# A Macroeconomic Model with Financial Panics

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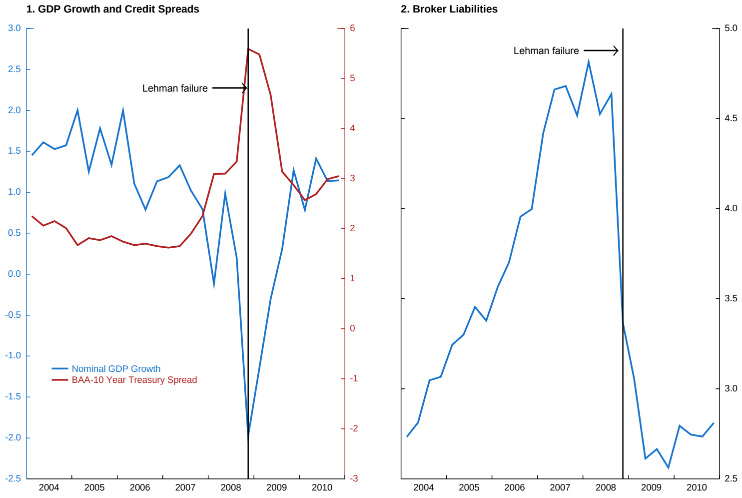
March 2018

[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 goal:
  - 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
- Explore qualitatively and quantitatively:
  - Spillover of crisis to real activity
  - Role of monetary policy and macro-prudential policy

# Motivation



1. GDP Growth and Credit Spreads
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
6
5
4
3
2
1
0
-1
-2
-3
Lehman failure
Nominal GDP Growth
BAA-10 Year Treasury Spread
2004
2005
2006
2007
2008
2009
2010
2. Broker Liabilities
5.0
4.5
4.0
3.5
3.0
2.5
Lehman failure
2004
2005
2006
2007
2008
2009
2010

# 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 $\rightarrow$
  - 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

# Evolution and Financing of Capital

- End of period capital $S_t$ vs. beginning $K_t$

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

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

- $S_t \to K_{t+1}$:

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

$\xi_{t+1} \equiv$ "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

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

$$\varsigma(S_t^h, S_t) = \frac{\chi}{2}(\frac{S_t^h}{S_t} - \gamma)^2 S_t$$

- Marginal rate of return on intermediated capital

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

- Marginal rate of return on directly held capital

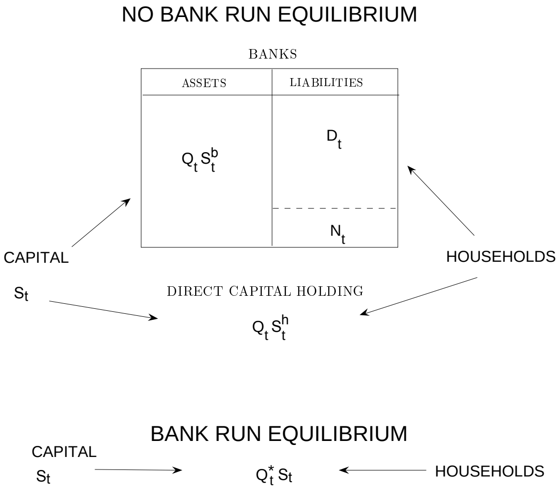
$$R_{t+1}^h = \frac{1}{1+\frac{\partial\zeta(\cdot)}{\partial S_t^h}\frac{1}{Q_t\lambda_t}}R_{t+1}^b$$

with

$$\frac{\partial\varsigma(\cdot)}{\partial S_t^h} = max\left\{\chi(\frac{S_t^h}{S_t} - \gamma), 0\right\}$$

For $S_t^h/S_t > \gamma$, increasing marginal cost of direct finance

# Household and Bank Intermediation



# Bankers

- Bankers exit with exogenous probability $1 - \sigma$
- Objective

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

- Net worth $n_t$ accumulated via retained earnings - no new equity issues

$$\begin{aligned} n_{t+1} &= R^b_{t+1} Q_t s^b_t - \overline{R}_{t+1} d_t \quad \text{if no run} \\ &= 0 \quad \text{if run} \end{aligned}$$

