SYSTEM DYNAMICS AND STRESS TESTING

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Outline

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

- 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
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

- Basel III regulation
  - Capital
  - Liquidity
  - Leverage

- Cournot Nash Equilibrium

- Market Leverage

- Macro feedback
  - Credit growth
  - GDP growth

- Endogenous Asset Prices

- Bank Strategy

Macro feedback
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.

- Lack of Coordination
- Bounded Rationality
Policy Instruments

- **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

- **Macroprudential policy**
  - LTI, DSTI

- **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

\[
\max_{c^i_t} \sum_{s=0}^{w} c^i_t \left( i_t - E_t \left( i^d_t \bigg| c^i_t, \sum_{j \neq i} c^j_t \right) \right) \cdot (1 - \text{cap}_t) - \text{ROE} \cdot \text{cap}_t - E_t \left[ PD_{t+s} \sum_{j \neq i} c^j_t, g_t \left( c^i_t, \sum_{j \neq i} c^j_t \right) \right] \cdot \text{LGD}
\]

\[
\left( 1 + \text{ROE} \right)^s
\]

Balance sheet capacity

\[
s.t. \quad c^i_t + c_{s-1} \cdot \delta + Q^i \cdot p_t + \text{cash}_t \leq K_t \left( c^i_t \right) \cdot \mu^\text{max}_t
\]

\[
\mu_t^\text{max} = \frac{\mu^\text{max} + \epsilon^2}{1 + \kappa^s \cdot \omega^s_t \cdot \sigma^2_t \left( c^i_t, p_t \right) + \kappa^{u} \cdot \omega^{u}_st \cdot \left( \frac{\text{ROE}_t}{\text{ROE}_{t-1}} \right)^2}
\]

Basel III Regulation

\[
\text{cap}_t = \left( PD^c_t \left( PD, R_{t} \left( PD_t \right) \right) - PD_t \right) \cdot \text{LGD}_t
\]

\[
\text{cash}_t \geq \text{runoff}_t \cdot D_t \left( K_t \left( c^i_t \right) \right)
\]

\[
\text{RWA}_t = 12.5 \cdot \text{cap}_t \cdot c^i_t
\]
Credit Policy

- Credit allocation
  \[ c^i_t = \sum_{j=1}^{\tau} L^j_t = \tau \cdot L_t \]

- Banks’ underwriting standards define the LTI distribution
  \[ L^j_t = B^j_t \cdot E_t(I^j_t) \]
  such that
  \[ B^j_t < B^r_t \]

- Subject to regulatory policy
  \[ \frac{L_t}{E_t(I^j_t)} \leq B^\text{max}_t \]

- Credit flow depends on underwriting standards and income
  \[ c^i_t = \sum_{j=1}^{\tau} B^j_t \cdot E_t(I^j_t) \]
At the optimum:

\[ c_t^* = \frac{i_t - i_t^d \left| c_t^* \right| \left(1 - \text{cap}_t \left| c_t^* \right\right) - \text{ROE} \cdot \text{cap}_t \left| c_t^* \right| - \text{PD}_t^* \left( c_t^* \right) \cdot \text{LGD}}{\frac{\partial i_t^d}{\partial c_t^i} \left| c_t^* \right| \left(1 - \text{cap}_t \left| c_t^* \right\right) - i_t^d \left| c_t^* \right| \cdot \frac{\partial \text{cap}_t}{\partial c_t^i} \left| c_t^* \right| + \text{ROE} \cdot \frac{\partial \text{cap}_t}{\partial c_t^i} \left| c_t^* \right| + \frac{\partial \text{PD}_t^s}{\partial c_t^i} \left| c_t^* \right| \cdot \text{LGD}} \]

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

where market risk is defined according to Basel IMM approach

\[
\delta_t = i_t^d \cdot (1 - \text{capmk}_t) + \text{ROE} \cdot \text{capmk}_t
\]

\[
\text{capmk}_t = G(0.99) \cdot 3 \cdot \sqrt{10} \cdot \sigma_t^2
\]

and the volatility of asset prices follows an autoregressive process

\[
\sigma_t^2 = \theta \cdot \sigma_{t-1}^2 + (1 - \theta) \cdot \log(p_t / p_{t-1})^2
\]
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
  \[ \{ E_t(I^j_t) \} \text{ if } \tau > j \Rightarrow E_t(I^\tau_t) < E_t(I^j_t) \]

- Income linked to growth subject to shocks
  \[ I^j_t = I^j_{t-1} \cdot (1 + \sigma \cdot g_t) + \tilde{\epsilon}_t \]

- The probability of default of borrower \( j \)
  \[ PD_{t+s}^j = \left\{ \# I^j_{t+s} \left[ (1 - \delta) + i_t^j \right] \cdot L^j_t > I^j_{t+s} \right\} \]

- The probability of default of the portfolio
  \[ PD_t^j(c_t^j) = \sum_{j=1}^{\tau} PD_t^j \]

- PD rises with credit growth and declines with growth
  \[ \frac{\partial PD_t^j}{\partial c_t^j} > 0 \text{ and } \frac{\partial PD_t^c}{\partial c_t^j} > 0 \]
  \[ \frac{\partial PD_t^j}{\partial E_t(g_t)} < 0 \text{ and } \frac{\partial PD_t^c}{\partial E_t(g_t)} > 0 \]
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

