A Theory of Endogenous Asset Fire Sales, Bank Runs and Financial Contagion

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Banking crises with twin illiquidity

- Banking crises with ‘twin’ illiquidity problems
  - market illiquidity (mis-pricing of assets)
    - gaps between the market price and the fundamental value of an asset
  - funding illiquidity (bank runs)
    - banks struggling to roll over their short term debts
- The development of banking crises is often a vicious cycle
  - one bank failure
  - $\Rightarrow$ asset prices drop
  - $\Rightarrow$ more failures
  - $\Rightarrow$ prices drop further,...
- Modelling the vicious cycle using global games
  - bank runs’ impacts on asset prices
  - contagion can still emerge as a multiple-equilibria phenomenon
  - evaluate public policies, especially, asset purchase programs

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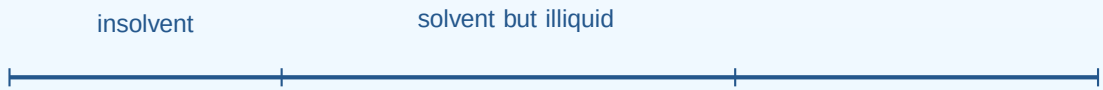
Overview: Endogenous Asset Fire Sales and Bank Runs

- A two-way feedback between asset fire sales and bank runs
- Fuelled by a lack of information
  - fundamental runs indistinguishable from coordination failures
  - a main challenge to LoLR policies
  - endogenous asset price determined by info asymmetry



- A vicious cycle
  - creditors panic and run
  - banks forced into early liquidation
  - adverse selection leading to a low asset price
  - the low price justifies the run in the first place
- Unique equilibrium for a *given belief* on the systematic risk

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Overview: Multiple Equilibria and Financial Contagion

- Banks' exposure to aggregate/systematic risk
- Contagion through asset prices & information externalities
  - the observation of a run $\Rightarrow$ pessimistic belief about the common risk
  - lower willingness to pay $\Rightarrow$ precipitates contagious runs at other banks
- Contagion can emerge as a multiple-equilibria phenomenon
  - coordination on the belief about the systematic risk
  - global-games approach no longer guarantees uniqueness
  - for the same fundamental, multiple equilibria with different numbers of runs
  - driven by pessimistic beliefs & reflecting financial fragility
- In sum, a financial fragility model
  - based on information friction
  - featuring the 'twin illiquidity' problem and the vicious cycle
  - market participants' beliefs, asset prices, runs, contagion, all endogenous
  - unique policy implications due to endogenous prices and multiple equilibria

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Policy Implications

- A balanced-budget asset purchase program break down the vicious cycle
  - a regulator can reduce financial stability with no better information
  - eliminates ‘bad’ equilibria, but does not kill ‘good’ ones
  - the importance of commitment power
- Regulatory disclosure: more information does not necessarily help.
  - when the regulator does have better information
  - it may be suboptimal to commit to truthful revelation
    - a favorable announcement saves banks from illiquidity
    - acknowledging a crisis causes contagion
  - compared to asset purchase programs: more info does not necessarily help
- Capital may not be as useful as we thought in preventing bank runs
  - high capital = resilience
  - conditional on high capital, a run signals unusually high risks
  - lower asset prices $\Rightarrow$ runs in the first place

The Bank Run Literature

- Panic-based bank runs: multiple equilibria, sun-spot bank runs
  - Diamond-Dybvig (1983)
- Refinement by global games: unique (threshold) equilibrium
  - Morris & Shin (2000), Rochet & Vives (2004), Goldstein & Pauzner (2005)
  - unique equilibrium, cut-off fundamental, solvent but illiquid banks
  - empirical evidence: Gorton (1988), Calomiris & Gorton (1991), etc.
- Some limitation: simplifying assumption of exogenous fire-sale prices/losses
  - omitting the reinforcing effect of bank runs on asset fire sales
  - missing intricacies in policy analysis
- Our contribution to the bank run literature
  - endogenizing fire-sale prices based on information friction
  - policy implications: asset purchase program, regulatory transparency, capital