- Balance sheet

$$Q_t s^b_t = d_t + n_t$$

# Deposit Contract

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

- Deposit contract: (One period)

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

# Limits to Bank Arbitrage

- Moral Hazard Problem:
  - After banker borrows funds at $t$, it may divert fraction $\theta$ of assets for personal use.
  - If bank diverts, 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

- Endogenous leverage constraint:

$$Q_t s_t^b \leq \overline{\phi}_t n_t$$

  $\overline{\phi}_t$ depends on aggregate state only

- Note: $n_t \leq 0 \Rightarrow$ bank cannot operate (key for run equilbria)

# Bank Runs

- Self-fulfilling "bank run" equilibrium (i.e. rollover crisis) possible iff:
  - A depositor believes that if other households do not roll over their deposits, the depositor will lose money by rolling over.
  - Condition met iff banks' net worth $n_t$ goes to zero during a run
    - $n_t = 0 \rightarrow$ bank would divert any new deposit

# Existence of Bank Run Equilibrium

- Forced liquidation $\rightarrow Q_t^* < Q_t$

$$Q_t^* = E_t\{(\Lambda_{t,t+1}\xi_{t+1}(Z_{t+1} + (1-\delta)Q_{t+1})\} - \chi(\frac{S_t^h}{S_t} - \gamma)\frac{1}{\lambda_t}$$

evaluated at $\frac{S_t^h}{S_t} = 1$.

- Run equilibrium exists if

$$x_t = \frac{\xi_t(Z_t + (1-\delta)Q_t^*)S_{t-1}^b}{\overline{R}_t D_{t-1}} < 1$$

or equivalently if $\xi_t < \xi_t^R$

$$x_t\left(\xi_t^R\right) = \frac{\xi_t^R(Z_t + (1-\delta)Q_t^*)S_{t-1}^b}{\overline{R}_t D_{t-1}} = 1$$

# Run Equilibrium

- Run at $t+1$ if : (i) A run equilibrium exists (ii) A sunspot occurs
- Assume sunspot occurs with probability $\varkappa$.
- $\rightarrow$ The time $t$ probability of a run at $t+1$ is

$$p_t = \Pr{}_t\{\xi_{t+1} < \xi^R_{t+1}\} \cdot \varkappa$$

# Production, Pricing and Monetary Policy (Standard)

- Production, resource constraint and $Q$ relation for investment

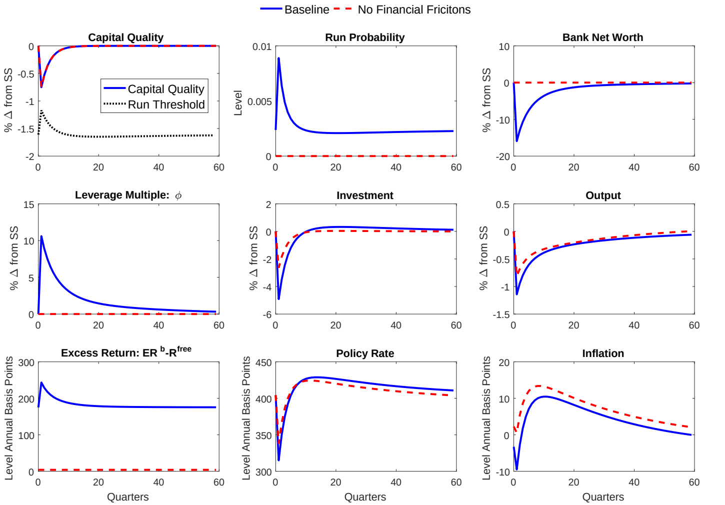
$$Y_t = AK_t^{\alpha} L_t^{1-\alpha}$$
$$Y_t = C_t + I_t + G$$
$$Q_t = \Phi(\tfrac{I_t}{K_t})$$

- Monopolistically comp. producers with quadratic costs of nominal price adjustment (Rotemberg)

