A Macroeconomic Model with Financial Panics

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1 The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Board or the Federal Reserve System
What we do

- Incorporate banks and banking panics in simple macro model

- Broad goal:
  - Develop framework to understand dynamics of recent financial crisis

- Specific goals:
  - Characterize sudden/discrete nature of financial collapse in fall 2008
    - No observable large exogenous shock
    - Gorton (2010), Bernanke (2010): Bank runs at heart of collapse
  - Model credit boom preceding crisis
    - Optimistic beliefs before crisis (Bordalo et al (2017))
    - Increases susceptibility to runs
Motivation

1. GDP Growth and Credit Spreads

- Nominal GDP Growth
- BAA-10 Year Treasury Spread

Lehman failure

2. Broker Liabilities

Lehman failure
How we differ

- Conventional financial accelerator/credit cycle models (e.g. Gertler/Kiyotaki 2011)
  - Mutual feedback between borrower balance sheets and real activity
  - Local approximations $\rightarrow$ dynamics linear

- Models with occasionally binding balance sheet constraints (e.g. Brunnermeier/Sannikov 2014, He/Krishnamurthy, 2016)
  - Moving from unconstrained to constrained region $\Rightarrow$ nonlinear contraction

- This paper: both occasionally binding constraints and bank runs
  - Runs more significant source of non-linearity
  - Richer macro model
Model Overview

- Simple New Keynesian model with investment

- Banks intermediate funds between households and productive capital
  - Hold imperfectly liquid long term assets and issue short term debt →
  - Vulnerable to panic failure of depositors to roll over short term debt
    - Based on GK (2015) and GKP (2016)
    - In turn based on Cole/Kehoe(2001) self-fulfilling sovereign debt

- Households may directly finance capital, but less efficient at margin than banks
End of period capital $S_t$ vs. beginning $K_t$

$$S_t = \Gamma(I_t) + (1 - \delta)K_t$$

$$\Gamma' > 0, \Gamma'' < 0$$

$S_t \rightarrow K_{t+1}$:

$$K_{t+1} = \xi_{t+1}S_t$$

$\xi_{t+1} \equiv \text{”capital quality” shock}$

$S_t^b$ intermediated by banks; $S_t^h$ directly held by households

$$S_t = S_t^b + S_t^h$$
Household and Bank intermediation

- Marginal rate of return on intermediated capital

\[ R_{t+1}^b = \xi_{t+1} \frac{Z_{t+1} + (1 - \delta)Q_{t+1}}{Q_t} \]

- If \( S^h_t / S_t > \gamma \), (utility) cost to household of direct finance

\[ \varsigma(S^h_t, S_t) = \frac{\chi}{2} \left( \frac{S^h_t}{S_t} - \gamma \right)^2 S_t \]

- Marginal rate of return on directly held capital

\[ R_{t+1}^h = \frac{1}{1 + \frac{\partial \varsigma(\cdot)}{\partial S^h_t}} R_{t+1}^b \]

with

\[ \frac{\partial \varsigma(\cdot)}{\partial S^h_t} = max \left\{ \chi \left( \frac{S^h_t}{S_t} - \gamma \right), 0 \right\} \]

For \( S^h_t / S_t > \gamma \), increasing marginal cost of direct finance
Bank Decision Problem

- **Objective**

\[ V_t = E_t \Lambda_{t,t+1} \left( (1 - \sigma) n_{t+1} + \sigma V_{t+1} \right) \]

\( \sigma \equiv \text{exogenous survival probability} \)

- **Net worth** \( n_t \) accumulated via retained earnings - no new equity issues

\[ n_{t+1} = \begin{cases} R^k_{t+1} Q_t s_t^b - \overline{R}_{t+1} d_t & \text{if no run} \\ 0 & \text{if run} \end{cases} \]

- **Balance sheet**

\[ Q_t s_t^b = d_t + n_t \]
Deposit Contract

\( \overline{R}_{t+1} \equiv \text{deposit rate}; \ R_{t+1} \equiv \text{return on deposits} \)
\( p_t \equiv \text{run probability}; \ x_{t+1} < 1 \equiv \text{recovery rate} \)

- Deposit contract: (One period)

\[
R_{t+1} = \begin{cases} 
\overline{R}_{t+1} \text{ with prob. } 1 - p_t \\
x_{t+1} \overline{R}_{t+1} \text{ with prob. } p_t 
\end{cases}
\]