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The Global Games Literature

- Refinement and unique equilibrium: first application: Morris & Shin (1998)
  - bank runs: Rochet & Vives (2004), Goldstein & Pauzner (2005)
- When can multiple equilibria resurface?
  - Signaling (policy trap)
    - Angeletos et. al. (2006), Angeletos & Pavan (2013)
  - Repeated attack and learning
    - Angeletos et. al. (2007)
  - Agents coordinate on the public signal of asset prices
    - Angeletos & Werning (2006), Ozdenoren & Yuan (2008)
    - fragility takes the form of excessive asset price volatility
- Our contribution is most related to the last strand of the literature
  - a two-dimensional setup: idiosyncratic vs. systematic risk
  - fragility takes the form of systemic bank failures unrelated to fundamentals
  - one step beyond: how to eliminate ‘bad’ equilibria

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Model Setup

Banks, their Assets and Liabilities

- Ex ante identical banks, indexed by $j = 1, 2, 3, ..., N$
- Three dates: $t = 0, 1, 2$
- Assets: 1 unit long-term risky portfolio, unit size, maturing at $t = 2$
  - each individual bank generates a cash flow $\tilde{\theta}^j \sim U(\underline{\theta}_s, \overline{\theta})$
  - aggregate states $s \in \{G, B\}$, with $\underline{\theta}_B < \underline{\theta}_G$
  - prior beliefs: $Prob(s = G) = Prob(s = B) = 1/2$
  - $\theta \Leftrightarrow$ idiosyncratic risk, $s \Leftrightarrow$ systematic risk
- Liabilities: financed by equity E, deposits F and short-term debts $1 - E - F$
  - deposits: fully insured, risk-free rate normalized to 1
  - short-term debts: demandable and risky
    - gross interest rate r_D at $t = 2$, and qr_D at $t = 1$
    - $D_1 = (1 - E - F)qr_D$
    - $D_2 = (1 - E - F)r_D + F$
- Banks are passive, forced into liquidation when runs occur

Parametric Assumptions

- Risky banking
  - $D_2 > \underline{\theta}_s$
- Substantial use of retail/stable funding
  - $F > D_1$
- Moderate penalty for early withdrawals
  - $q > 1/2 + \underline{\theta}_G/2D_2$
  - consistent with banks' function of providing liquidity insurance
- We do not endogenize banks' capital structure.
- As long as an optimal capital structure satisfies these parametric assumptions,
- $\Rightarrow$ all of our results will qualitatively hold.

Secondary Asset Market and Informational Friction

- Early liquidation $\Rightarrow$ assets sold to uninformed asset buyers
  - observe neither θ nor s
  - cannot distinguish the illiquid from the insolvent
  - can observe the number of bank runs M, $M \in \{0, 1, 2, ..., N\}$
  - based on M, form rational beliefs about θ and State s
- Asset buyers offer a price schedule $\mathbb{P} = (P_1\ P_2\ ...\ P_N)$
  - purchasing assets for price P_M when observing M bank runs
  - price competition in the secondary asset market
  - in the equilibrium, buyers only break even
  - zero expected profit based on their posterior beliefs

Wholesale Creditors & Runs

- A continuum of creditors
  - holding the short-term demandable debt of all banks
  - two actions at each bank, 'withdraw' at $t = 1$ or 'wait' till $t = 2$
  - observe price schedule $\mathbb{P}$
  - no common knowledge on θ's
  - for each bank, privately observe noisy signals about θ
    - private signal $x_i^j = \theta^j + \epsilon_i^j$, for a creditor i at bank j
    - ϵ_i^j uniformly distributed on $[-\epsilon, \epsilon]$, ϵ arbitrarily small
    - ϵ_i^j independent across banks and individual creditors
- Simultaneous moves
  - simultaneous individual decisions on 'withdraw' or 'wait'
  - simultaneous decisions on all banks
- Refinement by global games

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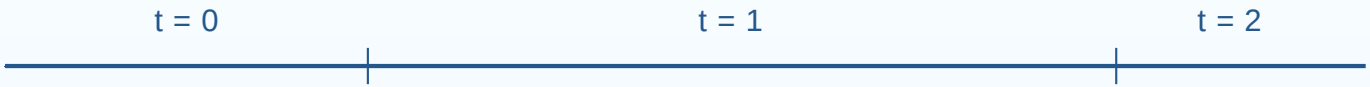
Timing of the game



Banks are established, with their portfolios and liability structures as given.