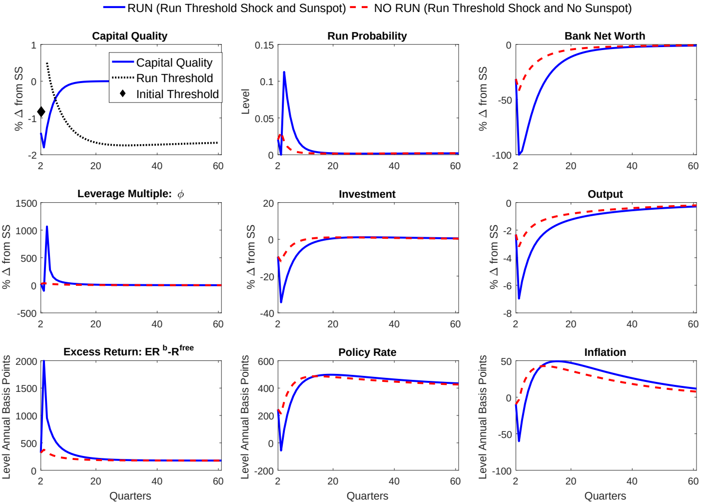
- Monetary policy: simple Taylor rule

$$R_t^n = \frac{1}{\beta}(\frac{P_t}{P_{t-1}})^{\kappa_\pi}(\Theta_t)^{\kappa_y}$$

# Response to a Capital Quality Shock: No Run Case

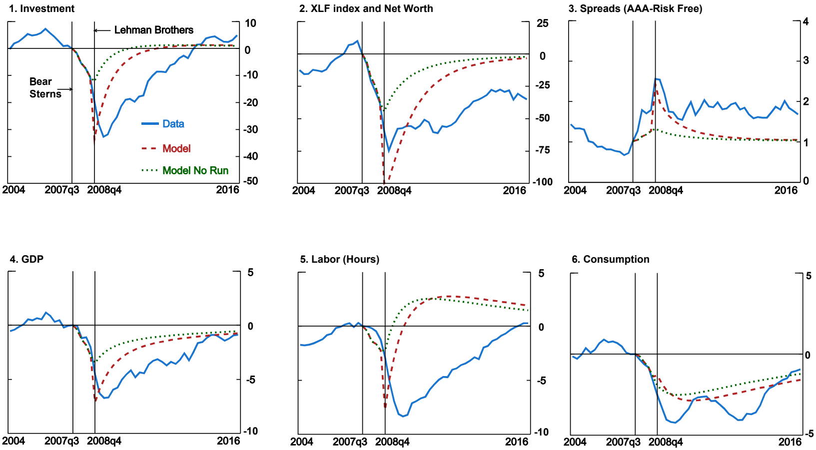


# Response to a Sequence of Shocks: Run VS No Run



# Financial Crisis: Model vs Data

| SHOCKS: | -.3% | -.6% | -.5% | -.8% | -.7% |
|---|---|---|---|---|---|
| | 2007Q4 | 2008Q1 | 2008Q2 | 2008Q3 | 2008Q4 |



# Conclusion

- Incorporated banking sector within 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
- Next steps:
  - Macroprudential policy (Run Externality)
  - Lender-of-last resort policies

# Conditions for Bank Run Equilibrium

- We can simplify existence condition for BRE:

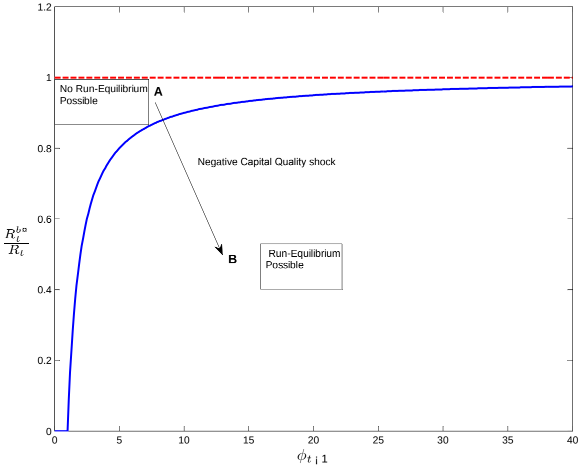
$$x_t = \frac{R_t^{b*}}{\overline{R}_t} \cdot \frac{\phi_{t-1}}{\phi_{t-1}-1} < 1$$