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

- Market clearing

\[
\frac{V_t}{p_t} + \sum_{i=1}^{N} Q^i_t(p_t) = S
\]
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

\[ NAV_t = NAV_{t-1} \cdot \frac{K_t - F_{t-1}}{K_{t-1}} \]

\[ r_t^{NAV} = \ln \left( \frac{NAV_t}{NAV_{t-1}} \right) \]

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

\[ r_t = (1 - a) \cdot r_{t-1} + ar_t^{NAV} \]
Macro-feedback
Macro-feedback effects

- **IS Curve**
  \[ E_t(g_t) = \alpha_y \cdot E_{t-1}(g_t) + (1 - \alpha_y) \cdot E_t(g_{t+1}) + \beta_y \cdot \log\left(\frac{N \cdot cs_{t-1}}{N \cdot cs_{t-2}}\right) - \gamma_y \cdot (i^l_t - \rho) + \epsilon^y_t \]

- **Expectations Augmented Phillips Curve**
  \[ E_t(\pi_t) = \alpha_\pi \cdot E_{t-1}(\pi_t) + (1 - \alpha_\pi) \cdot E_t(\pi_{t+1}) + \beta_\pi \cdot E_t(g_t) + \epsilon^\pi_t \]

- **Monetary Policy “Taylor-type” Rule**
  \[ r_t = \alpha_r \cdot \left[ (\rho + \pi^T) + \beta_r \cdot (E_t(\pi_t) - \pi^T) + \gamma_r \cdot (E_t(g_t) - y^*) \right] + (1 - \alpha_r) \cdot r_{t-1} + \epsilon^r_t \]

- **Credit spreads**
  \[ s_t = \rho_s \cdot s_{t-1} + \alpha_s \cdot libor_i + \frac{CAR_i}{rCAR} + \epsilon^s_t \]

- **Global funding conditions**
  Excess regulatory capital

- **Interest rates**
  \[ i^d_t = r_t + s_t + \epsilon^d_t \]
  \[ i^l_t = \alpha_l \cdot (i^d_t + m) + (1 - \alpha_l) \cdot (y^* - E_t(g_t)) + \epsilon^l_t \]

- **Funding costs (policy rate, bank credit spreads)**

- **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

\[ g_t = \alpha_y \cdot g_{t-1} + \gamma_y \cdot y^* + \left(1 - \alpha_y - \gamma_y\right) \cdot \log \left(\frac{N \cdot cs_{t-1}}{N \cdot cs_{t-2}}\right) + \varepsilon_t^y \]
Calibration
Key Initial Conditions

- **Core parameters**
  
  \[ N = 5 \quad T = 60 \]

- **Balance sheet**
  
  \[ A_0 = 183.4 \]
  \[ cs_0 = 157.0 \]
  \[ cash_0 = 26.41 \]
  \[ runoff = 0.15 \]
  \[ K_0 = 7.336 \]
  \[ D_0 = 176.06 \]
  \[ \lambda_t = 25 \]
  \[ CAR_0 = 11.4\% \]
  \[ RW_A_0 = 64.351 \]
  \[ \mu_{\text{max}} = 25 \]
  \[ \mu_1^{\text{max}} = 24.75 \text{ given } \kappa = 100, \sigma_0^2 = 0.0001 \]

- **Rates**
  
  \[ i_t^l = 0.06 \]
  \[ i_0^l = 0.04 \]
  \[ ROE = 0.08 \]

- **Credit risk**
  
  \[ PD_0 = 0.16\% \]
  \[ PD_0^c = 4.78\% \]
  \[ PD_t = 0.005 + 0.0056 \cdot \ln \left( \frac{N \cdot cs_t}{N \cdot cs_{t-1}} \right) - 0.09E_t \left( g_t \right) + \varepsilon_t^{PD} \]
  \[ LGD = 0.6 \]

- **Macroeconomy**
  
  \[ g_0 = 0.03 \]
  \[ \Delta c_0 = 0 \]
  \[ y^* = 0.03 \]
  \[ \pi_0 = 0.02 \]
  \[ y_n_0 = 319.4 \]
  \[ y_0 = 0.86 \cdot y_n_0 \]
  \[ \rho_y = 0.8 \]
  \[ \gamma_y = 0.1 \]
Baseline

CAR-at Risk ✔
Adverse Scenarios

- **GDP shock**
  
  \[
  \begin{align*}
  &if \ t = 10 \quad \varepsilon_t^y = -0.01 \\
  &if \ t \in [12, 20] \quad \varepsilon_t^y = -0.02
  \end{align*}
  \]

- **Funding (liquidity) shock**
  
  \[
  \begin{align*}
  &if \ t \in [12, 60] \quad \varepsilon_t^\lambda = -4
  \end{align*}
  \]

- **Market (liquidity) shock**
  
  \[
  \begin{align*}
  &if \ t \in [12, 20] \\
  &\begin{cases}
  \sigma = 0.05 \\
  \chi_t < 0
  \end{cases}
  \end{align*}
  \]
GDP shock

Bank Solvency
(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
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.
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