A Macroeconomic Model with Financial Panics

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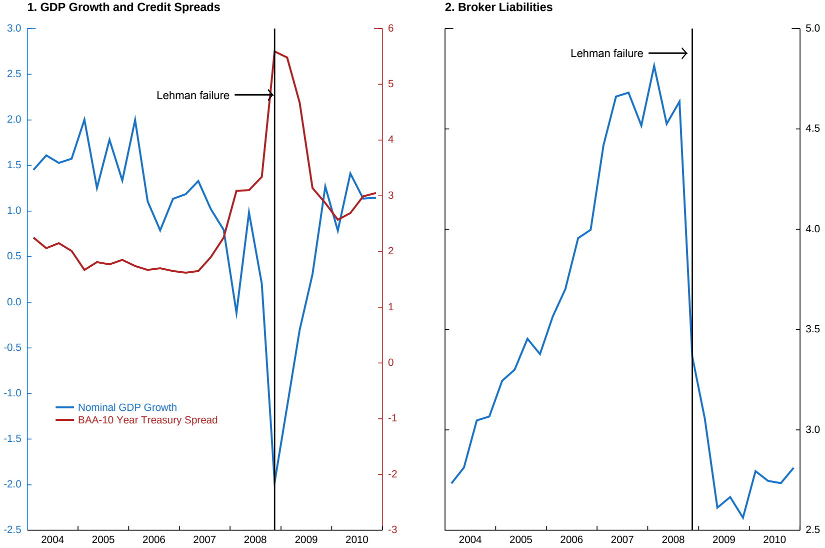
[1] The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Board or the Federal Reserve System

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
2. Broker Liabilities
Lehman failure
Lehman failure
Nominal GDP Growth
BAA-10 Year Treasury Spread
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
5.0
4.5
4.0
3.5
3.0
2.5
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

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

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

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

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

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

- Rate of return on intermediated capital

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

- Utility cost to household of direct finance

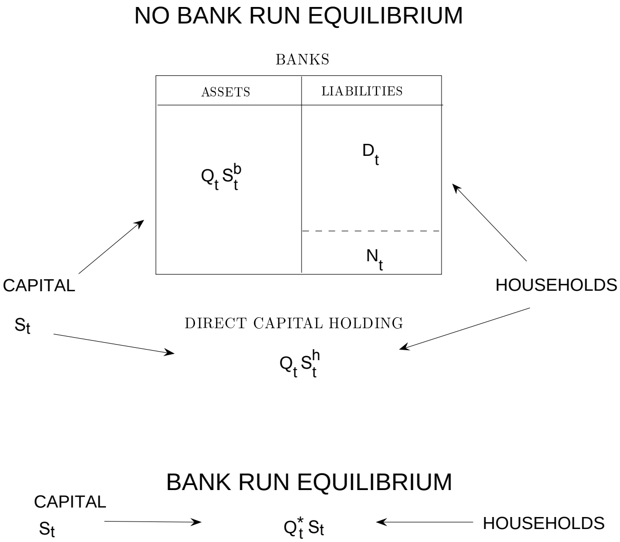
$$\varsigma(S^h_t, S_t) = \frac{\chi}{2} \left(\frac{S^h_t}{S_t} \right)^2 S_t$$

- Marginal rate of return on directly held capital

$$R^h_{t+1} = \frac{1}{1 + \chi \frac{S^h_t}{S_t}} R^b_{t+1}$$

Where $\chi \frac{S^h_t}{S_t}$ is the marginal cost of direct finance

Household and Bank Intermediation



Bank Decision Problem

- Objective

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

$\sigma \equiv$ exogenous survival probability

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

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

- Balance sheet

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

Deposit Contract

$\overline{R}_t \equiv$ 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)

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

- Recovery rate:

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

Bank Decision Problem: Perfect vs. Imperfect Markets

- Perfect markets:

  Banks issue deposits until:

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

  $\Rightarrow$ Leverage constraints do not arise
  $\Rightarrow$ Financial panics cannot arise

- Limits to arbitrage:

  Occasionally binding leverage constraints$\Rightarrow$

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

  Bank runs possible: extreme increases in $E_t \Lambda_{t,t+1} \{ R^k_{t+1} - R_{t+1} \}$

Limits to Bank Arbitrage

- Moral Hazard Problem:
  - After banker borrows funds at t, it may divert fraction θ 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 :

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

$$\overline{\phi}_t = \frac{\psi_t}{\theta}$$

- Note:
  - $n_t \leq 0 \Rightarrow$ bank cannot operate (key for run equilbria)
  - $E_t\{R^k_{t+1} - R_{t+1}\}$ countercyclical $\Rightarrow \overline{\phi}_t$ countercyclical.

