BANK OF CANADA
BANQUE DU CANADA

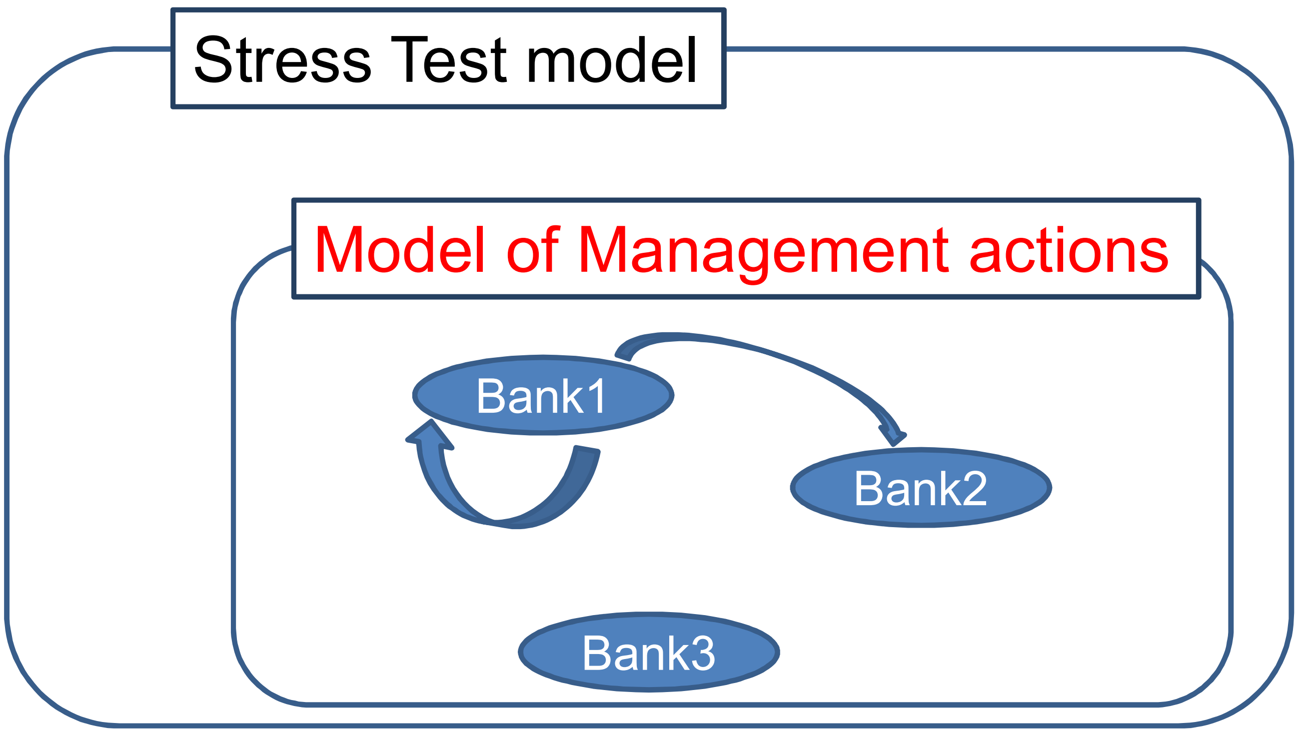
Stressed but not helpless: strategic behavior of banks under adverse market conditions

Grzegorz Hałaj and Sofia Priazhkina

EBA Workshop 2019
Paris, November 28, 2019

Motivation

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



BANK OF CANADA
BANQUE DU CANADA

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

BANK OF CANADA
BANQUE DU CANADA

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

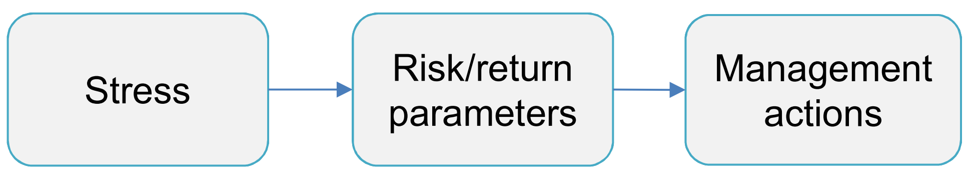
BANK OF CANADA
BANQUE DU CANADA

New Dynamic Balance Sheet (DBS) model

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

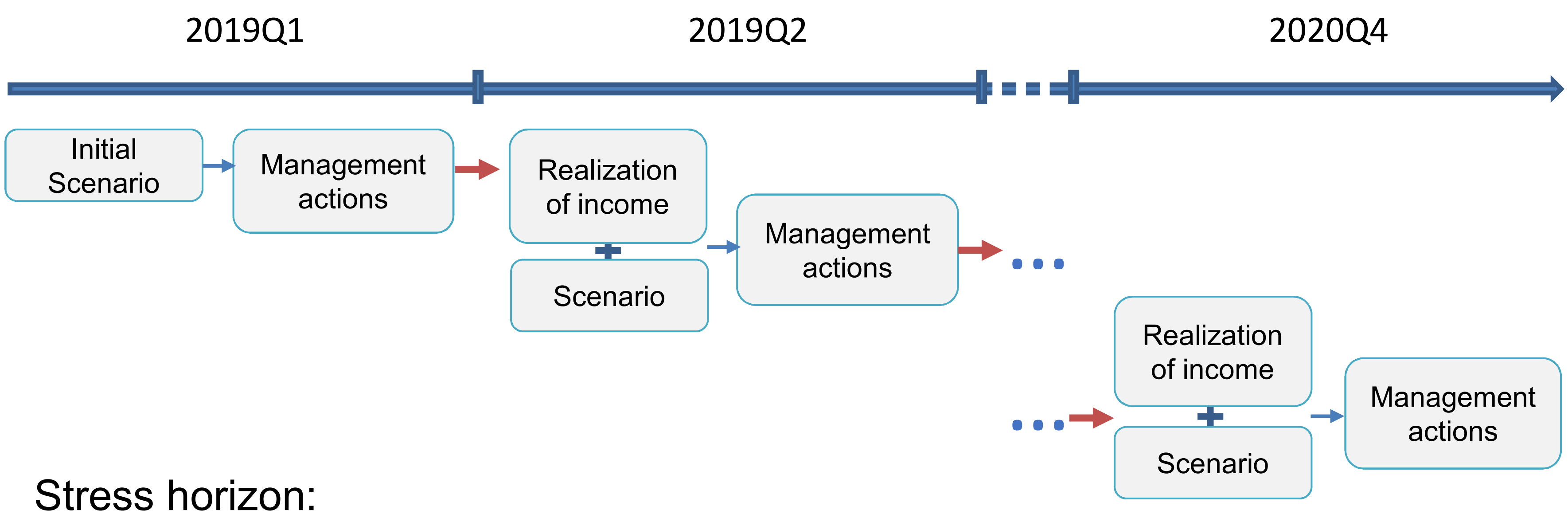
- **Management actions**:
  - Banks rebalance their portfolios of assets
  - Given elasticity of funding costs and risk/return of each asset