- Recovery rate (no sequential service constraint):

\[
x_{t+1} = \frac{\xi_{t+1} \left[ Z_{t+1} + (1 - \delta) Q^*_t \right]}{\overline{R}_{t+1} D_t} S^b_t
\]
Perfect markets:

Banks issue deposits until:

\[ E_{t\Lambda_{t,t+1}}\{R_{t+1}^k - R_{t+1}\} = 0 \]

⇒ Leverage constraints do not arise
⇒ Financial panics cannot arise

Limits to arbitrage:

Occasionally binding leverage constraints⇒

\[ E_{t\Lambda_{t,t+1}}\{R_{t+1}^k - R_{t+1}\} > 0 \]

Bank runs possible: extreme increases in \( E_{t\Lambda_{t,t+1}}\{R_{t+1}^k - R_{t+1}\} \)
Moral Hazard Problem:

- After banker borrows funds at $t$, it may divert fraction $\theta$ of assets for personal use.

- If bank does not honor its debt, creditors can
  - recover the residual funds and
  - shut the bank down.

$\Rightarrow$ Incentive constraint (IC)

$$\theta Q_t s_t^b \leq V_t$$
Solution

- Can show $V_t = \psi_t n_t$ with $\psi_t \geq 1$ and increasing in $E_t\{R^k_{t+1} - R_{t+1}\}$

- Combine with $IC \rightarrow$ endogenous leverage constraint:

$$Q_t s^b_t \leq \overline{\phi}_t n_t$$

$$\overline{\phi}_t = \frac{\psi_t}{\theta} \rightarrow \text{decreasing in } \theta \text{ and increasing in } E_t\{R^k_{t+1} - R_{t+1}\}$$

- Note:
  - $E_t\{R^k_{t+1} - R_{t+1}\}$ countercyclical $\Rightarrow \overline{\phi}_t$ countercyclical.
  - $n_t \leq 0 \Rightarrow$ bank cannot operate (key for run equilibria)
Homogeneity: $\phi_t \equiv \frac{Q_t s^b_t}{n_t}$ and $\bar{\phi}_t$ independent of bank-specific factors

$\rightarrow$ Aggregate leverage constraint

$$Q_t s^b_t \leq \bar{\phi}_t N_t$$

$\rightarrow$ $E_t \Lambda_{t,t+1} \{R^k_{t+1} - R_{t+1}\} > 0$

Aggregate net worth

$$N_t = \sigma[(R^k_t - R_t)\phi_{t-1} + R_t]N_{t-1} + \zeta S_{t-1}$$

Absent runs, conventional financial accelerator with non-linearity
Bank Runs

- Self-fulfilling "bank run" equilibrium (i.e. rollover crisis) possible if:
  - A depositor believes that if other households do not roll over their deposits, the depositor will lose money by rolling over.
  - Condition met if banks’ net worth $n_t$ goes to zero if others run
    - $n_t = 0 \rightarrow$ banks cannot operate
  - Run equilibrium exists if recovery rate $x_t$ satisfies
    \[
    x_t = \frac{\xi_t (Z_t + (1 - \delta)Q^*_t)S^b_{t-1}}{\overline{R}_t D_{t-1}} < 1
    \]
    - $x_t < 1 \rightarrow n_t = 0$ after run
Run and Run Probability $p_t$

- Run equilibrium occurs if
  - Run equilibrium exists
  - Sunspot is observed

- Assume sunspot occurs with probability $\kappa$.

→ The time $t$ probability of a run at $t + 1$ is

$$p_t = \Pr_t \{x_{t+1} < 1\} \cdot \kappa$$

- $\Pr_t \{x_{t+1} < 1\}$ countercyclical $\rightarrow p_t$ countercyclical
Liquidation Price $Q_t^*$

- After bank run at $t$:
  \[ S_t^h = S_t \]

- Household euler equation for capital $\rightarrow$
  \[ Q_t^* = E_t \left\{ (\Lambda_{t,t+1} + (1 - \delta)Q_{t+1}) \right\} - \chi \left( \frac{S_t^h}{S_t} - \gamma \right) \frac{1}{\lambda_t} \]
  evaluated at $\frac{S_t^h}{S_t} = 1$.