Aggregation: No Run Case

Homogeneity: $\phi_t \equiv \frac{Q_t s_t^b}{n_t}$ and $\overline{\phi}_t$ independent of bank-specific factors

- $\rightarrow$ Aggregate leverage constraint

$$Q_t S_t^b \leq \overline{\phi}_t N_t$$

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

- Aggregate net worth

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

- 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 iff banks' net worth n_t goes to zero if others run
    - $n_t = 0 \rightarrow$ banks cannot operate

Conditions for Bank Run Equilibrium (BRE)

- Run equilibrium exists at $t+1$ if

$$\xi_{t+1}\left(Z^*_{t+1} + (1-\delta)Q^*_{t+1}\right) S^b_t < D_t \bar{R}_t \tag{1}$$

where $Q^*_{t+1} \equiv$ liquidation price:

$$Q^*_t = E_t\{\Lambda_{t,t+1}\xi_{t+1}(Z_{t+1} + (1-\delta)Q_{t+1}\} - \chi \frac{S^h_t}{S_t}$$

evaluated at $\frac{S^h_t}{S_t} = 1$

- $\iota_{t+1} \equiv$ sunpot variable; if $\iota_{t+1} = 1$ depositors panic when run possible

- Run occurs if (i) equation (1) is satisfied and (ii) $\iota_{t+1} = 1$

Run Probability p_t

- Assume sunspot occurs with probability $\varkappa$.

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

$$p_t = \Pr{}_t \left\{ \xi_{t+1} \left(Z^*_{t+1} + (1-\delta) Q^*_{t+1} \right) S^b_t < D_t \bar{R}_t \right\} \cdot \varkappa$$

$\Leftrightarrow$

$$p_t = \Pr{}_t \left\{ \xi_{t+1} \left(Z^*_{t+1} + (1-\delta) Q^*_{t+1} \right) < \frac{D_t \bar{R}_t}{S^b_t} \right\} \cdot \varkappa$$

$\rightarrow$ Higher leverage ratios $\frac{D_t \bar{R}_t}{K^b_t}$ increase run probability