- **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

	Dependent variable:	
	diff(cost of repo)	diff(cost of funding)
	(1)	(2)
$\text{diff}(\frac{TA}{E})$	0.0002**	0.00003
	(0.0001)	(0.00002)
$\text{diff}\left(\frac{F2}{F0+F1+F2+F3}\right)$		−0.002**
		(0.001)
diff(tBill3m)	0.227***	0.031***
	(0.049)	(0.007)
Observations	240	240
R^2	0.119	0.120
Adjusted R^2	0.092	0.090
F Statistic	15.619*** (df = 2; 232)	10.538*** (df = 3; 231)
Note:		*p<0.1; **p<0.05; ***p<0.01

plug in

2) Sensitivity of prices to changes in transacted volumes

balance sheet item	q1	median	q3
L0	0.00000026	0.00000040	0.00000079
L1	0.00000044	0.00000076	0.00000150
L2	0.00000095	0.00000137	0.00000209
L3	0.00000056	0.00000073	0.00000138
L4	0.00000081	0.00000138	0.00000211
L5	0.00000164	0.00000490	0.00001253
L6	0.00001623	0.00002518	0.00009995
L7	0.00000579	0.00000813	0.00188304
S0	0.00000021	0.00000025	0.00000033
S1	0.00000601	0.00001345	0.00002124
S2	0.00000094	0.00000188	0.00000270
S3	0.00000001	0.00000004	0.00000012

+10 CAD bn (Δ volume) => -95 bps (Δ return)

Stress scenario applied to six Canadian D-SIBs

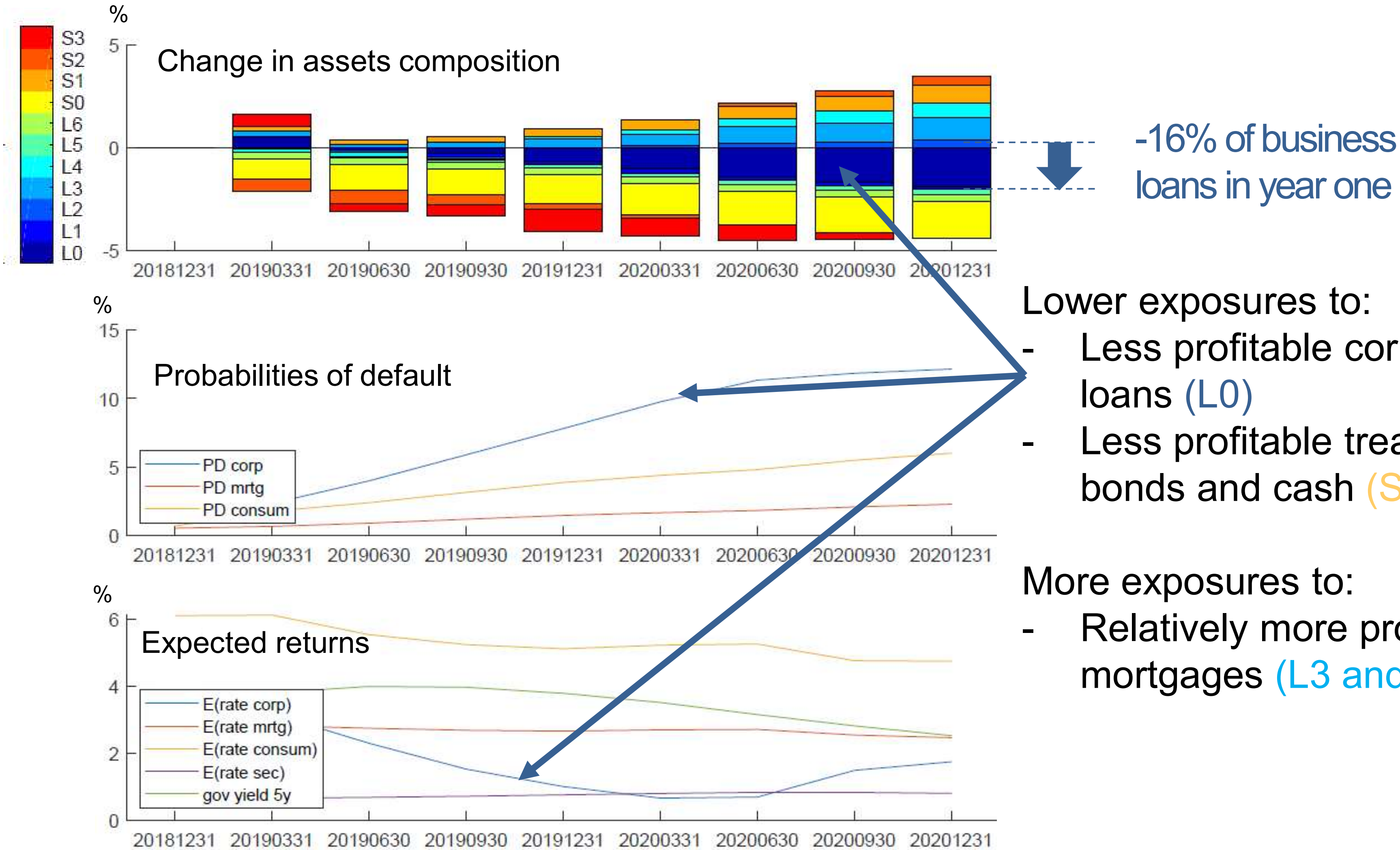
We use confidential supervisory data for individual banks