- $\rightarrow Q_t^* < Q_t$

- At $t + 1$ new banks enter and assets slowly return to banking system
Production, Pricing and Monetary Policy (Standard)

- Production, resource constraint and $Q$ relation for investment
  \[ Y_t = AK_t^\alpha L_t^{1-\alpha} \]
  \[ Y_t = C_t + I_t + G \]
  \[ Q_t = \Phi(I_t) \]

- Monopolistically comp. producers with quadratic costs of nominal price adjustment (Rotemberg)
  - Adjust output to meet demand
  - New Keynesian Phillips curve relating inflation to marginal cost

- Monetary policy: simple Taylor rule
  \[ R_t^n = \frac{1}{\beta} \left( \frac{P_t}{P_{t-1}} \right)^{\kappa_\pi} (\Theta_t)^{\kappa_y} \]
## Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard Parameters</strong></td>
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<tr>
<td>$\beta$</td>
<td>Impatience</td>
<td>.99</td>
<td>Risk Free Rate</td>
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<td>Risk Aversion</td>
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<td>Literature</td>
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<tr>
<td>$\varphi$</td>
<td>Frish Elasticity</td>
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<td>$\epsilon$</td>
<td>Elasticity of subst across varieties</td>
<td>11</td>
<td>Markup 10%</td>
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<tr>
<td>$\alpha$</td>
<td>Capital Share</td>
<td>.33</td>
<td>Capital Share</td>
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<td>$\delta$</td>
<td>Depreciation</td>
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<td>$\frac{L}{K} = .025$</td>
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<td>Elasticity of q to i</td>
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<td>$\rho^{vr}$</td>
<td>Investment Technology Parameter</td>
<td>-.83%</td>
<td>$\frac{L}{K} = .025$</td>
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<td>$G$</td>
<td>Government Expenditure</td>
<td>.45</td>
<td>$\frac{G}{Y} = .2$</td>
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<td>$\rho^{jr}$</td>
<td>Price adj costs</td>
<td>1000</td>
<td>Slope of Phillips curve .01</td>
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<td>$\kappa_\pi$</td>
<td>Policy Response to Inflation</td>
<td>1.5</td>
<td>Literature</td>
</tr>
<tr>
<td>$\kappa_y$</td>
<td>Policy Response to Output</td>
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<td>Literature</td>
</tr>
<tr>
<td><strong>Financial Intermediation Parameters</strong></td>
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<tr>
<td>$\sigma$</td>
<td>Banker Survival rate</td>
<td>.93</td>
<td>Leverage $\frac{QS^b}{N} = 10$</td>
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<tr>
<td>$\zeta$</td>
<td>New Bankers Endowments as a share of Capital</td>
<td>.1%</td>
<td>% $\Delta I$ in crisis $\approx 35%$</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Share of assets divertible Threshold for</td>
<td>.22</td>
<td>Spread Increase in Crisis $= 1.5%$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>HH Intermediation Costs</td>
<td>.61</td>
<td>$\frac{S^b}{S} = .33$</td>
</tr>
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<td>$\chi$</td>
<td>HH Intermediation Costs</td>
<td>.105</td>
<td>$ER^b - R = 2%$ Annual</td>
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<td>$\kappa$</td>
<td>Sunspot Probability</td>
<td>.15</td>
<td>Run Probability 4% Annual</td>
</tr>
<tr>
<td>$\sigma(\epsilon^\xi)$</td>
<td>std of innovation to capital quality</td>
<td>.5%</td>
<td>std Output (C+I)</td>
</tr>
<tr>
<td>$\rho^\xi$</td>
<td>serial correlation of capital quality</td>
<td>.7</td>
<td>std Investment</td>
</tr>
</tbody>
</table>
Response to a Capital Quality Shock: No Run Case
Response to a Sequence of Shocks: Run VS No Run

RUN (Run Threshold Shock and Sunspot) vs NO RUN (Run Threshold Shock and No Sunspot)