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

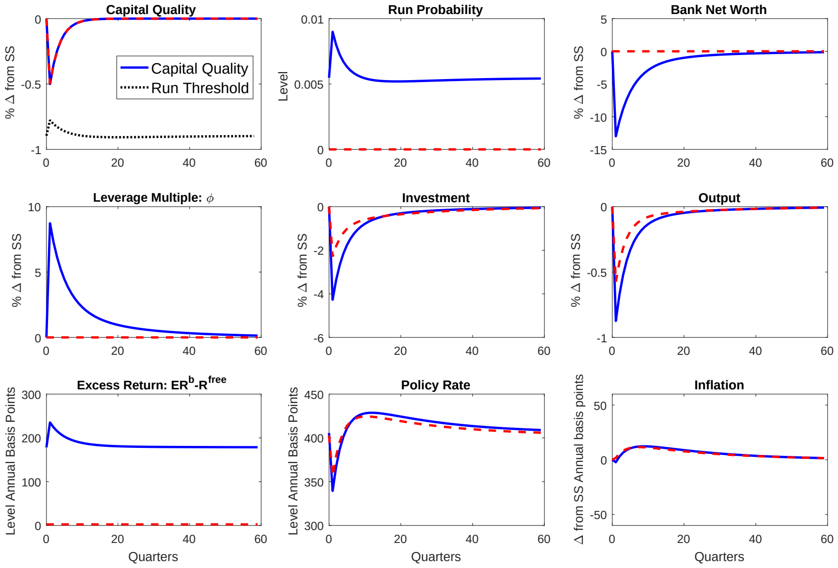
- Monetary policy: simple Taylor rule

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

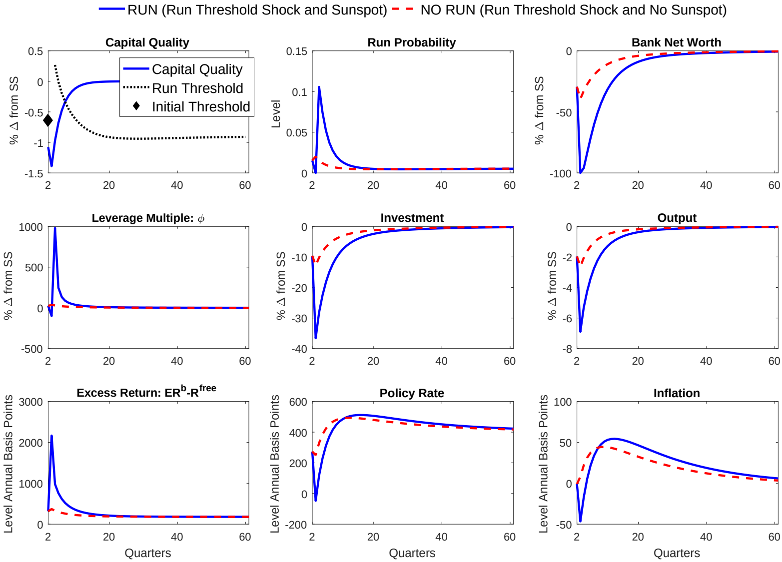
Calibration

Parameter	Description	Value	Target
Standard Parameters			
β	Impatience	.99	Risk Free Rate
γ_h	Risk Aversion	2	Literature
φ	Frish Elasticity	2	Literature
ϵ	Elasticity of subst across varieties	11	Markup 10%
α	Capital Share	.33	Capital Share
δ	Depreciation	.025	$\frac{I}{K} = .025$
η	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	$\frac{G}{Y} = .2$
ρ^{jr}	Price adj costs	1000	Slope of Phillips curve .01
κ_π	Policy Response to Inflation	1.5	Literature
κ_y	Policy Response to Output	.5	Literature
Financial Intermediation Parameters			
σ	Banker Survival rate	.93	Leverage $\frac{QS^b}{N} = 10$
ζ	New Bankers Endowments as a share of Capital	.1%	% Δ I in crisis $\approx$ 35%
θ	Share of assets divertible	.22	Spread Increase in Crisis = 1.5%
γ	Threshold for HH Intermediation Costs	.61	$\frac{S^b}{S} = .33$
χ	HH Intermediation Costs	.105	$ER^b - R = 2\%$ Annual
$\varkappa$	Sunspot Probability	.15	Run Probability 4% Annual
$\sigma(\epsilon^\xi)$	std of innovation to capital quality	.5%	std Output (C+I)
ρ^ξ	serial correlation of capital quality	.7	std Investment

Response to a Capital Quality Shock: No Run Case

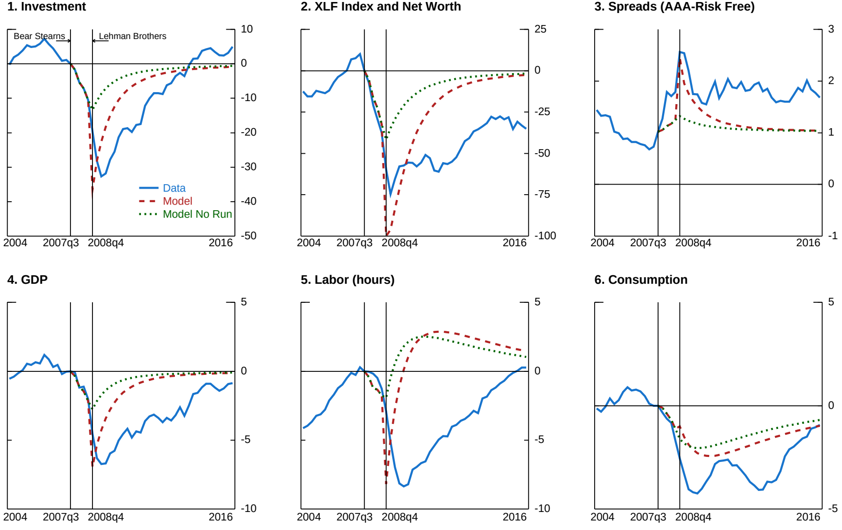


Response to a Sequence of Shocks: Run VS No Run



Financial Crisis: Model vs Data

Shocks :	-0.2 %	-0.5 %	-0.4 %	-0.6 %	-0.6 %
Threshold :	-0.9 %	-0.8 %	-0.7 %	-0.7 %	-0.6 %
	2007q4	2008q1	2008q2	2008q3	2008q4



