Systemic Credit Freeze in Financial Lending Networks

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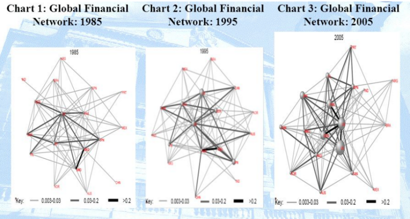
Motivation

- By the onset of the financial crisis of 2008, the US financial system had become increasingly more interconnected.
    - Complex lending relations: interbank and overnight lending, securitized lending such as repo market.
- Failure of an institution triggers financial distress for its counterparties or those holding its shares.
- Lenders need to also assess creditworthiness of borrowers of the borrower, and so on.



- Collapse of Lehman Brothers in September 2008 causes many institutions to lose access to credit (credit freeze).

Ex-Ante vs. Ex-Post

- Ex-Post Contagion: the failure of one institution can cause other institutions to fail.
- Ex-Ante Considerations: credit freezes induced by the fear future liquidity or profitability of borrowers might be compromised because of ex-post effects.

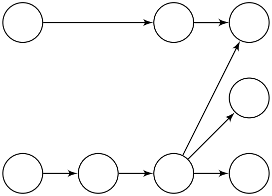
> "You have a neighbor, who smokes in bed...Suppose he sets fire to his house. You might say to yourself...'I'm not gonna call the fire department. Let his house burn down. It's fine with me.' But then, of course, what if your house is made of wood? And it's right next door to his house? What if the whole town is made of wood?"
>
> Ben Bernanke
> Chair of Federal Reserve Bank
> during the 2008 financial crisis

> Institutions such as Goldman Sachs, Credit Suisse and Deutsche Bank had "little or no interest to renew repos [for Bear Stearns] in the face of concerns over the dealer bank's solvency."
>
> Darrell Duffie
> *How Big Banks Fail and What to do About It*
> March 27, 2010

> "If we start taking novations [credit contracts for Bear Stearns], people pull their business, they pull their collateral, you're out of business."
>
> Gary Cohn
> Co-President
> Goldman Sachs
> March 11, 2008

Ex-Post Analysis

- Basic setup: n backs, survival of bank i *depends* on both (1) an idiosyncratic shock at i, and (2) the survival of other banks.
- We model the dependence structure in (2) using a network T:



- Main point: A single negative shock can spread to the rest of the network, causing systemic trouble.
- Studied extensively in previous literature: Acemoglu, Ozdaglar and Tahbaz-Salehi (2015), Cabrales, Gale and Gottardi (2015), Elliott, Golub and Jackson (2014), Gai and Kapadia (2010), Jorian and Zhang (2010)

This Talk

- More importantly, banks fear future liquidity problems ex-ante, leads to systemic credit freeze.
- We develop a stylized model of ex-ante credit freezes in a financial network:
  - Banks have outside known liabilities (e.g., employee wages, operational costs) and also hold assets with random value.
  - Some banks can lend to clients located at the leaves of the network which a fixed demand for funds.
  - Lending contracts determined by potential lenders who offer an interest rate and borrowers decide to borrow as much as desired.
  - Potential lenders can always freeze credit by offering no contract and avoiding any subsequent losses.
- Introduce shocks to equity value distribution that increase a bank's probability of default.
- Characterize the subgame perfect equilibria of this financial network.

Main Results

- Comparative statics for the chain network. Freeze occurs when:
  - Many layers of financial intermediation or liquidity mismatch is small.
  - Asset markets are weak and/or unstable.
  - Portfolios of assets across banks are independent or anti-correlated.
- In tree networks, where each bank can borrow from at most one other bank, freezes are "simple" in the sense that:
  1. They always originate with the affected bank (the bank receiving the shock).
  2. The set of banks experiencing a credit freeze is a connected set.
- In general networks, a negative shock can affect the equilibrium in nuanced ways and freezes may "complex."
- Because systemic credit freeze can occur from a small, isolated shock to risk, (relatively) inexpensive policy can restore large amounts of lending.

Related Literature

- Empirical evidence of credit freezes in interbank lending
  - Adrian et al. (2013); Alfonso, Kovner and Schoar (2010); Brunnermeier (2009)
- Endogenous network formation
  - Leitner (2004); Babus (2006); Blume et al. (2011)
- Single bank or pair of banks accessing credit market
  - Gorton and Metrik (2012); Diamond and Rajan (2011); Caballero and Simsek (2013)
- Ex-ante fears captured through coordination game
  - Allen and Babus (2009); Anand et al. (2012); building off global games literature of Shin and Morris (2001)
  - No ex-post trigger

Banks, Depositors, and Clients

1. Client project ($\mathcal{C}$): Non-financial project with funding level x and unit capacity has production technology:

$$f(x) = \begin{cases} r^*, & \text{if } x \geqslant 1 \\ 0, & \text{otherwise} \end{cases}$$

   where $r^* > 1$.

