SYSTEM DYNAMICS AND STRESS TESTING

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Outline

- Objective
- System Dynamics
- Banks
- Borrowers
- Non-bank Financial Institutions
- Macro-feedback
- Calibration

Objective

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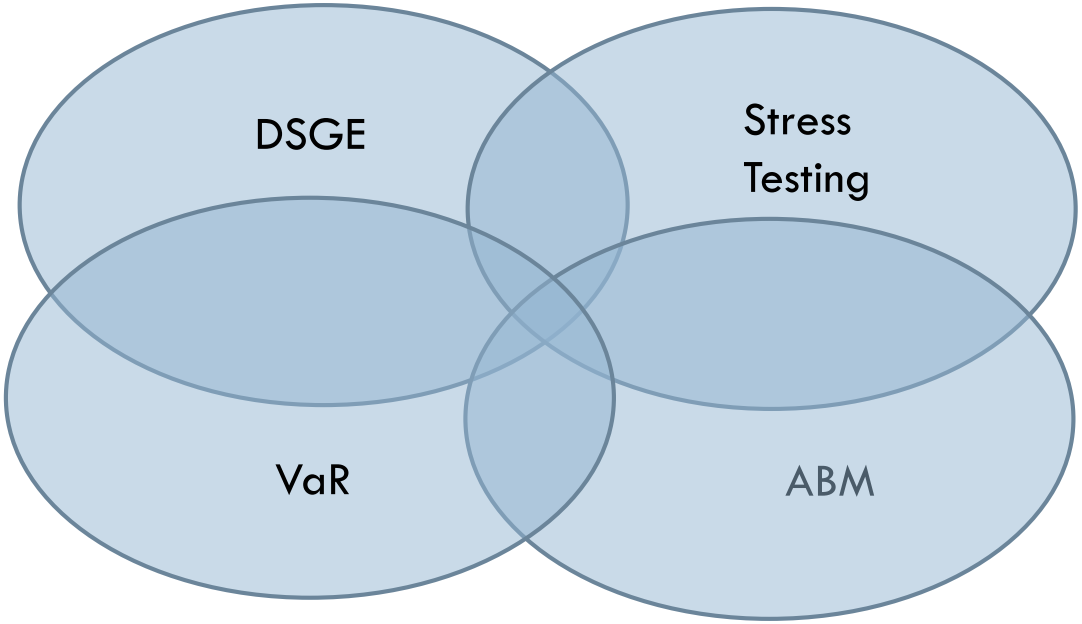
- Identify shocks and quantify feedback effects that might affect financial stability and the real economy
  - Assess banks' individual behavior and system-wide dynamics under different scenarios
  - Examine propagation of shocks within the financial system
  - Measure the impact on credit growth and GDP growth
- Facilitate a rapid policy response to shocks
  - Evaluate the impact of changes to bank capital regulation…
  - … and other financial sector policies
    - Liquidity regulation, regulatory treatment of provisions (IFRS 9), NPL guidance, LTRO, banking system structure