1. s and $\boldsymbol{\theta}$ are realized.
2. Asset buyers post a price schedule $\mathbb{P}$.
3. For each bank that they lend to, creditors receive private noisy signals about the bank's cash flow θ.
4. Knowing signals and the price scheme, creditors decide to run or not.
5. After observing the number of bank runs, buyers purchase assets at the quoted price.

1. Returns become public.
2. Remaining obligations are settled.

- Results robust to sequence of events on date 1

Solution and Applications

The Equilibrium Concept and Solution

- A market equilibrium associated with M runs, $\{P_M^*, \theta_M^*\}$, $M \in \{1, 2, ..., N\}$
  - Bayesian Nash equilibrium
  - threshold equilibrium for bank run game $\theta_M^* \equiv \hat{\theta}(P_M^*)$
    - when there are M runs in the economy, a run occurs iff $\theta < \theta_M^*$
  - uninformed asset buyers make zero profit in expectation
    - offering P_M^* when observing M bank runs
    - forming rational beliefs about $\boldsymbol{\theta}$ and s
    - breaking even: $P_M^* = E\left[\theta | \theta < \hat{\theta}(P_M^*), M\right]$
    - unable to make profitable deviations
- The procedure to solve for an equilibrium
  1. restricting equilibrium prices, $\underline{P} \leq P_M^* < D_2$
  2. solving the bank run game, $\hat{\theta}(P_M)$
  3. formulating asset buyers' rational beliefs
  4. P_M^* (and corresponding θ_M^*) pinned down by asset market competition

Bank Run Game for a *Given* Asset Price $\underline{P} \leq P_M < D_2$

- Threshold equilibrium refined by global games for a given $P_M \in [\underline{P}, D_2)$
- Threshold strategy: 'withdraw' if $x_i < \hat{\theta}$, 'wait' if $x_i > \hat{\theta}$
  - establish the existence of upper and lower dominance regions
    - upper dominance region: $\left(\theta^U(P_M), \overline{\theta}\right]$
    - lower dominance region: $\left[\underline{\theta}, \theta^L\right)$
    - $\theta^L = D_2, \theta^U(P_M) = F/(1 - D_1/P_M)$
  - creditors' beliefs about the total withdrawals L in the interim range $[\theta^L, \theta^U]$
    - $L \sim U(0,1)$ for creditors who observe the critical signal
    - mixed distribution for other creditors
- Critical creditors' indiff condition $\Rightarrow$ a unique equilibrium for the bank run game

$$\hat{\theta}(P_M) = \frac{D_2 - D_1}{1 - qD_1/P_M} \in \left[\theta^L, \theta^U(P_M)\right)$$

- Lower asset price adds to bank run risks, $\partial\hat{\theta}(P_N)/\partial P_M < 0$

Baseline Model: Equilibrium Asset Fire Sales and Bank Runs

- A baseline model with only one state: $\underline{\theta}_B = \underline{\theta}_G = \underline{\theta}$
  - no contagion, nor belief updating about s
  - price reflecting only asymmetric information
  - closed-form solutions
- Equilibrium asset price P_e pinned down by the zero-profit condition

$$P_e = \frac{\underline{\theta} + \hat{\theta}(P_e)}{2}$$

- Unique equilibrium: $P_e \in [\underline{P}, D_2)$ and $\theta_e \in (\theta^L, \theta^U(P_e))$

$$P_e = \frac{\Psi + \sqrt{\Psi^2 - 8qD_1\underline{\theta}}}{4}$$

$$\theta_e = \frac{\Psi + \sqrt{\Psi^2 - 8qD_1\underline{\theta}} - 2\underline{\theta}}{2}, \ \Psi \equiv (D_2 - D_1) + 2qD_1 + \underline{\theta}$$

- Inefficiency captured by $\theta_e - D_2$

The Fully-Fledged Model

- Introducing different states $\underline{\theta}_B < \underline{\theta}_G$
- Posterior belief ω_N^s for State s, conditional on the number of bank runs
- Multiple bank runs as a signal that $s = B$ more likely
- Price competition leads to the zero-profit conditions

$$\Pi_M(P_M^*) \equiv \omega_M^G(P_M^*)\frac{\underline{\theta}_G + \hat{\theta}(P_M^*)}{2} + \omega_M^B(P_M^*)\frac{\underline{\theta}_B + \hat{\theta}(P_M^*)}{2} - P_M^* = 0$$