with

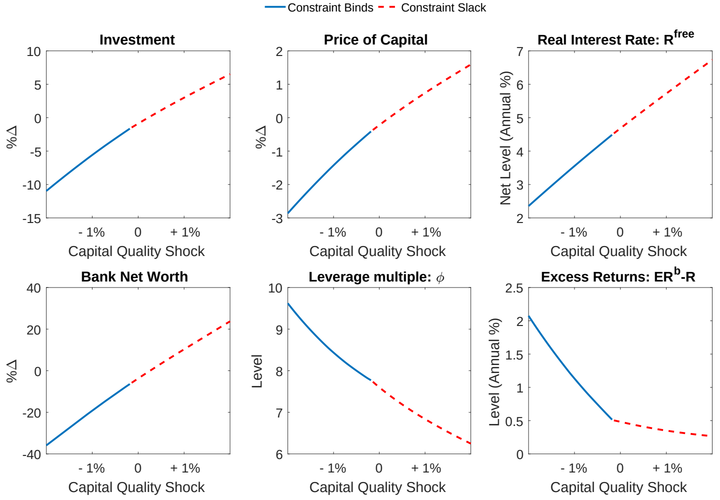
$$R_t^{b*} = \frac{\xi_t[Z_t+(1-\delta)Q_t^*]}{Q_{t-1}}; \quad \phi_{t-1} = \frac{Q_{t-1}S_{t-1}^b}{N_{t-1}}$$

- Likelihood BRE exists decreasing in $Q^*(\cdot)$ and increasing in $\phi_{t-1}$
- $\phi_{t-1}$ countercyclical $\rightarrow$ likelihood BRE exists is countercyclical.