Modeling Approach



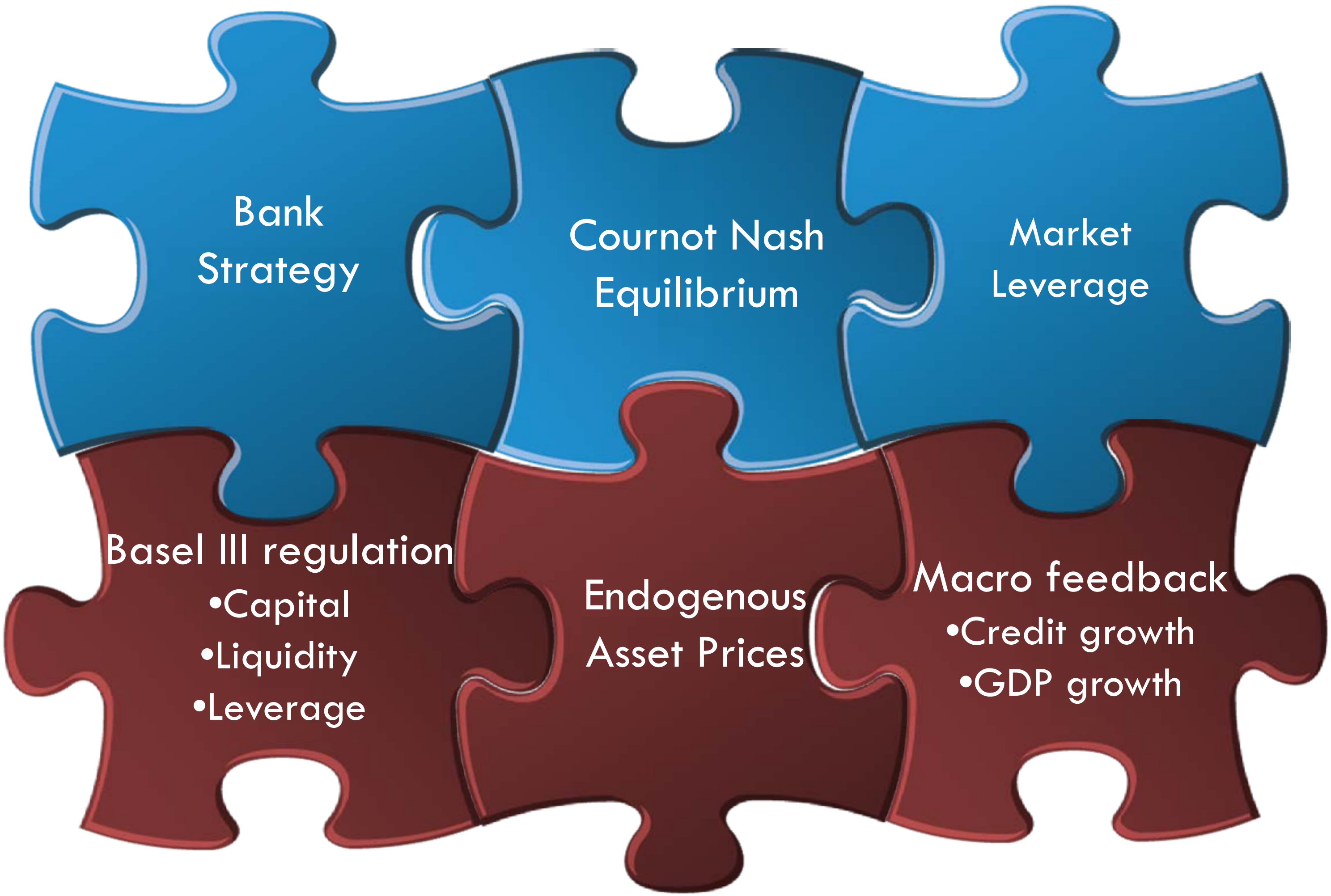
Examine the transmission mechanism of different types of shocks:
exogenous risk (scenario) and endogenous risk (firms' reaction to shocks)