Macro scenario

		Historical stress periods		Pre-stress periods		Adverse Scenario	
		1991	2009	2017	2018	2019	2020
Canada							
	Real GDP growth (annual rate)	-3.4	-4.0	3.0	2.1	-3.0	-4.3
	10-year government bond yield	9.8	3.0	1.9	2.4	3.7	3.7
	3-month government bond yield	10.0	0.2	0.7	1.4	3.5	3.0
	House price (2017=100)	0.5	0.8	100	104	86	73
	Equity price (2017=100)	0.2	0.7	100	103	61	70
Unites States							
	Real GDP growth (annual rate)	-0.9	-3.0	2.2	2.9	-2.5	-3.0
	10-year government bond yield	8.0	2.8	2.3	2.9	3.8	3.4
	House price (2017=100)	0.4	0.8	100	107	103	102
	Equity price (2017=100)	0.2	0.5	100	113	75	84

BANK OF CANADA
BANQUE DU CANADA

Assets shrink: substitute away risky business lending



Lower exposures to:

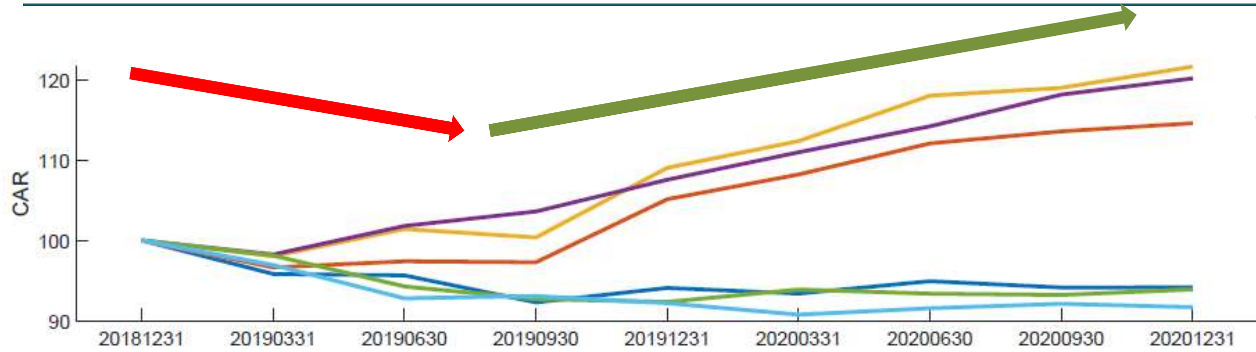
- Less profitable corporate loans (L0)
- Less profitable treasury bonds and cash (S0)

More exposures to:

- Relatively more profitable mortgages (L3 and L4)