- Forward-looking asset buyers and their rational expectation
  - understand bank run games played according to the price schedule
  - aware of the impacts of their price on the average asset quality
  - knowing their offered price affects perceived distributions of θ and s

Fully-Fledged Model (Cont'd)

- Equilibrium price schedule $\mathbb{P}^* = (P_1^*, P_2^*, ..., P_N^*)$ + multiple threshold equilibria θ_M^*
  - $M = 1, 2, ..., N$
  - a bank with $\theta < \theta_M^*$ fails when there are M runs in the economy
  - analytical solution can no longer be derived
- Ranking the equilibria
  - more runs observed $\Rightarrow$ pessimistic ex-post belief on s
  - for $M_1 < M_2 < N$, we have $\theta_{M_1}^* < \theta_{M_1}^*$ and $P_{M_1}^* > P_{M_2}^*$
  - a bank with $\theta \in (\theta_{M_1}^*, \theta_{M_2}^*)$ is exposed to contagion
- Multiple states $\Rightarrow$ global games no longer guarantees uniqueness
  - coordination on the belief about the systematic risk s
  - different θ_M^* associated with different belief ω_M^B

Contagion and Multiple Equilibria: an Illustration with $N = 2$

- Contagion and multiple equilibria: an illustration with $N = 2$
- Example: Bank A with $\theta^A \in [\theta_1^*, \theta_2^*)$, and Bank B with $\theta^B < \theta_1^*$
  - equilibrium outcome with $M = 1$ or $M = 2$
  - creditors' strategy: run iff $x < \theta_1^* \Rightarrow$ one run observed $\Rightarrow$ asset price P_1^* $\Rightarrow$ threshold strategy θ_1^* rationalised
  - creditors' strategy: run iff $x < \theta_2^* \Rightarrow$ two runs observed $\Rightarrow$ asset price P_2^* $\Rightarrow$ threshold strategy θ_2^* rationalised
- Wholesale creditors are aware of the price impact of their runs.
- Contagion is self-fulfilling and fuelled by pessimistic beliefs
  - pessimistic beliefs ω_2^B
  - $\Rightarrow$ depressed asset prices
  - $\Rightarrow$ more bank runs
  - $\Rightarrow$ pessimistic belief justified