System Dynamics

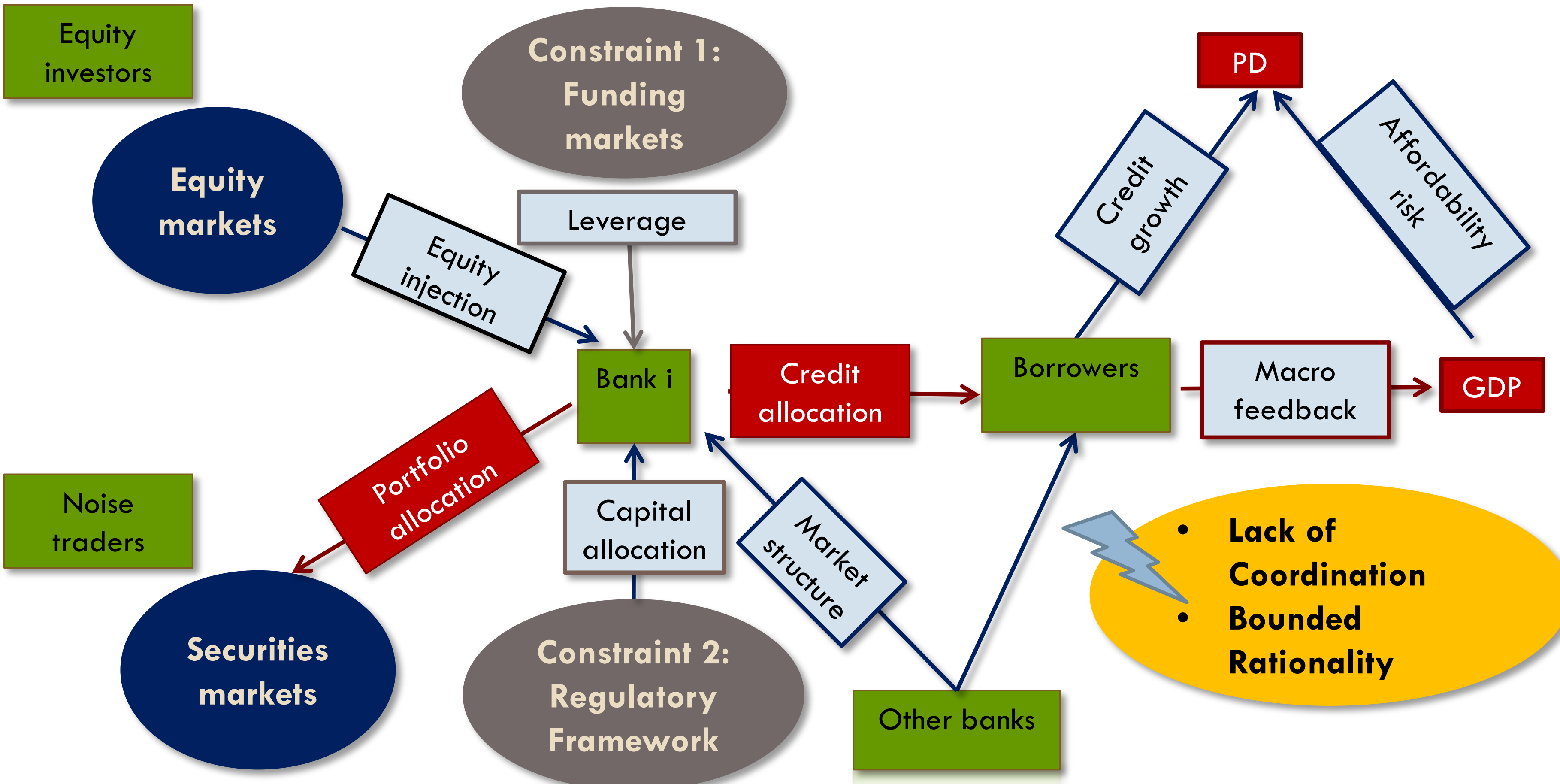
Key Features

- Incorporates behavioral response (banks, non-banks)
- Examines interaction of risks (credit risk, market risk, liquidity risk)
- Endogenizes funding access (leverage), fire sales (portfolio rebalancing), capital dynamics (equity)
- Enables a consistent macroprudential policy framework
- Flexible and transparent tool:
  - Banks' business models (business strategy; ROE targets; funding model)
  - Binding regulatory/market constraints

Ingredients



System Interactions



- At each time step, banks optimize their balance sheet, investors inject/withdraw capital, and noise traders rebalance their asset holdings
- Implications for credit risk, asset volatility, bank capital position, credit growth, GDP growth

Policy Instruments

Banks

- Monetary Policy
  - LTRO, TLTRO
  - Forward Guidance
  - Asset purchases/collateral framework
- Accounting Policy
  - Provisions
- Prudential
  - Capital requirements: structural (min), cyclical (buffers)
  - IRB correlation factor
  - LGD floor
  - Run-off rate (LCR), funding structure (NSFR)
  - Guidance on NPL/write-offs

Borrowers

- Macroprudential policy
  - LTI, DSTI

Noise Traders

- Liquidity regulation
  - Redemption policy

Banks

Credit Division

- **Cournot competition** Credit allocation maximizes expected net profits given current state, subject to constraints.

Payer swap — **Capital regulation** — **Expectations in light of current state**

$$Max_{c_t^i} \sum_{s=0}^{w} \frac{\left[i_l - E_t\left(i_t^d \middle| c_t^i, \sum_{j \neq i} c_t^j \right) \cdot (1 - cap_t) - ROE \cdot cap_t \right] - E_t\left[PD_{t+s} \middle| PD_t = PD_t\left(c_t^i, \sum_{j \neq i} c_t^j, g_t\left(c_t^i, \sum_{j \neq i} c_t^j \right) \right) \right] \cdot LGD}{(1 + ROE)^s} \cdot c_t^i$$

Balance sheet capacity

$$s.t. \quad c_t^i + cs_{t-1} \cdot \delta + Q_t^i \cdot p_t + cash_t \leq K_t\left(c_t^i\right) \cdot \mu_t^{\max} \qquad \mu_t^{\max} = \frac{\mu^{\max} + \varepsilon_t^{\lambda}}{1 + \kappa^s \cdot \omega_{st}^s \cdot \sigma_t^2\left(c_t^i, p_t\right) + \kappa^u \cdot \omega_{st}^u \cdot \left(\frac{ROE_t}{ROE_{t-1}} \right)^2}$$

Basel III Regulation

$$cap_t = \left(PD_t^c\left(PD_t, R_t\left(PD_t \right) \right) - PD_t \right) \cdot LGD_t \qquad cash_t \geq runoff_t \cdot D_t\left(K_t\left(c_t^i \right) \right) \qquad RWA_t = 12.5 \cdot cap_t \cdot c_t^i$$

