress-test toolkit (relax static assumption)
  2. Allows for evaluation of Basel III effectiveness
  3. Identify parameters that drive shock amplification

- Future work
  - Calibrations + integration within BoC stress-test framework
Thank you!
Mechanism in one period: banking system

Bank 1

<table>
<thead>
<tr>
<th>ASSETS</th>
<th>LIABILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOANS</td>
<td>FUNDING</td>
</tr>
<tr>
<td>SECURITIES</td>
<td>CAPITAL</td>
</tr>
</tbody>
</table>

MARKET supply vs demand (loans, funding, collateral…)

Bank 2

<table>
<thead>
<tr>
<th>ASSETS</th>
<th>LIABILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOANS</td>
<td>FUNDING</td>
</tr>
<tr>
<td>SECURITIES</td>
<td>CAPITAL</td>
</tr>
</tbody>
</table>

Bank 3

<table>
<thead>
<tr>
<th>ASSETS</th>
<th>LIABILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOANS</td>
<td>FUNDING</td>
</tr>
<tr>
<td>SECURITIES</td>
<td>CAPITAL</td>
</tr>
</tbody>
</table>
Mechanism in one period: shock and rebalancing

Shock to risk/return parameters (e.g. PD)

Asset & Liability management: Rebalancing (Δ loans)

Market supply vs demand (loans, funding, collateral…)

Bank 1

Bank 2

Bank 3
Mechanism in one period: externalities

Result: unique Nash equilibrium of rebalancing strategies
Calibration strategy: six Canadian D-SIBs

We use confidential supervisory data

<table>
<thead>
<tr>
<th>bank number</th>
<th>assets</th>
<th>loans</th>
<th>deposits</th>
<th>capital</th>
<th>CET1</th>
<th>Leverage</th>
<th>LCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>714</td>
<td>322</td>
<td>168</td>
<td>43</td>
<td>11.2%</td>
<td>4.2%</td>
<td>1.5%</td>
</tr>
<tr>
<td>2</td>
<td>911</td>
<td>480</td>
<td>202</td>
<td>57</td>
<td>11.3%</td>
<td>4.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>3</td>
<td>541</td>
<td>317</td>
<td>153</td>
<td>24</td>
<td>12.1%</td>
<td>4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>4</td>
<td>245</td>
<td>117</td>
<td>53</td>
<td>12%</td>
<td>10.7%</td>
<td>3.7%</td>
<td>1.4%</td>
</tr>
<tr>
<td>5</td>
<td>1190</td>
<td>514</td>
<td>257</td>
<td>72%</td>
<td>10.5%</td>
<td>4.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>6</td>
<td>1227</td>
<td>577</td>
<td>454</td>
<td>73%</td>
<td>10.8%</td>
<td>3.9%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

**Table 1.** System of Canadian DSIBs

Note: in CAD billion (if not indicated that in %), quarterly average across 2015Q2 - 2018Q2. Source: regulatory reports and authors’ calculations
Business lending is less attractive and decreases 

-16% of business loans 

Because of:

- Higher default risk
- Lower expected return
Management actions considered in the model

- Broad range of actions possible: selected based on banks’ recovery plans and stress testing experience
- Fully taken - Asset management: liquidate or purchase securities, modify maturing loan exposures or give new loans
- Partially taken - Liability management: account for changing funding costs when balance sheet size changes;
- Not taken - Equity management: raise equity and/or change dividend policy.
Modeling RWA weights: Basel III

- Risk weights aligned with scenario based on IRB formulas and banks’ submissions
- Used Basel formulas to model RWA sensitivity to PD/LGD scenario
- Aggregation of exposures:
  – Corporate: Financial institutions, SME, HVCRE, Mortgage,
  – Retail: mortgage, consumer (qual. revolving), other retail
  – Depends on PD, LGD, and loan type
- Used LCR formulas with OSFI weights
## Timeline