Boom leading to the bust: news driven optimism

- Capital quality:

$$\xi_{t+1} = \rho^{\xi}\xi_t + \epsilon^{\xi}_{t+1}$$

- At $t = 0$ bankers learn that unusually large realization of ϵ^{ξ}_{t+1} of size $B > 0$ will happen at $t^B \in \{1, ..., T\}$ with prob. $\overline{P}^B_0 < 1$

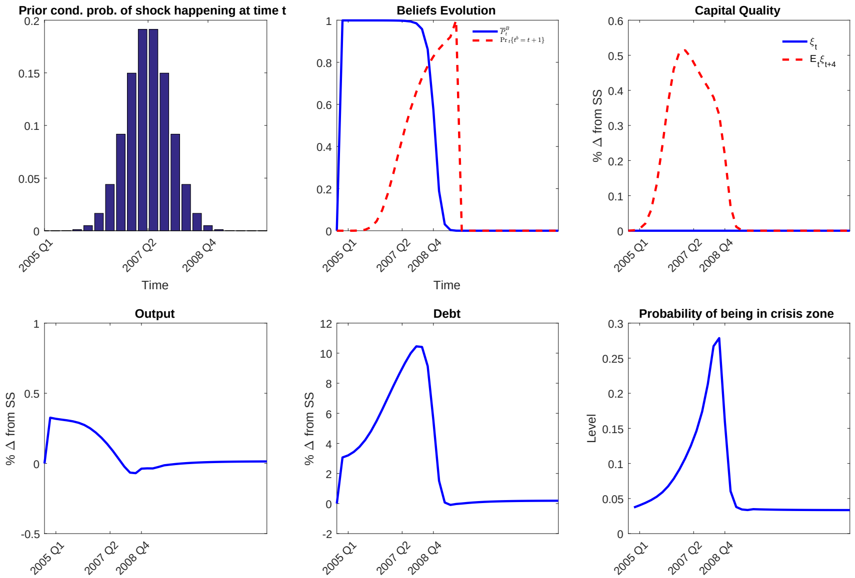
- $\Pr_0\{t^B = t\}$ is a truncated Normal (discrete approx.)

- Agents update $\Pr_t$ and $\overline{P}^B_t$ by observing ϵ^{ξ}_t

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

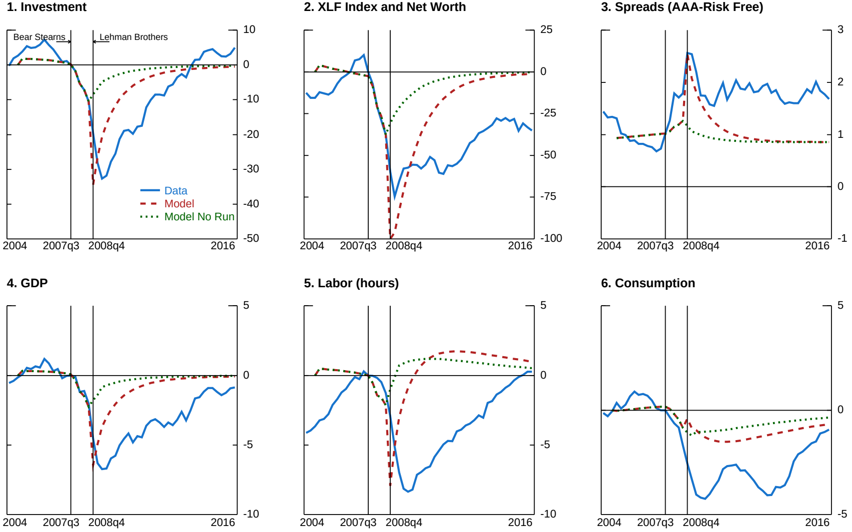
- Implies forecast errors in line with evidence, e.g. Bordalo et al 2017

Optimism, credit boom and financial vulnerability (no run)