Credit Policy

- Credit allocation

$$c_t^i = \sum_{j=1}^{\tau} L_t^j = \tau \cdot L_t$$

- Banks' underwriting standards define the LTI distribution

$$L_t^j = \mathrm{B}_t^j \cdot E\left(I_t^j\right)$$

$$\textit{such that}$$

$$\mathrm{B}_t^j < \mathrm{B}_t^{\tau}$$

- Subject to regulatory policy

$$\frac{L_t}{E\left(I_t^j\right)} \leq \boxed{\mathrm{B}_t^{\max}}$$

- Credit flow depends on underwriting standards and income

$$c_t^i = \sum_{j=1}^{\tau} \mathrm{B}_t^j \cdot E_t\left(I_t^j\right)$$

Credit Allocation

- At the optimum:

$$c_t^* = \frac{\overbrace{i_l - i_t^d\big|_{c_t^*} \cdot \left(1 - cap_t\big|_{c_t^*}\right) - ROE \cdot cap_t\big|_{c_t^*}}^{\text{Interest margin}} \; \overbrace{- PD_t^*\left(c_t^{i*}\right) \cdot LGD}^{\text{Expected losses}}}{\underbrace{\left[\frac{\partial i_t^d}{\partial c_t^i}\bigg|_{c_t^*} \cdot \left(1 - cap_t\big|_{c_t^*}\right) - i_t^d\big|_{c_t^*} \cdot \frac{\partial cap_t}{\partial c_t^i}\bigg|_{c_t^*}\right]}_{\text{Funding cost effect}} + \underbrace{ROE \cdot \frac{\partial cap_t}{\partial c_t^i}\bigg|_{c_t^*}}_{\text{Capital regulation effect}} + \underbrace{\frac{\partial PD_t^s}{\partial c_t^i}\bigg|_{c_t^*} \cdot LGD}_{\text{Credit risk effect}}}$$

Provided the bank has enough BS capacity (determined by loan tenure, market leverage, regulatory framework)

Securities Division

- Banks exploit mispricing of securities:
  - (i) securities are measured at fair value (trading book)
  - (ii) banks take into account the cost of capital to cover market risk

Business model

$$Q_t^i \cdot p_t = \begin{cases} 0 & \text{if } L > p_t + \delta_t \\ \beta_i \cdot \left(L - \left(p_t + \delta_t\right)\right) \cdot K_t - cash_t - cs_{t-1} \cdot \delta - c_t^i & \text{if } L - \dfrac{\lambda_t^{\max}}{\beta_i} < p_t + \delta_t < L \\ \lambda_t^{\max} \cdot K_t - cash_t - cs_{t-1} \cdot \delta - c_t^i & \text{else} \end{cases}$$

- where market risk is defined according to Basel IMM approach

$$\delta_t = i_t^d \cdot \left(1 - capmk_t\right) + ROE \cdot capmk_t \qquad capmk_t = G(0.99) \cdot 3 \cdot \sqrt{10} \cdot \sigma_t^2$$

- and the volatility of asset prices follows an autoregressive process

$$\sigma_t^2 = \theta \cdot \sigma_{t-1}^2 + (1-\theta) \cdot \log\left(p_t / p_{t-1}\right)^2$$

Evolution of Capital

- Capital evolves with
  - Dynamic balance sheet (rebalancing of portfolio)
  - Mark-to-market gains/losses in traded securities
  - Net interest income
  - Loan loss provisions (new credit + revision of provisions from credit risk migration)
  - Investors' capital flow
  - Dividend payout

- If capital falls below the minimum regulatory level
  - Banks continue operating even if their capital falls below regulatory minimum (benchmark)
  - Banks are forced to be raise capital to satisfy the regulatory minimum (recapitalization)
  - Credit and dividend payout is constrained (CCB)

Non-Banks

Borrowers

- Income distribution

$$\left\{E_t\left(I_t^j\right)\right\}\ if\ \tau > j \Rightarrow E_t\left(I_t^\tau\right) < E_t\left(I_t^j\right)$$

- Income linked to growth subject to shocks

$$I_t^j = I_{t-1}^j \cdot \left(1 + \sigma_I \cdot g_t\right) + \tilde{\varepsilon}_t$$ ⟵ **Stochastic**

- The probability of default of borrower *j*

$$PD_{t+s}^j = \left\{\# I_{t+s}^j \middle| \left[\left(1-\delta\right) + i_t^l\right] \cdot L_t^j > I_{t+s}^j\right\}$$

- The probability of default of the portfolio

$$PD_t^i\left(c_t^i\right) = \sum_{j=1}^{\tau} PD_t^j$$

- PD rises with credit growth and declines with growth

$$\frac{\partial PD_t}{\partial c_t^i} > 0\ and\ \frac{\partial PD_t}{\partial c_t^i} > 0$$

$$\frac{\partial PD_t}{\partial E_t\left(g_t\right)} < 0\ and\ \frac{\partial PD_t^c}{\partial E_t\left(g_t\right)} > 0$$

Noise Traders

- The price of securities is determined by aggregate demand from banks and noise traders (Thurner et al, 2012)
- Noise traders are willing to hold additional securities at a lower price – fire sales channel
- Noise traders' demand given by value of holdings

$$\log(V_t) = \rho \cdot \log(V_{t-1}) + (1-\rho) \cdot \log\left(L \cdot \frac{S}{N \cdot Q^b}\right) + \sigma \cdot \tilde{\chi}_t$$