<table>
<thead>
<tr>
<th>t=1</th>
<th>t=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>assets and liabilities</td>
<td>assets and liabilities</td>
</tr>
<tr>
<td>mature and deliver</td>
<td>mature and deliver</td>
</tr>
<tr>
<td>payoff</td>
<td>payoff</td>
</tr>
<tr>
<td>bank adjusts balance sheet</td>
<td>bank complies with regulatory ratios</td>
</tr>
<tr>
<td>market losses applied</td>
<td>regulatory ratios checked by modeller</td>
</tr>
</tbody>
</table>
Incentives of banks: utility and strategy

**Notation:** $x_b$ - vector of marginal changes in holdings of assets with respect to the status quo composition $a_b$

- restoring to status quo requires replenishing maturing exposures
- price elasticities control for unobservables: if overall market expands/contracts, it impacts current asset prices

**Incentives:** each bank maximizes expected return to shareholders:

$$\max_{x_b} E_{t+1|t} \left( \frac{e_b + Net\ Income_b(x_b, x_{-b})}{e_b} \right) - \gamma Var_{t+1|t} \left( \frac{e_b + Net\ Incom_{b,x_b(x_{b,x_{-b}})}}{e_b} \right)$$

Income is a quadratic function of $x_b$ (funding is chosen based on weights)

$$Net\ Income_b = I_b^{loans} + I_b^{sec} + I_b^{non-i} - Fund\ Cost_b$$
Incentives of banks: feedback effects

- Sales/purchases of securities are costly: linear price impact $\alpha^S$ for each bank $b$ → quadratic loss:
  \[
  \left( x_b^S + \mu_b a_b^S \right) \alpha^S \left( x_b^S + \sum x_{-b}^S \right) \\
  \frac{\text{volume trans.}}{\text{price change}}
  \]

- The future interest income is subject to recovery/momentum $\beta^S$:
  \[
  r_b^{S \times} = r_b^S + \beta^S \alpha^S \left( x_b^S + \sum x_{-b}^S \right) + \varepsilon_b^S
  \]

- Expansion of loan market dampens marginal returns while shrinking – profitable opportunities → quadratic loss on new loans
  \[
  r_b^{L \times} = r_b^L + \left( x_b^L + \mu_b a_b^L \right) \alpha^L \left( x_b^L + \sum x_{-b}^L \right) \\
  \frac{\text{volume trans.}}{\text{price change}}
  \]

- Funding cost increases when banks become less solvent/liquid ($c_r^f$ is different for collateralized funding $f = 3$)
  \[
  c_b^f = c_b^{f,0} + \sum_{k\in\{b,-b\};r\in\{lev,lcr,car\}} c_r^f \frac{1}{(r_k^r - r^r)}
  \]
Quadratic optimization: best response

We can re-formulate the problem as mean-variance optimization w.r.t. $x$

$$x_b^* = \arg\min_{x_b} \frac{1}{2} x_b' Q_b x_b + x_b' (m^0_b + \sum_k m_{bk} x_k)$$

subject to regulatory constraints + boundary conditions

$$\frac{CET1 \text{ Capital}}{RWA(x_b)} \geq \alpha^{CET1}$$
$$\frac{HQLA(x_b)}{\text{Net Cash Outflows}(x_b)} \geq \alpha^{LCR}$$
$$\frac{T1 \text{ Capital}}{\text{Asset Exposure}(x_b)} \geq \alpha^{LEV}$$

Matrices $m^0_b, m_{bk}$ and $Q_b$ are functions of

- Loan characteristics: $E[\text{returns}], \text{maturities}, \text{price sensitivities}$
- Market effects: $E[\text{returns}], \text{price sensitivities}$
- Current exposures + regulatory gaps
- Variances/Covariances
- Non-interest income & Funding cost sensitivities
Limitation of DBS

- **Objectives**: alternating objectives between business-as-usual and stress periods (maximize probability of survival, with time varying risk aversion)

- **Actions**: changing of funding mix, raising of capital

- **Sensitivities**: no stress period in the data used for estimation (short time series)

- **Externalities**: perfect information on actions of others (banks may only learn about other banks’ moves by observing the market)
Theoretical Results