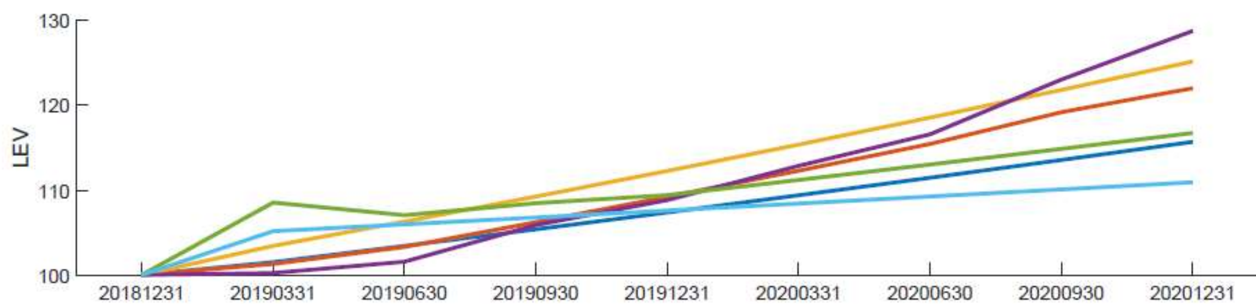
BANK OF CANADA
BANQUE DU CANADA

Financial ratios under stress: mostly non-binding



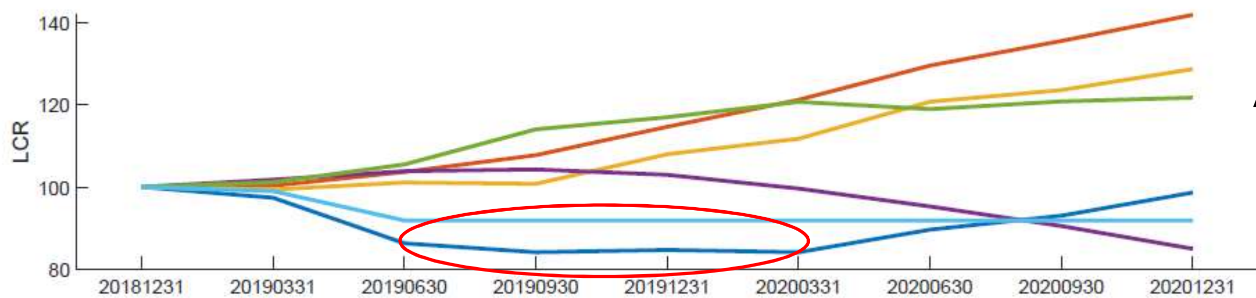
Capital ratio non-binding

First decline then rebuild



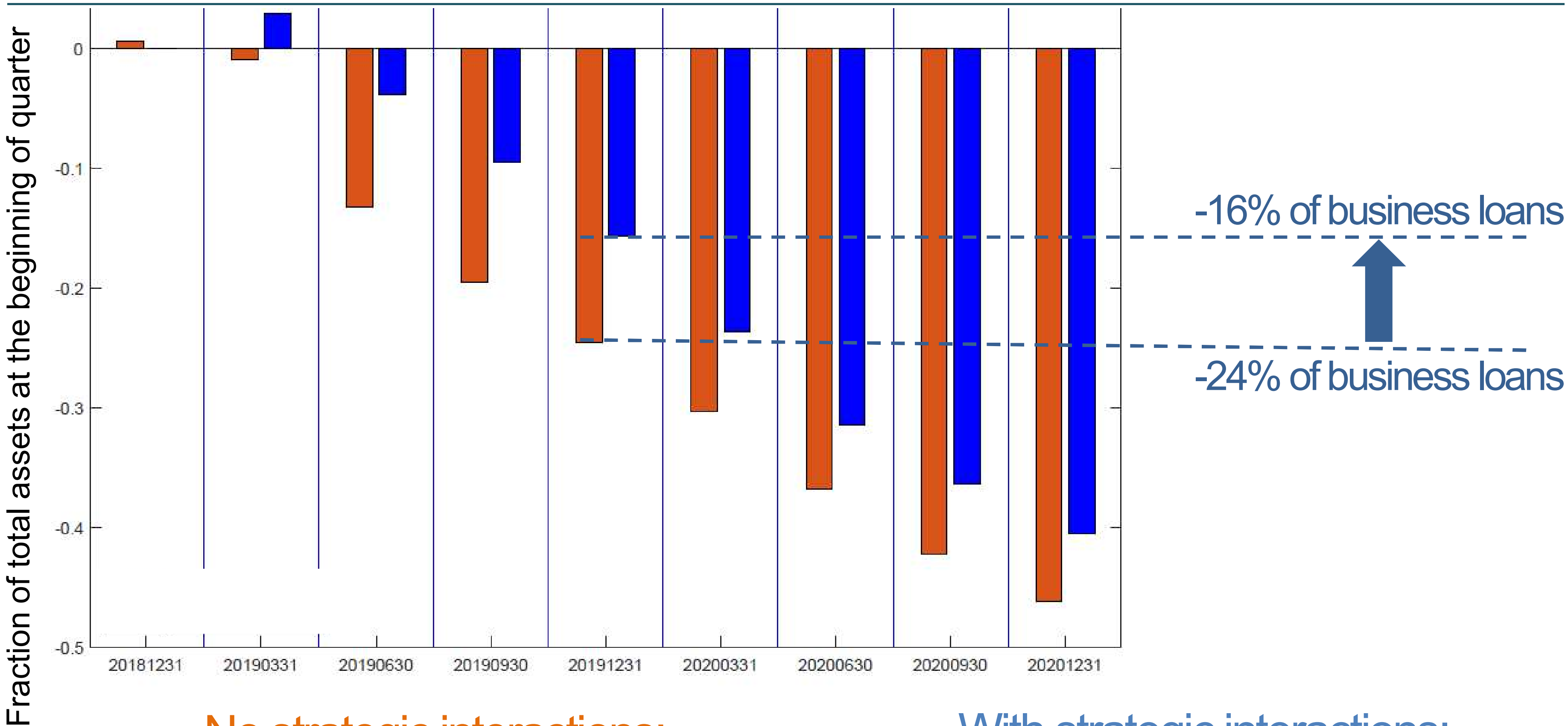
Leverage ratio non-binding

Balance sheets shrink so leverage ratios improve



A few banks may be liquidity constrained

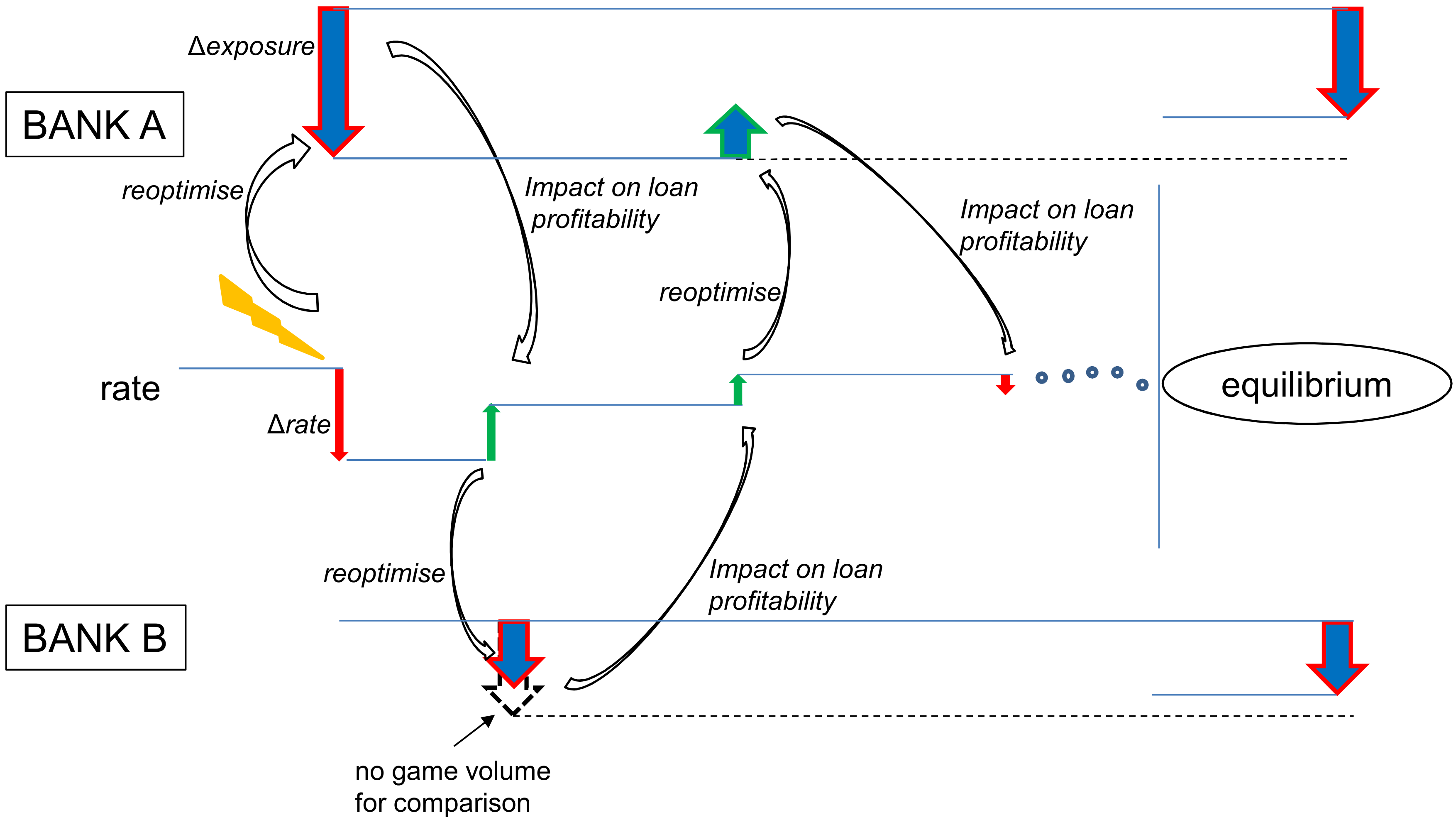
Strategic interactions reduce the credit crunch