← **Stochastic**

- Market clearing

$$\frac{V_t}{(p_t)} + \sum_{i=1}^{N} Q_t^i(p_t) = S$$

Equity Investors

- A pool of investors inject/withdraw capital based on a moving average of banks' recent performance (Thurner et al, 2012)

$$F_t = b \cdot (r_t - ROE) \cdot K_t$$

- The performance of the bank is measured in terms of its net asset value

$$NAV_t = NAV_{t-1} \cdot \frac{K_t - F_{t-1}}{K_{t-1}} \qquad r_t^{NAV} = \ln\left(\frac{NAV_t}{NAV_{t-1}}\right)$$

- Investors make decisions based on an exponential moving average of returns

$$r_t = (1-a) \cdot r_{t-1} + a r_t^{NAV}$$

Macro-feedback

Macro-feedback effects

- IS Curve

$$E_t(g_t)=\alpha_y \cdot E_{t-1}(g_t)+(1-\alpha_y)\cdot E_t(g_{t+1})+\beta_y \cdot \log(N \cdot cs_{t-1} / N \cdot cs_{t-2})-\gamma_y \cdot (i_t^l-\rho)+\varepsilon_t^y$$

- Expectations Augmented Phillips Curve

$$E_t(\pi_t)=\alpha_\pi \cdot E_{t-1}(\pi_t)+(1-\alpha_\pi)\cdot E_t(\pi_{t+1})+\beta_\pi \cdot E_t(g_t)+\varepsilon_t^\pi$$

- Monetary Policy "Taylor-type" Rule

$$r_t=\alpha_r \cdot [(\rho+\pi^T)+\beta_r \cdot (E_t(\pi_t)-\pi^T)+\gamma_r \cdot (E_t(g_t)-y^*)]+(1-\alpha_r)\cdot r_{t-1}+\varepsilon_t^r$$

- Credit spreads

$$s_t=\rho_s \cdot s_{t-1}+\alpha_s \cdot libor_t+\gamma_t \cdot \frac{CAR_t}{rCAR_t}+\varepsilon_t^s$$

Global funding conditions
Excess regulatory capital

- Interest rates

$$i_t^d=r_t+s_t+\varepsilon_t^d$$

Funding costs (policy rate, bank credit spreads)

$$i_t^l=\alpha_l \cdot (i_t^d+m)+(1-\alpha_l)\cdot (y^*-E_t(g_t))+\varepsilon_t^l$$

Lending rates (funding costs, pass-through, borrower credit spreads)

Reduced-form

- For the calibration, the following macro-econometric equation is estimated
- Key variables:
  - Expected GDP growth
  - Potential output
  - Credit growth

$$g_t = \alpha_y \cdot g_{t-1} + \gamma_y \cdot y^* + \left(1 - \alpha_y - \gamma_y\right) \cdot \log\left(N \cdot cs_{t-1} / N \cdot cs_{t-2}\right) + \varepsilon_t^y$$

Calibration

Key Initial Conditions

- Core parameters $N = 5 \quad T = 60$
- Balance sheet

$A_0 = 183.4$

$cs_0 = 157.0$

$cash_0 = 26.41$

$runoff = 0.15$

$K_0 = 7.336$

$D_0 = 176.06$

$\lambda_t = 25$

$CAR_0 = 11.4\%$

$RWA_0 = 64.351$

$\mu^{\max} = 25$

$\mu_1^{\max} = 24.75 \text{ given } \kappa = 100, \sigma_0^2 = 0.0001$

$\delta = 0.983$

$w = 60$

- Rates

$i_0^l = 0.06$

$i_0^l = 0.04$

$ROE = 0.08$

Securities market

$p_0 = 0.9\left(L = 1\right)$

$V_0 = 900$

$S = 1000$

$\sigma = 0.0001$

$\sigma_0^2 = 0.0001$

- Credit risk

$PD_0 = 0.16\%$

$PD_0^c = 4.78\%$

$$PD_t = 0.005 + 0.0056 \cdot \ln\left(\frac{N \cdot cs_t}{N \cdot cs_{t-1}}\right) - 0.09 E_t\left(g_t\right) + \varepsilon_t^{PD}$$