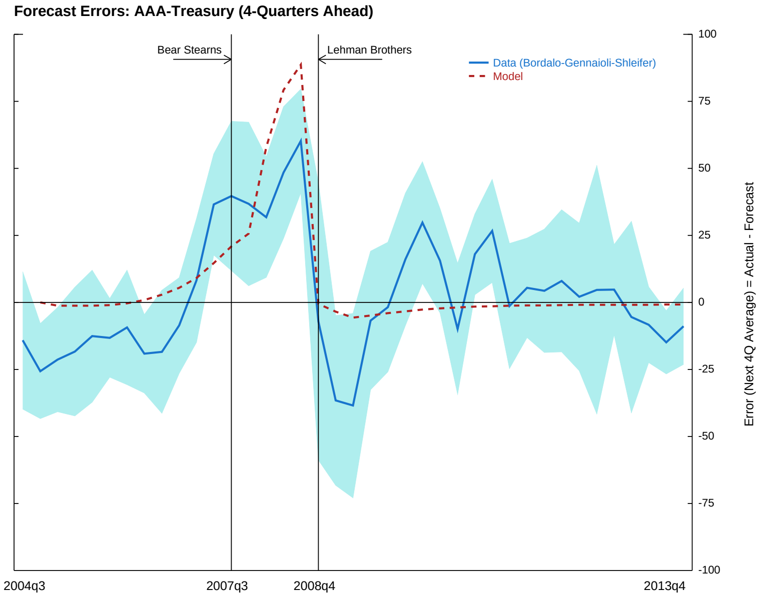


Financial Crisis After Credit Boom: Model vs Data

	2007q4	2008q1	2008q2	2008q3	2008q4
Shocks :	-0.2 %	-0.4 %	-0.3 %	-0.5 %	-0.0 %
Threshold :	-0.1 %	-0.1 %	0.0 %	-0.0 %	-0.0 %



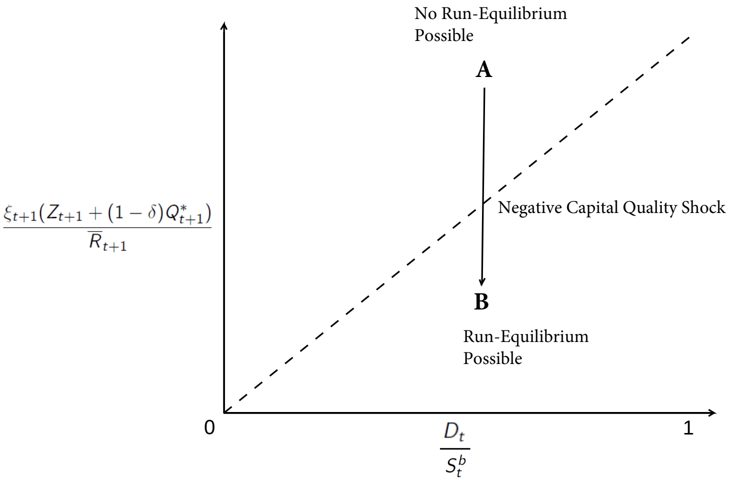
Forecast Errors in Credit Spreads (Baa-10yr Treasury)



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:
  - Macroprudential policy (Run Externality)
  - Lender-of-last resort policies

Run Equilibrium Threshold



Conditions for Bank Run Equilibrium

- We can simplify existence condition for BRE:

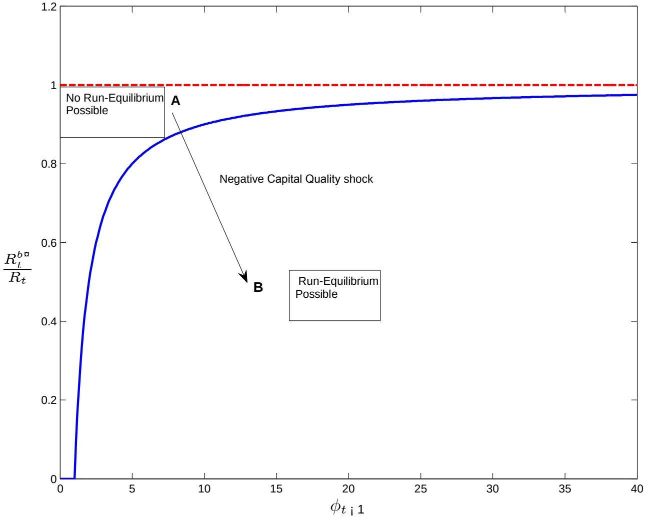
$$x_t = \frac{R_t^{b*}}{\overline{R}_t} \cdot \frac{\phi_{t-1}}{\phi_{t-1}-1} < 1$$

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 ϕ_{t-1}
- ϕ_{t-1} countercyclical $\rightarrow$ likelihood BRE exists is countercyclical.

Run Equilibrium Threshold



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

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