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

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

DBS mechanics: Nash game



BANK OF CANADA
BANQUE DU CANADA

Sensitivity analysis: risk aversion and LCR requirement

Change in average CAR from baseline:

	ΔCAR (bps)
LCR ↘ 60%	**2.5**
risk aversion ↗ 5	**5.5**

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

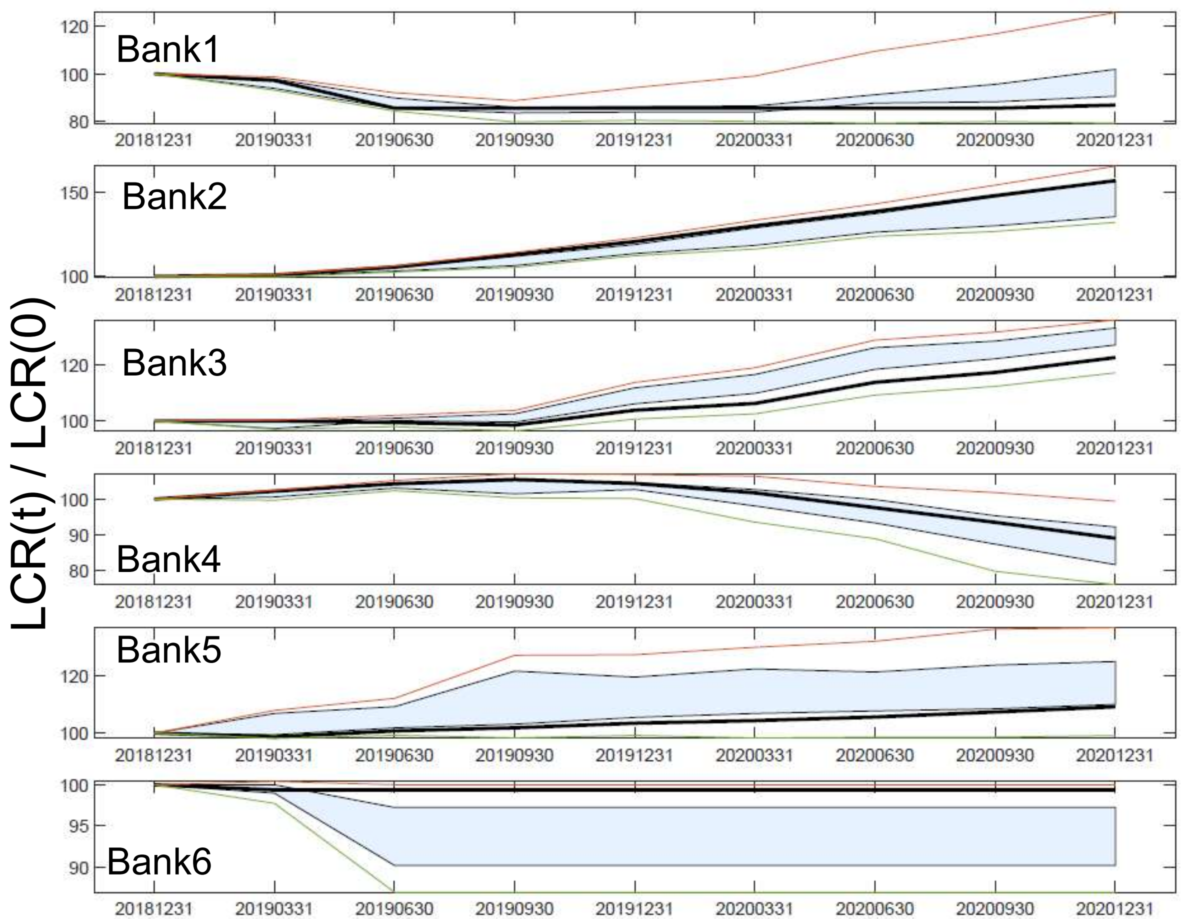
Changes of business loans from baseline:

	Δ business loans (in pp)
LCR ↘ 60%	**0.1**
risk aversion ↗ 5	**-1.7**

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

BANK OF CANADA
BANQUE DU CANADA

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

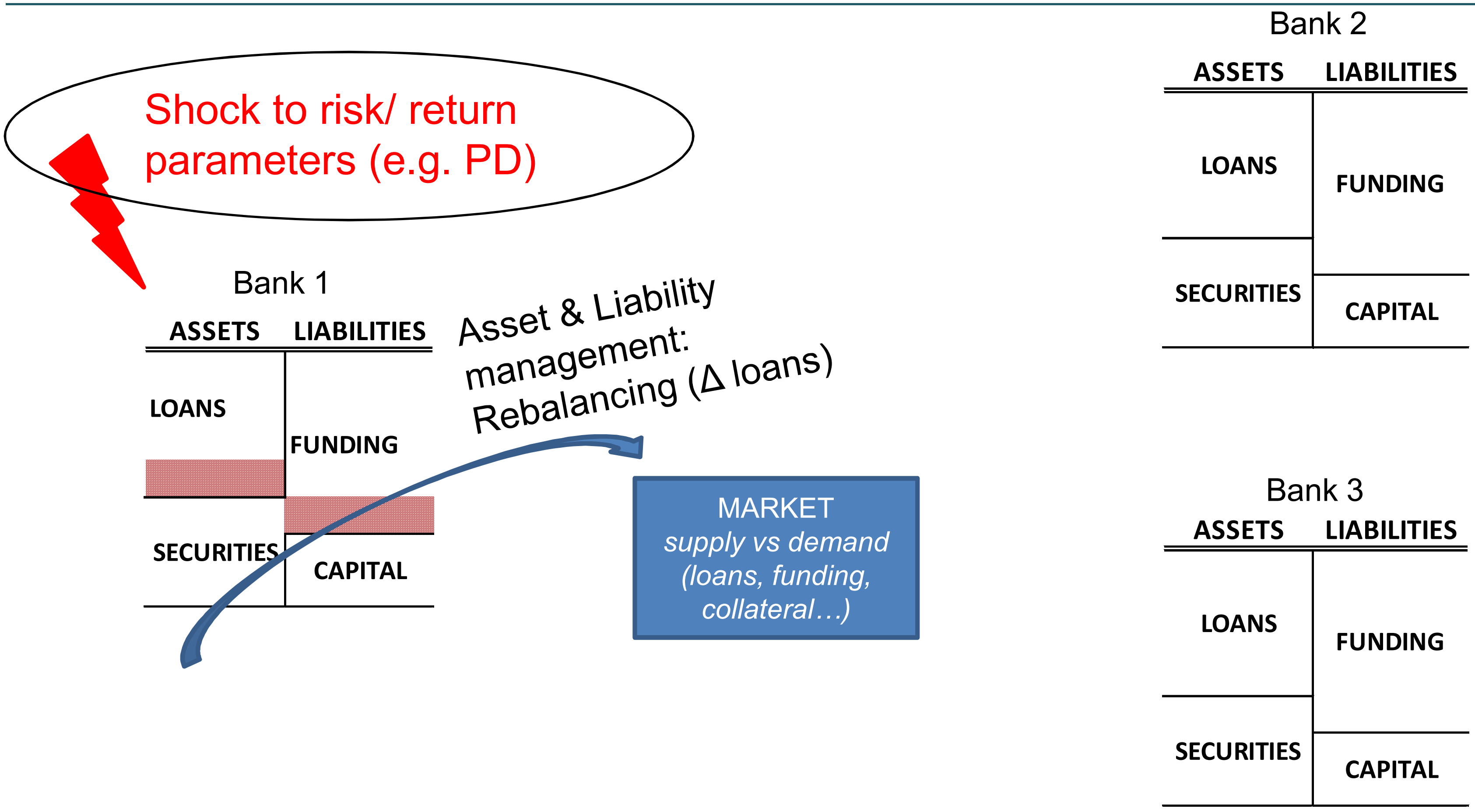
BANK OF CANADA
BANQUE DU CANADA

Thank you!