$LGD = 0.6$

- Macroeconomy

$g_0 = 0.03$

$\Delta c_0 = 0$

$y^* = 0.03$

$\pi_0 = 0.02$

$yn_0 = 319.4$

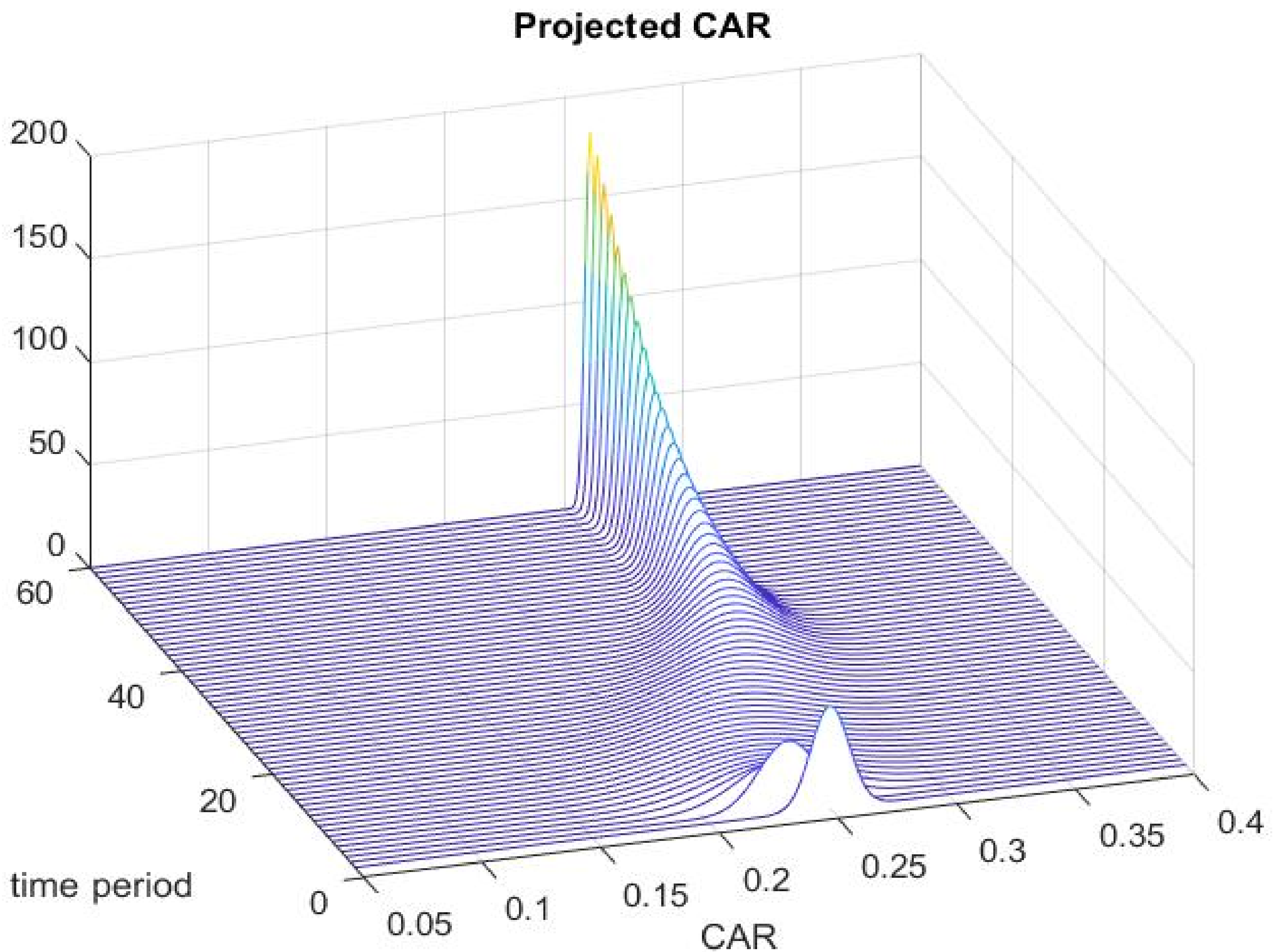
$y_0 = 0.86 \cdot yn_0$

$\rho_y = 0.8$

$\gamma_y = 0.1$

Baseline

CAR-at Risk ✓



Adverse Scenarios

- GDP shock

$$\begin{aligned} &if\ \ t = 10 && \varepsilon_t^y = -0.01 \\ &if\ \ t \in [12,20] && \varepsilon_t^y = -0.02 \end{aligned}$$