- Nash equilibrium exists and is unique → requires solving Kuhn-Tucker conditions (Rosen (1965))
- Without regulatory constraints:

\[
\begin{bmatrix}
x_1 \\
x_2 \\
\vdots \\
x_{N^b}
\end{bmatrix} = - \begin{bmatrix}
Q_1 & m'_{12} & \cdots & m'_{1,N^b} \\
m'_{21} & Q_2 & \cdots & m'_{2,N^b} \\
\vdots & \vdots & \ddots & \vdots \\
m'_{N^b,1} & m'_{N^b,2} & \cdots & Q_{N^b}
\end{bmatrix}^{-1} \begin{bmatrix}
m^0_1 \\
m^0_2 \\
\vdots \\
m^0_{N^b}
\end{bmatrix}
\]

- Not easy to solve KKT for granular balance sheets → Gauss-Seidel algorithm is applied to solve the problem numerically
Theoretical Results

- Regulatory constraints: signal for funding providers + Kuhn-Tucker problem
- Example: one bank with / without regulatory constraint
  - shadow cost of regulation for banks’ shareholders

\[
\lambda^{CET1} = \frac{1}{\tau^{CET1} \sigma_b} \omega' x_b^* - \frac{e}{\tau^{CET1} \sigma_b} \left( \frac{1}{\tau^{CET1}} - \frac{1}{\tau_0^{CET1}} \right)
\]

\[
x_b = x_b^* - \lambda^{CET1} \tau^{CET1} Q_b^{-1} \omega
\]

- Reduction in loan provisioning and fire sales
Calibration strategy: estimation of elasticities

Price sensitivities: estimated from the data for 2015-2018 assuming
1) no regulatory pressure and 2) observed balance sheets are Nash equilibrium
3) same funding sensitivity for unsecured funding

Regression equation for loan of type \(i\) of bank \(b\) at time \(t\) (similar for securities):

\[
\rho_{b,i,t}^L = \alpha_{b,i,t}^L \left( \mu_{b,i,t}^{L,x} a_{b,i,t}^{L,x} + 2x_{b,i,t}^L + \sum_k x_{k,i,t}^L \right) 
+ c^f \left( \frac{1 - \tau_{b,t}^{lev}}{\tau_{b,t}^{lev}} \nu' w_{b,t} + \frac{2}{\Delta \tau_{b,t}^{lev}} + \sum_k \frac{1}{(N_b - 1)} \frac{1}{\Delta \tau_{k,t}^{lev}} \right) 
+ c_{f,\text{coll}}^f \left( \frac{1}{\tau_{b,t}^{lev}} \nu^{\text{coll}} w_{b,t}^{\text{coll}} + \frac{2u_{b,t}^{\text{coll}}}{\Delta \tau_{b,t}^{lev}} + \sum_k \frac{1}{(N_b - 1)} \frac{u_{b,t}^{\text{coll}}}{\Delta \tau_{k,t}^{lev}} \right) + \varepsilon_{b,i,t}^L
\]

where \(\rho_{b,i,t}^L\) is expected return adjusted for covariances

\[
\rho_{b,i,t}^L = \tau_{b,i,t}^{L,c,\text{new}} - c_{b,t}^{0'} w_{b,t} + z_{b,t} + \frac{2\gamma}{e_{b,t}} \sum \text{Cov}_t(\ldots)
\]
Stressed banks reduce their balance sheet

Historical Stress

-0.14 billions (-3% of initial size)

Aggregate volume across DSIBs, billions

Historical Stress

Aggregate volume across DSIBs, billions

20181231 20191231 20201231

S3 Reverse Repo
S2 Corporate Bonds
S1 Equities
S0 Cash and Treasuries
L6 Government
L5 Non-Residential Mortgages
L4 Residential Mortgages Insured
L3 Residential Mortgages Uninsured
L2 Consumer
L1 Financial
L0 Business
Disregard earlier comment about smaller change!

Nicolas Whitman, 09/10/2019
Potential extensions

- **Other objective**: maximize something else than return on equity during stress (e.g. probability of survival)
- **Additional actions**: changes in funding mix (e.g. capital)
- **Add more players**: rather than just banks
- **Add informational frictions**: banks could learn by observing market prices instead of assuming perfect information
- **Add a macro feedback loop**: but lending volume changes
- **Refine calibration**: so far no stress period in the data