**Capital Quality**
- **% Δ from SS**
- **Level**

**Run Probability**
- **% Δ from SS**
- **Level**

**Bank Net Worth**
- **% Δ from SS**
- **Level**

**Leverage Multiple: ϕ**
- **% Δ from SS**
- **Level**

**Investment**
- **% Δ from SS**
- **Level**

**Output**
- **% Δ from SS**
- **Level**

**Excess Return: ER^b-R^free**
- **Level Annual Basis Points**

**Policy Rate**
- **Level Annual Basis Points**

**Inflation**
- **Level Annual Basis Points**

Graphs showing the response of various economic indicators to a sequence of shocks, comparing Run and No Run scenarios.
Response to a Sequence of Shocks in Flex Price Economy: Run VS No Run

Capital Quality

Run Probability

Bank Net Worth

Leverage: \( \phi \)

Investment

Output

Excess Return: \( ER^{B-R_{free}} \)

Natural Rate

Consumption
Shocks: -0.2% -0.5% -0.4% -0.6% -0.6%
Threshold: -0.9% -0.8% -0.7% -0.7% -0.6%

1. Investment

2. XLF Index and Net Worth

3. Spreads (AAA-Risk Free)

4. GDP

5. Labor (hours)

6. Consumption
Boom leading to the bust: news driven optimism

- Capital quality:

\[ \xi_{t+1} = \rho \xi_t + \epsilon_{t+1} \]

- At \( t = 0 \) bankers learn that unusually large realization of \( \epsilon_{t+1} \) of size \( B > 0 \) will happen at \( t^B \in \{1, \ldots, T\} \) with prob. \( \overline{P}_0^B < 1 \)

- \( \Pr_0\{t^B = t\} \) is a truncated Normal (discrete approx.)

- Agents update \( \Pr_t \) and \( \overline{P}_t^B \) by observing \( \epsilon_t \)

- Prob. at \( t \) of shock at \( t + 1 \) is \( \Pr_t\{t^B = t + 1\} \cdot \overline{P}_t^B \)

- Implies forecast errors in line with evidence, e.g. Bordalo et al 2017
Optimism, credit boom and financial vulnerability (no run)

Prior cond. prob. of shock happening at time t

Beliefs Evolution

Capital Quality

Output

Debt

Probability of being in crisis zone
Financial Crisis After Credit Boom: Model vs Data

**Shocks:**
-0.2 %, -0.4 %, -0.3 %, -0.5 %, -0.0 %

**Threshold:**
-0.1 %, -0.1 %, 0.0 %, -0.0 %, -0.0 %

1. **Investment**

2. **XLF Index and Net Worth**

3. **Spreads (AAA-Risk Free)**

4. **GDP**

5. **Labor (hours)**

6. **Consumption**
Forecast Errors in Credit Spreads (Baa-10yr Treasury)

Forecast Errors: AAA-Treasury (4-Quarters Ahead)

Error (Next 4Q Average) = Actual - Forecast

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Conclusion

- Incorporated banking sector with conventional macro model
  - Banks occasionally exposed to self-fulfilling rollover crises
  - Crises lead to significant contractions in real economic activity

- Model captures qualitatively and quantitatively
  - Nonlinear dimension of financial crises
  - The broad features of the recent recent collapse
  - Credit boom preceding crisis

- Next steps:
  - Macropudential policy (Run Externality)
  - Lender-of-last resort policies
Run Equilibrium Threshold

\[ \frac{\xi_{t+1}(Z_{t+1} + (1 - \delta)Q^*_t)}{R_{t+1}} \]

No Run-Equilibrium Possible

Negative Capital Quality Shock

A

Run-Equilibrium Possible

B

0 1

\[ \frac{D_t}{S_t^b} \]
Conditions for Bank Run Equilibrium

- We can simplify existence condition for BRE:

\[ x_t = \frac{R^b_t}{R_t} \cdot \frac{\phi_{t-1}}{\phi_{t-1} - 1} < 1 \]

with

\[ R^b_t = \xi_t [Z_t + (1-\delta)Q^*_t] \]

\[ \phi_{t-1} = \frac{Q_{t-1}S^b_{t-1}}{N_{t-1}} \]

- Likelihood BRE exists decreasing in \( Q^*(\cdot) \) and increasing in \( \phi_{t-1} \)

- \( \phi_{t-1} \) countercyclical \( \rightarrow \) likelihood BRE exists is countercyclical.
Run Equilibrium Threshold

No Run-Equilibrium Possible

Negative Capital Quality shock

Run-Equilibrium Possible