- Funding (liquidity) shock

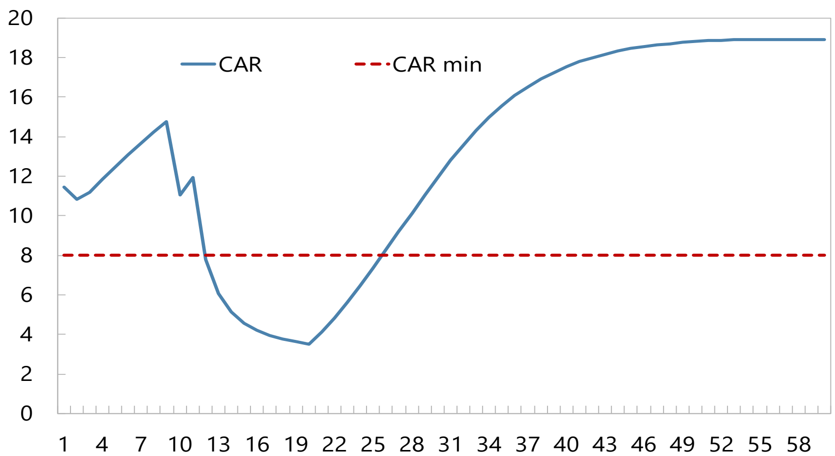
$$if\ \ t \in [12,60]\ \ \varepsilon_t^\lambda = -4$$

- Market (liquidity) shock

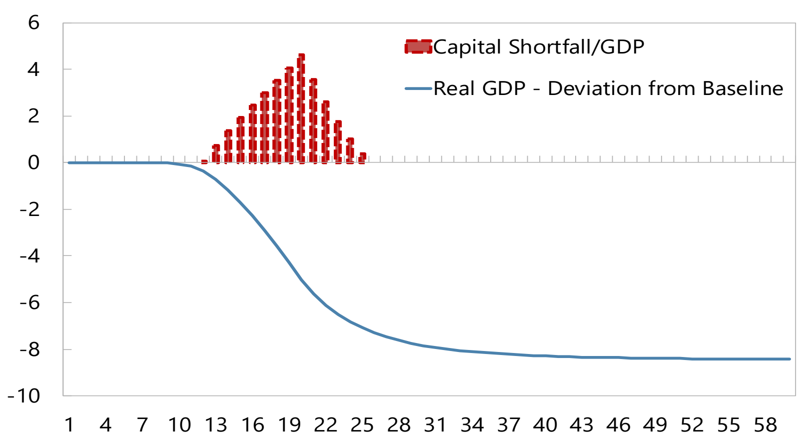
$$if\ \ t \in [12,20]\ \begin{cases} \sigma = 0.05 \\ \chi_t < 0 \end{cases}$$

GDP shock

Bank Solvency
(Percent)

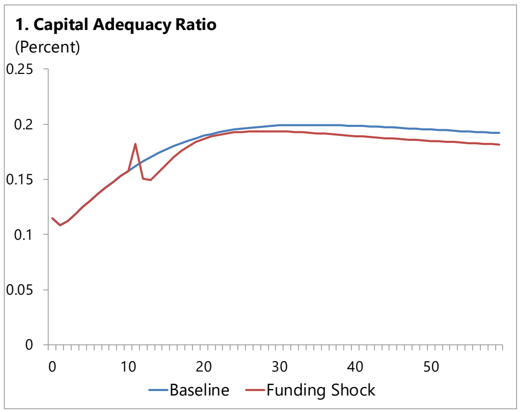


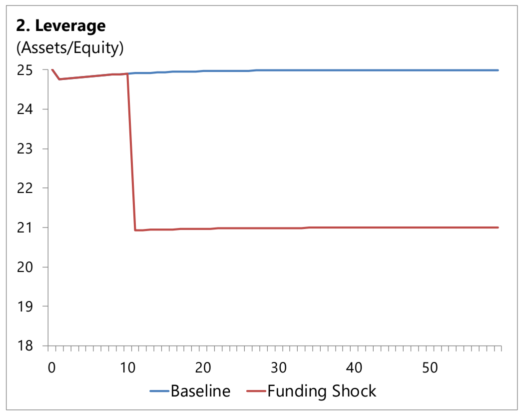
Real Effects
(Percent)

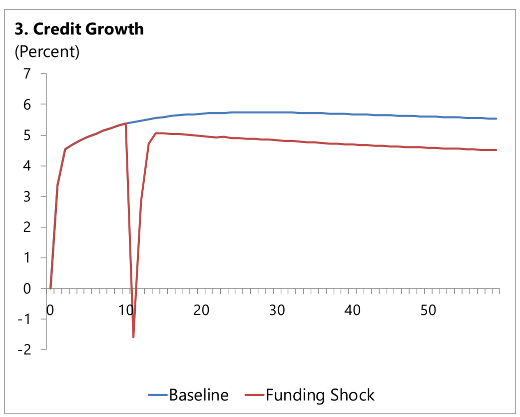


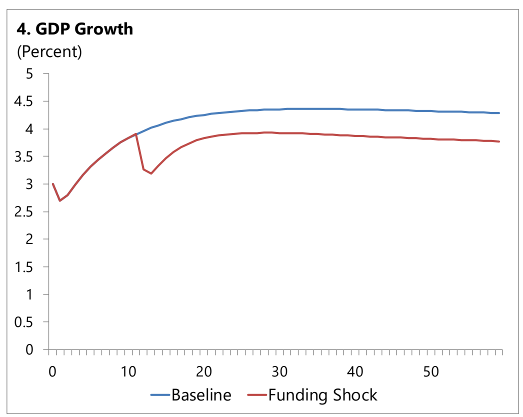
- GDP Projections are **endogenous** to banks' reaction to stress
- Despite recovery in banks' capital ratios, **permanent** real effects
- Recessions **deeper** and more **persistent** when second-round effects are included
- Bank **recapitalization** peaks at 5 percent of nominal GDP
- Over 5-year, cumulative **real gdp** declines by 8 percent relative to baseline