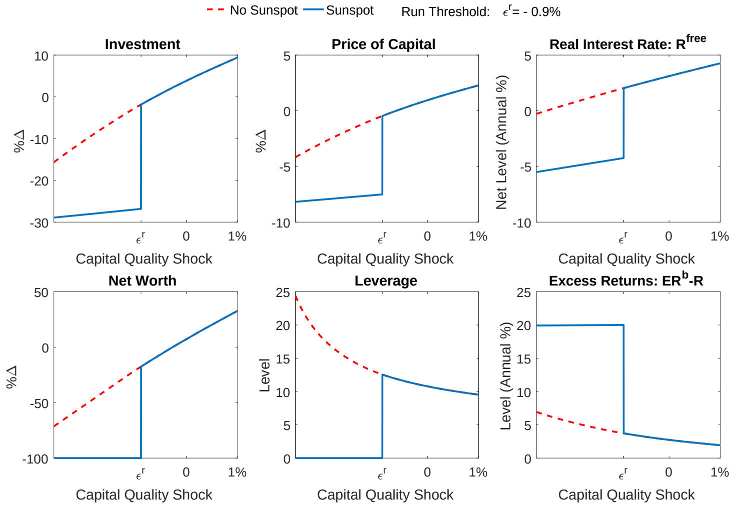
# Run Equilibrium Threshold



# Non-Linearities (or Lack Thereof) due to Occasionally Binding Constraints



# Non-Linearities From Runs



# Calibration

| Parameter | Description | Value | Target |
|---|---|---|---|
| | | | |
| Standard Parameters | | | |
| $\beta$ | Impatience | .99 | Risk Free Rate |
| $\gamma_h$ | Risk Aversion | 2 | Literature |
| $\varphi$ | Frish Elasticity | 2 | Literature |
| $\epsilon$ | Elasticity of subst across varieties | 11 | Markup 10% |
| $\alpha$ | Capital Share | .33 | Capital Share |
| $\delta$ | Depreciation | .025 | $\frac{I}{K} = .025$ |
| $\eta$ | Elasticity of q to i | .25 | Literature |
| $a$ | Investment Technology Parameter | .53 | $Q = 1$ |
| $b$ | Investment Technology Parameter | -.83% | $\frac{I}{K} = .025$ |
| $G$ | Government Expenditure | .45 | $\frac{G}{Y} = .2$ |
| $\rho^{jr}$ | Price adj costs | 1000 | Slope of Phillips curve .01 |
| $\kappa_\pi$ | Policy Response to Inflation | 1.5 | Literature |
| $\kappa_y$ | Policy Response to Output | .5 | Literature |
| Financial Intermediation Parameters | | | |
| $\sigma$ | Banker Survival rate | .93 | Leverage $\frac{QS^b}{N} = 10$ |
| $\zeta$ | New Bankers Endowments as a share of Capital | .1% | % $\Delta$ I in crisis $\approx$ 35% |
| $\theta$ | Share of assets divertible | .23 | Spread Increase in Crisis = 1.5% |
| $\gamma$ | Threshold for HH Intermediation Costs | .432 | $\frac{S^b}{S} = .5$ |
| $\chi$ | HH Intermediation Costs | .065 | $ER^b - R = 2\%$ Annual |
| $\varkappa$ | Sunspot Probability | .15 | Run Probability 4% Annual |
| $\sigma(\epsilon^\xi)$ | std of innovation to capital quality | .75% | std Output |
| $\rho^\xi$ | serial correlation of capital quality | .7 | std Investment |

# Households

- Within each household, $1-f$ "workers" and $f$ "bankers"
  - Workers earn wages
  - Bankers manage financial intermediaries and pay dividends
- Perfect consumption insurance within the family
- Bankers have finite expected horizons
  - With i.i.d. prob. $1-\sigma$, a banker exits next period.
  - $\Rightarrow$ expected horizon $= \frac{1}{1-\sigma}$ (Run leads to earlier exit)
  - Replaced by new bankers who receive start-up transfer from the family

# Household Optimization

Choose $\{C_t^h, L_t^h, D_t, S_t^h\}$ to maximize

$$U_t = E_t \sum_{i=0}^{\infty} \beta^i \left[ \ln C_{t+i}^h - \frac{1}{1+\varphi}(L_{t+i}^h)^{1+\varphi} - \frac{\chi}{2}(\frac{S_{t+i}^h}{S_{t+i}} - \gamma)^2 S_{t+i} \right]$$

s.t.

$$C_t^h + D_t + Q_t S_t^h = w_t L_t^h + R_t D_{t-1} + \xi_t [Z_t + (1-\delta) Q_t] S_{t-1}^h + \Pi_t - T_t$$

# Optimal Household Asset Demands

$\Lambda_{t,t+1} \equiv \beta^i C_t^h / C_{t+1}^h$; $^* \equiv$ conditional on run; $^- \equiv$ conditional on no run

- Deposits:

$$\{(1 - p_t)E_t^-(\Lambda_{t,t+1}) + p_t E_t^*(\Lambda_{t,t+1} x_{t+1})\} \cdot \overline{R}_{t+1} = 1$$

- Capital:

$$E_t\{\Lambda_{t,t+1} \frac{1}{1 + \frac{\partial \zeta(\cdot)}{\partial S_t^h} \frac{1}{Q_t \lambda_t}} R_{t+1}^b\} = 1$$

# Run Probability $p_t$

- Run at $t+1$ if : (i) A run equilibrium exists (ii) A sunspot occurs

- Condition (i) satisfied if

$$x_{t+1} = \frac{\xi_{t+1}(Z_{t+1} + (1-\delta)Q^*_{t+1})S^b_t}{\overline{R}_{t+1}D_t} < 1$$

- Assume sunspot occurs with probability $\varkappa$.

- $\rightarrow$ The time $t$ probability of a run at $t+1$ is

$$p_t = \Pr{}_t\{x_{t+1} < 1\} \cdot \varkappa$$

  - $\Pr{}_t\{x_{t+1} < 1\}$ countercyclical $\rightarrow$ $p_t$ countercyclical

# Response to a Sequence of Shocks in Flex Price Economy: Run VS No Run