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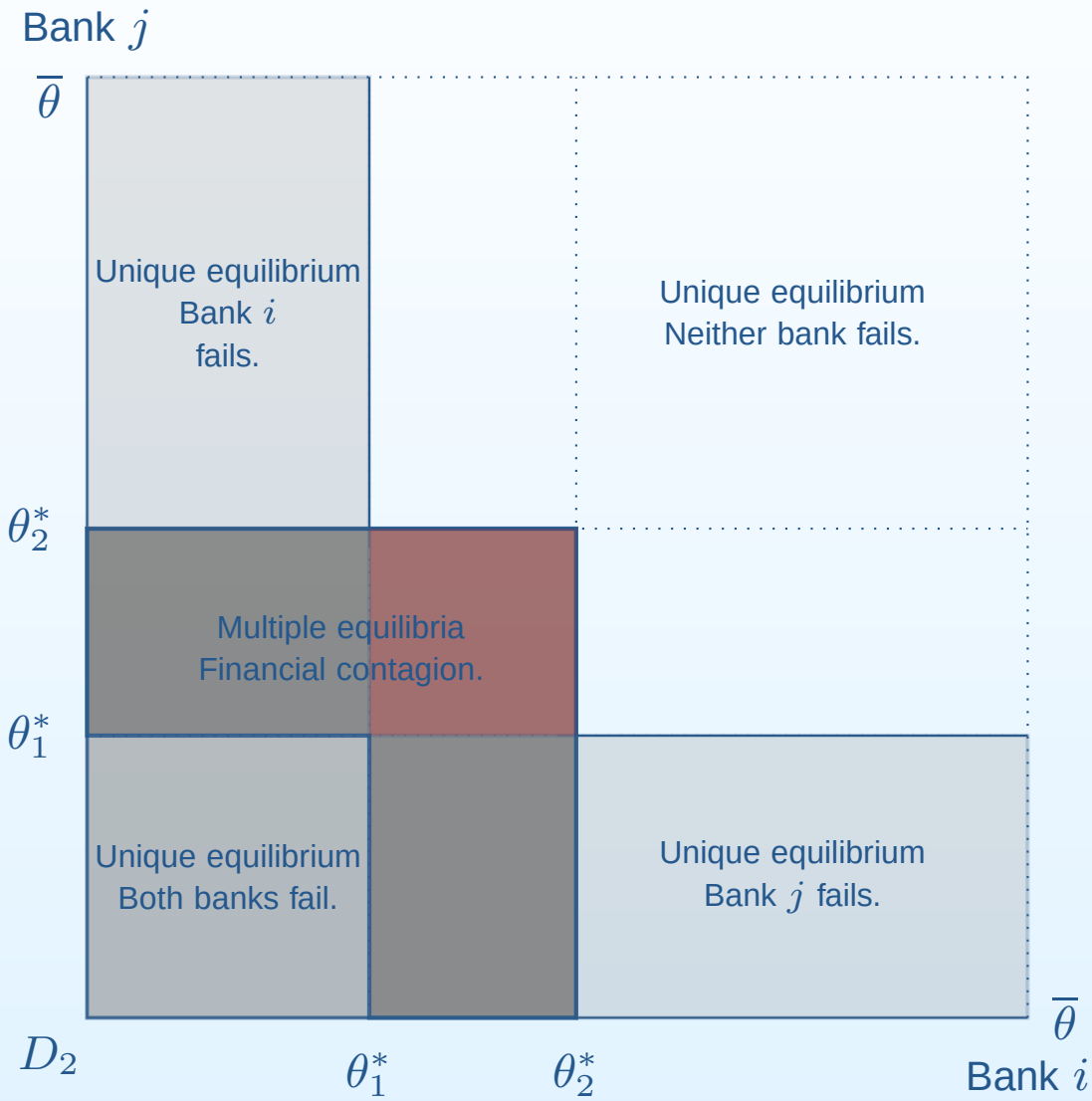
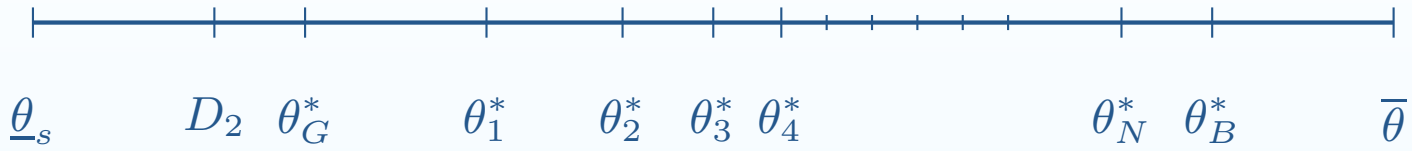
A Graphic Representation



Financial Fragility: General N-bank Case



- Each threshold equilibrium associated with one belief on s
  - θ^*_B associated with belief $prob(s = B) = 1$
  - θ^*_G with belief $prob(s = B) = 0$
  - $\theta^*_G < \theta^*_1 < \theta^*_2 < ... < \theta^*_N < \theta^*_B$ associated with ω^B_M, M = 1, 2, ..., N
  - As $N \to \infty$, $\theta^*_N \to \theta^*_B$
- Financial fragility: consider the following banking sector
  - $N \to \infty$, therefore maximum potential for (pessimistic) inferencing
  - robust performance of banks: θ just below θ^*_B for all banks
- Worst equilibrium (associated with $\omega^B_N \to 1$): all N banks fail at the same time!