BANK OF CANADA
BANQUE DU CANADA

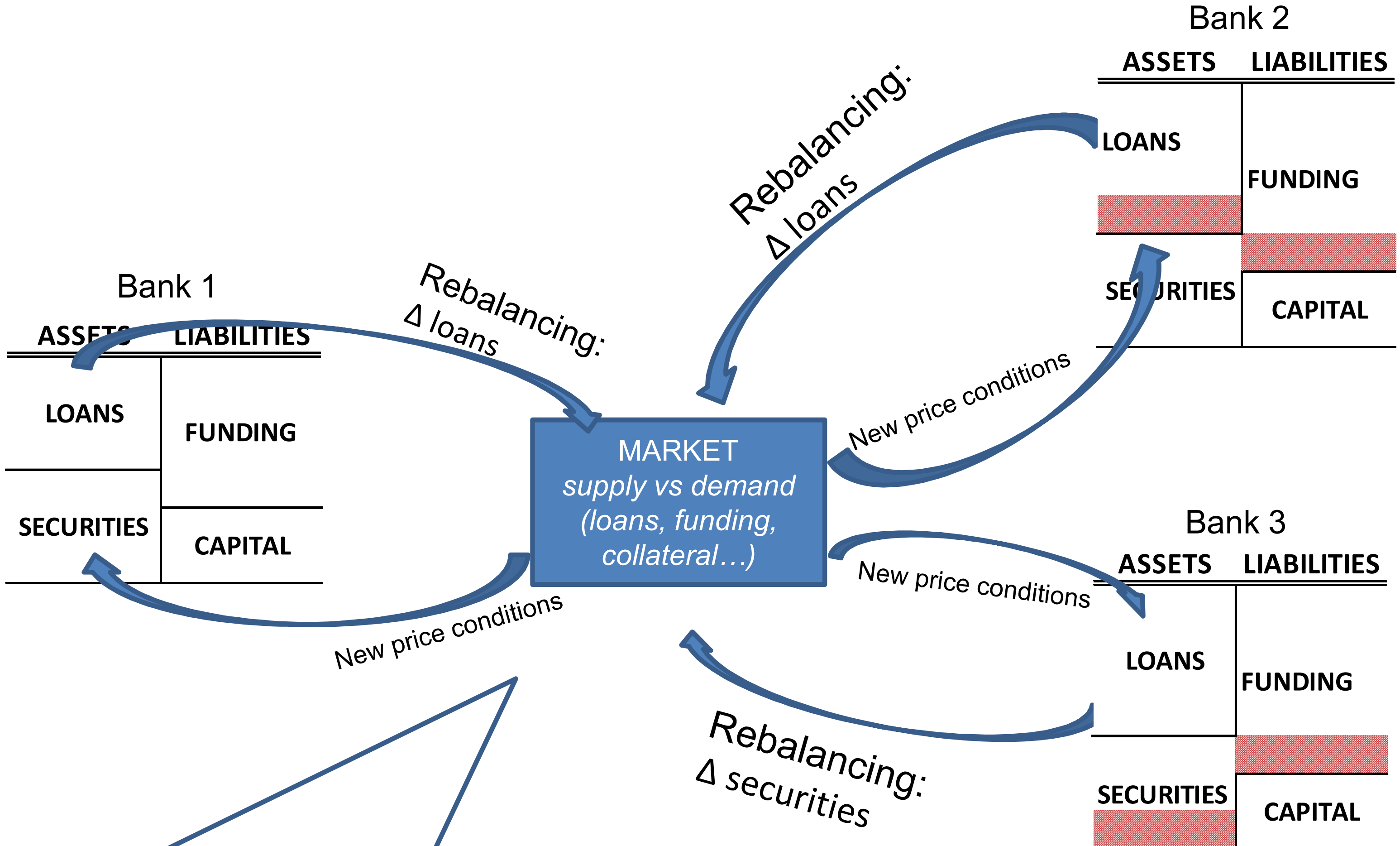
Mechanism in one period: banking system

Mechanism in one period: shock and rebalancing



BANK OF CANADA
BANQUE DU CANADA

Mechanism in one period: externalities



Result: unique Nash equilibrium of rebalancing strategies

Calibration strategy: six Canadian D-SIBs

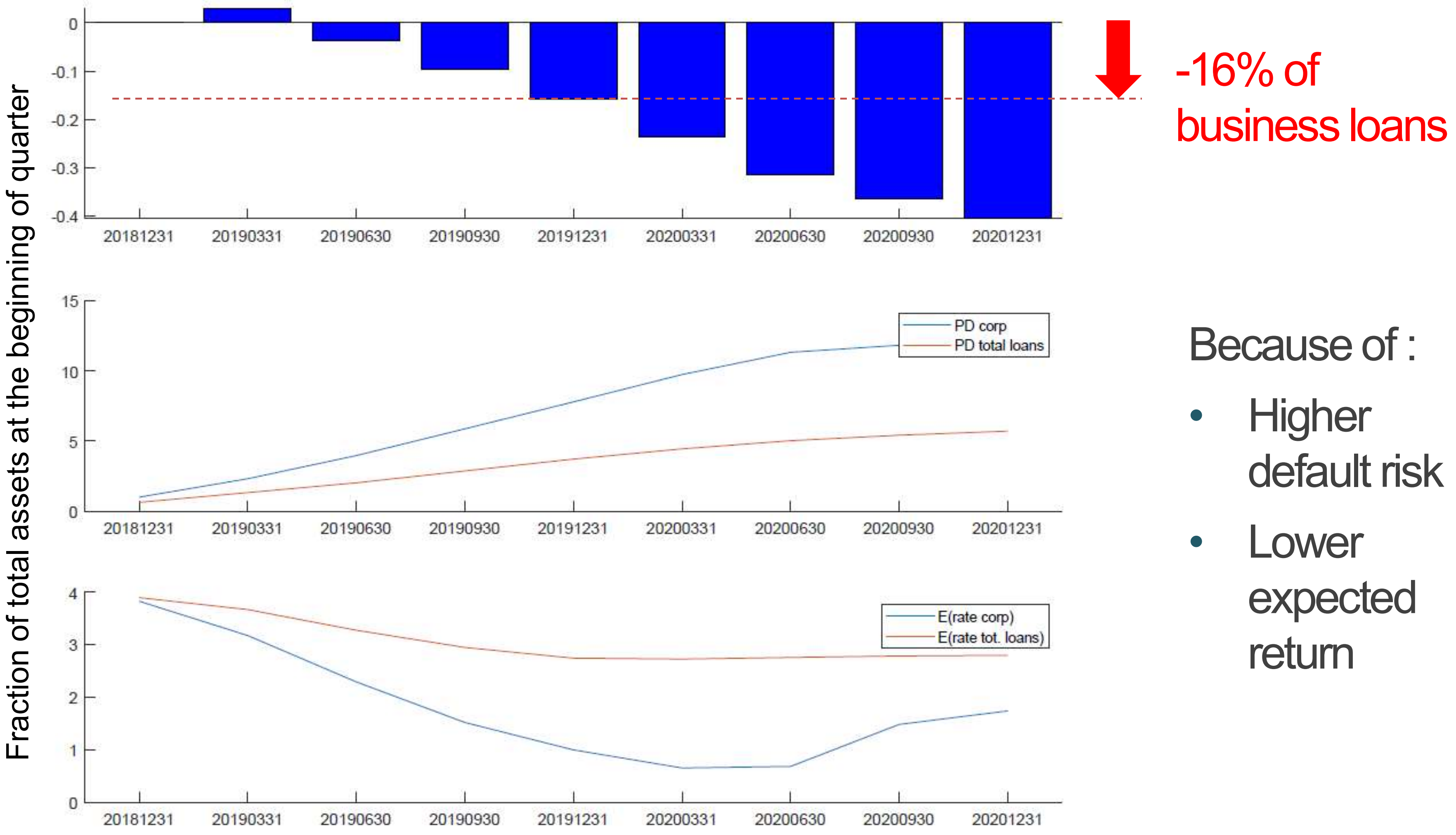
We use confidential supervisory data

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

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



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


assets and liabilities mature and deliver payoff
bank adjusts balance sheet
bank complies with regulatory ratios
market losses applied
assets and liabilities mature and deliver payoff
regulatory ratios checked by modeller
t=1
t=2

BANK OF CANADA
BANQUE DU CANADA

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:

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

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

$$Net\ Income_b = I_b^{loans} + I_b^{sec} + I_b^{non-i} \quad - Fund\ Cost_b$$

Incentives of banks: feedback effects

- Sales/purchases of securities are costly: linear price impact α^S for each bank b→ quadratic loss:

$$\underbrace{(x_b^S + \mu_b^S a_b^S)}_{volume\ trans.} \underbrace{\alpha^S(x_b^S + \sum x_{-b}^S)}_{price\ change}$$

- The future interest income is subject to recovery/momentum β^S:

$$r_b^{S,x} = r_b^S + \beta^S \alpha^S (x_b^S + \sum x_{-b}^S) + \varepsilon_b^S$$

- Expansion of loan market dampens marginal returns while shrinking -- profitable opportunities→ quadratic loss on new loans

$$r_b^{L,x} = r_b^L + \underbrace{(x_b^L + \mu_b^L a_b^L)}_{volume\ trans.} \underbrace{\alpha^L(x_b^L + \sum x_{-b}^L)}_{price\ change}$$

- Funding cost increases when banks become less solvent/liquid (c_r^f is different for collateralized funding $f = 3$)

$$c_b^f = c_b^{f,0} + \sum_{k=\{b,-b\};\, r=\{lev,lcr,car\}} c_r^f \frac{1}{(\tau_k^r - \tau^r)}$$

Quadratic optimization: best response

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

$$x_b^* = argmin_{x_b} \quad \frac{1}{2} x_b' Q_b x_b + x_b'(m_b^0 + \sum_k m_{bk} x_k)$$

subject to regulatory constraints + boundary conditions

$$\frac{CET1\ Capital}{RWA(x_b)} \geq \alpha^{CET1}$$

$$\frac{HQLA\ (x_b)}{Net\ Cash\ Outflows(x_b)} \geq \alpha^{LCR}$$

$$\frac{T1\ \ Capital}{Asset\ Exposure\ (x_b)} \geq \alpha^{LEV}$$

Matrices m_b^0, m_{bk} and Q_b are functions of

- Loan characteristics: E[returns], maturities, price sensitivities
- Market effects: E[returns], 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:

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{N^b} \end{bmatrix} = - \begin{bmatrix} Q_1 & m'_{12} & \vdots & m'_{1,N^b} \\ m'_{21} & Q_2 & \vdots & m'_{2,N^b} \\ \vdots & \vdots & \vdots & \vdots \\ m'_{N^b,1} & m'_{N^b,2} & \vdots & Q_{N^b} \end{bmatrix}^{-1} \begin{bmatrix} m_1^0 \\ m_2^0 \\ \vdots \\ m_{N_b}^0 \end{bmatrix}$$

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

BANK OF CANADA
BANQUE DU CANADA

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

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

$$x_b = x_b^* - \lambda^{CET1}\tau^{\text{CET1}}Q_b^{-1}\omega$$

- 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):

$$\rho^L_{b,i,t} = \alpha^L_i \left(\mu^{L,x}_{b,i,t} a^{L,x}_{b,i,t} + 2x^L_{b,i,t} + \sum_k x^L_{k,i,t} \right)$$

$$+c^f \left(\frac{1-\tau^{lev}_{b,t}}{\tau^{lev}_{b,t}} \nu' w_{b,t} + \frac{2}{\Delta\tau^{lev}_{b,t}} + \sum_k \frac{1}{(N_b-1)} \frac{1}{\Delta\tau^{lev}_{k,t}} \right)$$

$$+c^{f,coll} \left(\frac{1}{\tau^{lev}_{b,t}} \nu^{coll} w^{coll}_{b,t} + \frac{2w^{coll}_{b,t}}{\Delta\tau^{lev}_{b,t}} + \sum_k \frac{1}{(N_b-1)} \frac{w^{coll}_{b,t}}{\Delta\tau^{lev}_{k,t}} \right) + \varepsilon^L_{b,i,t}$$

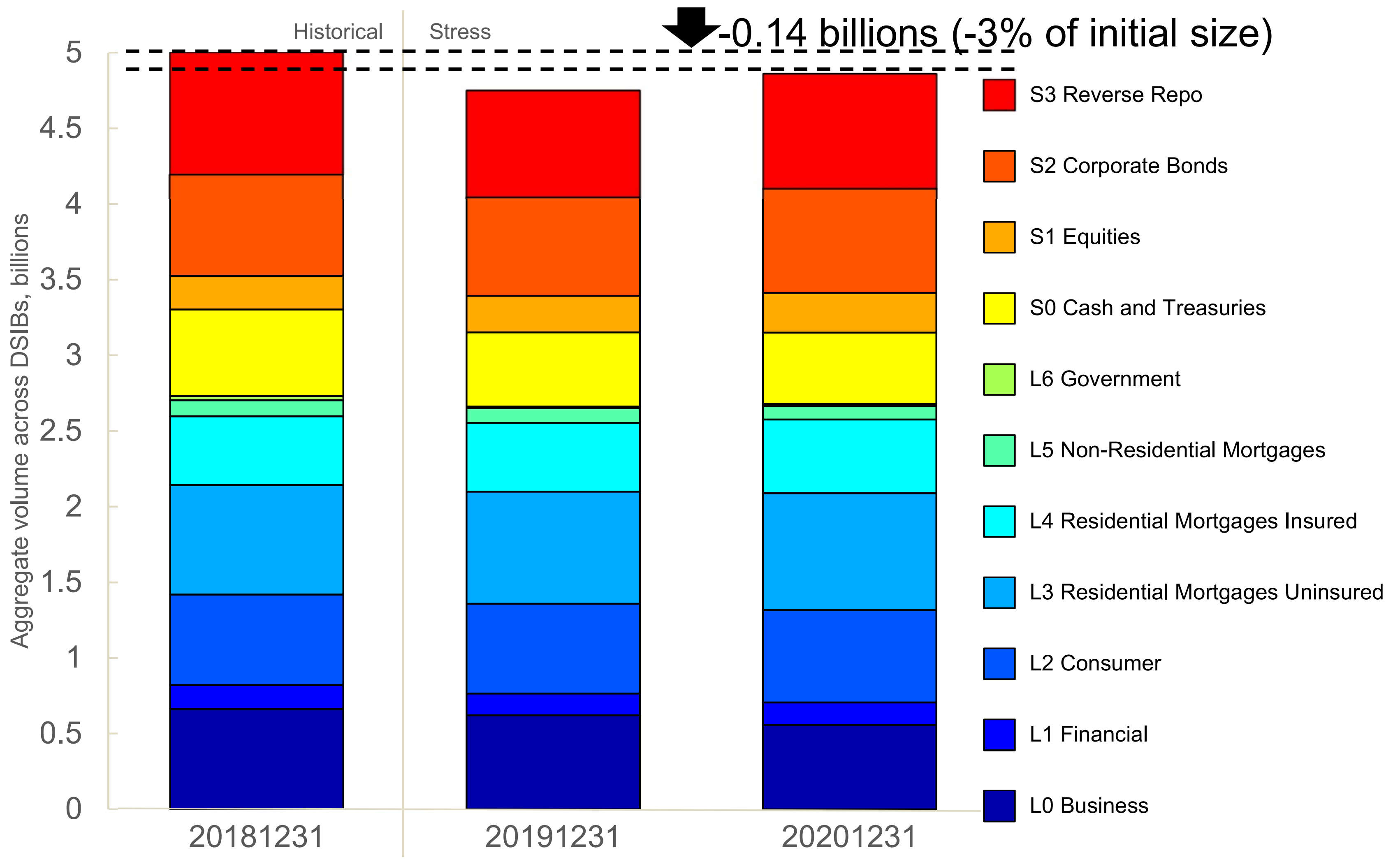
where $\rho^L_{b,i,t}$ is expected return adjusted for covariances

$$\rho^L_{b,i,t} = r^{L,c,new}_{b,i,t} - c^{0'}_{b,t} w_{b,t} + z_{b,t} + \frac{2\gamma}{e_{b,t}} \sum Cov_t(...)$$

NW6

BANK OF CANADA
BANQUE DU CANADA

Stressed banks reduce their balance sheet



Slide 32

NW6 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