Funding shock







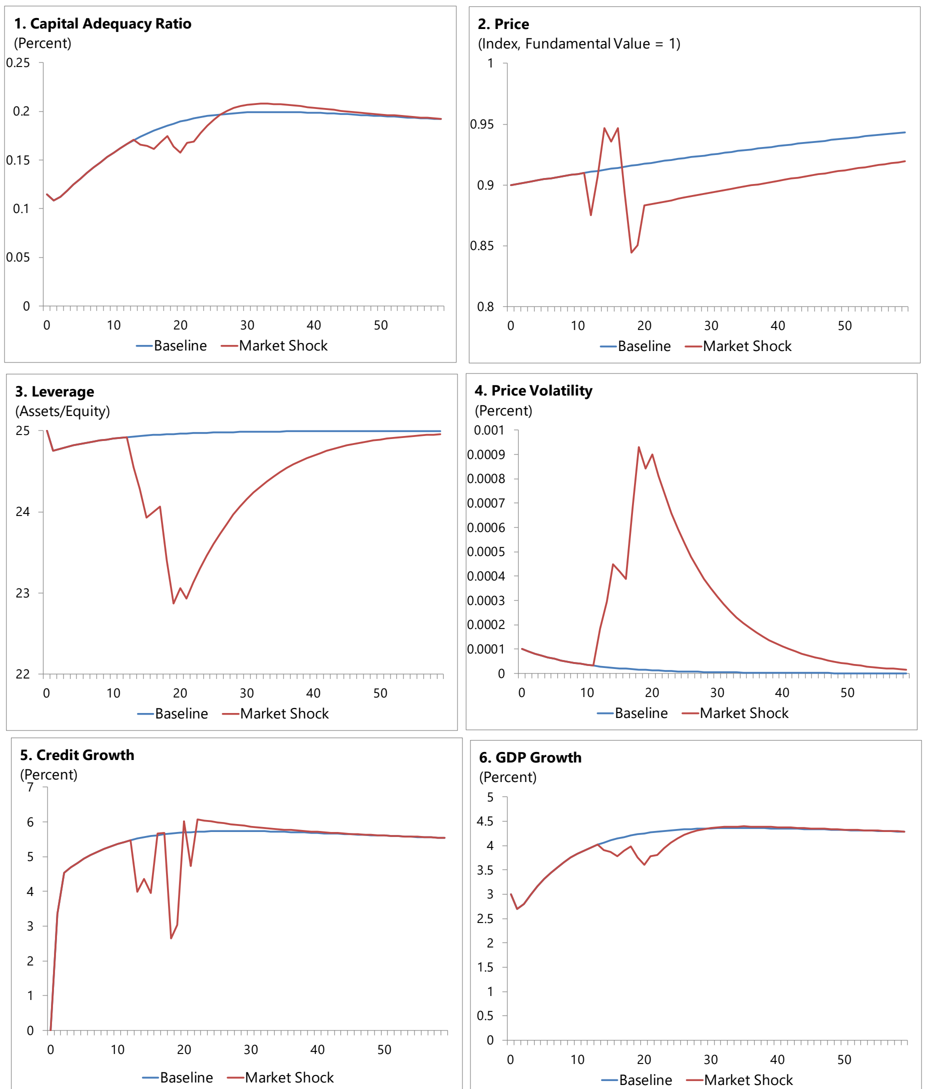


Bank Deleveraging has an initial positive impact on banks' capital ratios

Even if banks' capital position stabilizes, real effects become permanent

Over 5-year, cumulative real gdp declines by 2 percent relative to baseline

Market shock



- **A MARKET SHOCK (REDEMPTIONS FROM NOISE TRADERS) MORPHS INTO…**
- **…A LIQUIDITY SHOCK (THROUGH LEVERAGE CONSTRAINT) AND…**
- **…A CREDIT SHOCK (THROUGH BANKS' BEHAVIORAL RESPONSE)…**
- **… INCREASING DEFAULT RISK (THROUGH SECOND-ROUND EFFECTS)…**
- **…SLOWING DOWN ECONOMIC GROWTH…**
- **…CUMULATIVE REAL GDP DECLINES BY 1 PERCENT RELATIVE TO BASELINE**

Thank you