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Eliminating 'Bad' Equilibria: Asset Purchase Programmes

- Can a regulator improve welfare, *even without better information*?
- Asset purchase programs, or central banks as broker of last resort
  - commitment to purchase assets at price P_A^*
  - announcing P_A^* (a stand-by offer) before the realization of s and θ
  - in particular, P_A^* does not vary with N
  - P_A^* based on the prior belief ($\omega^B = 1/2$) $\Rightarrow$ ex-ante break-even
- Such a policy intervention
  - exclude 'bad' equilibria (associated with $\omega_M^B > 1/2$)
  - but does not kill 'good' equilibria (associated with $\omega_M^B < 1/2$)
- Illustration again with $N = 2$ case
  - reducing (though not eliminating) funding liquidity risk
  - a possibility to eliminate financial contagion ($\theta_A^* < \theta_1^*$)
- Lender of last resort or broker of last resort?

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Eliminating 'Bad' Equilibria: Asset Purchase Programmes (Cont'd)

- Ordinary asset buyers
  - for each realised M, requiring to break even from an ex-post perspective
    - profits: banks with $\theta \in [P_M^*, \theta_M^*)$
    - losses: banks with $\theta \in [\underline{\theta}_s, P_M^*]$
    - setting low P_M^* to break even (root of financial fragility)
  - pricing in new information (the number of bank runs)
  - the number of runs M, however, is endogenous to buyers' belief
  - a pessimistic belief (high ω_M^B) $\Rightarrow$ lower P_M $\Rightarrow$ more runs $\Rightarrow$ belief justified
- The regulator in the asset purchase program
  - P_A^* announced before the realization of s and θ
  - allowing the regulator to break even from an ex-ante perspective
  - move surplus across states: profits in State G, and losses in State B
  - in terms of breaking even, relying less on the reduction of asset prices
- Problem with the market: a lack of commitment power

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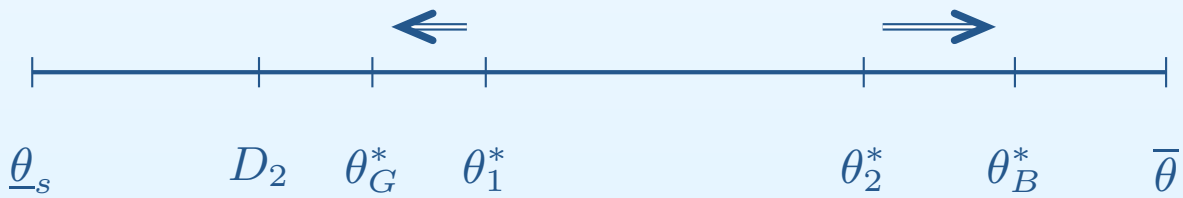
Other Policy Applications

Application I: Impacts of Regulatory Disclosures

- Financial contagion caused by market participants' uncertainty about s
- Question: if the regulator knows s, will it help to disclose it?
- Answer (assuming truthful revelation): Yes and No
  - a favourable disclosure ($s = G$) calms down the market
  - $\Rightarrow P_G^* > P_N^*$ and $\theta_G^* < \theta_1^*$
  - acknowledging a bad state ($s = B$) aggravates the crisis
  - $\Rightarrow P_B^* < P_N^*$ and $\theta_B^* > \theta_2^*$
- Asset purchase vs. regulatory disclosure: more info does not necessarily help!



Application II: Bank Capital and Liquidity Risk

- Can increasing capital ($E + \Delta$) effectively prevent bank runs?
- Conventional wisdom (exogenous asset price)
  - yes (buffer effect)
  - market value of equity = a buffer against fire-sale losses
- When asset price is endogenous
  - no necessarily (inferencing effect)
  - the equilibrium fire-sale price P_e decreases in observed capital level
  - fuelling runs in the first place, and offsetting some of the buffer effect
- Intuition
  - a well-capitalised bank is unlikely to experience a run
  - but if a run happens, asset buyers form very pessimistic beliefs
- Overall assessment:
  - in terms of preventing runs, capital may not be as effective as we thought
  - when $\underline{\theta} = 0$, capital has no impact on bank run risk at all

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Conclusion

Concluding Remarks

- A theory of endogenous asset fire sales, bank runs and contagion
- Bank runs and fire sales mutually reinforce each other
  - the feedback driven by a lack of information
- Financial contagion as a multiple-equilibria phenomena
- Balanced-budget asset purchase programmes can promote stability
  - the importance of commitment power
  - restricting the set of multiple equilibria
  - reducing inefficient bank runs
- (Re-)Evaluate the impact of capital and regulatory disclosure

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