2. Depositor ($\mathcal{D}$): Perfectly elastic supply of funds at interest rate r.
3. Bank ($\mathcal{B}$): Intermediaries between depositors and clients (and each other).

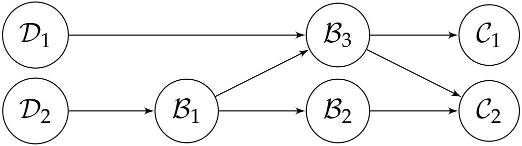


Figure: Potential Lending Network T.

Overview of Lending Game

- Take directed, potential lending network T as given. Let $\mathcal{N}_{in}(i)$ and $\mathcal{N}_{out}(i)$ denote the in and out-neighborhood of i, respectively.
- Lending game consists of three stages

1. Offer Stage: Banks make offers sequentially according to an order. At every time t, some bank i makes take-it-or-leave-it offer $R_{i\to j} \in \mathbb{R}_+$ to every bank $j \in \mathcal{N}_{out}(i)$. May withdraw offer after observing all offers made.
2. Borrowing Stage: Banks choose to borrow sequentially according to an order. At every time t, some bank j borrows $x_{i\to j} \in \mathbb{R}_+$ from every bank $i \in \mathcal{N}_{in}(j)$ at interest rate $R_{i\to j}$.
3. Repayment Stage: All liquidity shocks are realized, banks make repayments (if possible) and otherwise default on the loan.

Repayment Stage

- Each bank i has an outside balance sheet:
  - $v \geqslant 0$: outside, fixed liabilities
  - $\eta_i \geqslant 0$: random return of outside asset, drawn from joint distribution $G(\cdot)$
  - $z_i = \eta_i - v$: the random outside equity value of bank i
- The ex-post (endogenous) variables of the network are:
  - π_j: the profit of bank j
  - d_j: the event that bank j defaults (binary)
  - $y_{j \to i}$: the repayment of j to i
- Take as given the realized lending network $\tilde{T} = (\mathbf{R}, \mathbf{x})$ which specifies interest rates and borrowed funds in the network.
- A repayment equilibrium consists of the triple $(\boldsymbol{\pi}, \mathbf{d}, \mathbf{y})$, specifying defaults and repayments, conditional on the realizations of $\mathbf{z}$.

Repayment Equilibrium

- The (realized) profit of bank j is

$$\pi_j = z_j + \sum_{k \in \mathcal{N}_{out}(j)} y_{k \to j} - \sum_{i \in \mathcal{N}_{in}(j)} R_{i \to j} x_{i \to j}$$

- The default vector $\mathbf{d}$ satisfies $d_i = 1$ if and only if $\pi_i \leqslant 0$. The repayment vector $\mathbf{y}$ satisfies

$$y_{j \to i} = \begin{cases} R_{i \to j} x_{i \to j}, \text{ if } d_j = 0 \\ 0, \text{ if } d_j = 1 \end{cases}$$

  for all $(i \to j) \in T$.

- If a bank defaults, it repays nothing. This is known as the total failure model, where bankruptcy liquidation proceeds are zero.

Lending Equilibrium

- Every bank j maximizes expected upside profit minus a default cost $(F \geqslant 0)$ from bankruptcy, $\mathbb{E}[(\pi_j)_+ - F \cdot d_j]$, subject to the borrowing constraint:

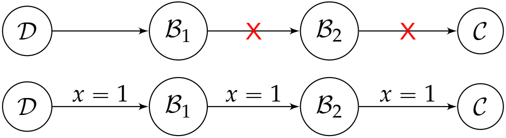
$$\sum_{i \in \mathcal{N}_{in}(j)} x_{i \to j} \geqslant \sum_{k \in \mathcal{N}_{out}(j)} x_{j \to k}$$

  and no bank withdraws its offer.

- Weak solution concept: subgame perfect equilibria of the lending game.
- Strong solution concept: trembling-hand perfect equilibrium with random perturbations to depositor rates.
- Essential uniqueness: two lending realized lending equilibrium networks $\tilde{T}^{(1)}, \tilde{T}^{(2)}$ are equivalent if $\mathbf{x}^{(1)} = \mathbf{x}^{(2)}$ and $R_{i \to j}$ agree wherever $x_{i \to j} > 0$.

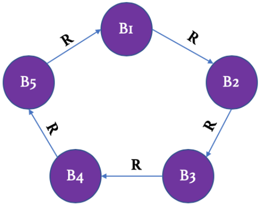
Existence and Uniqueness of Lending Equilibrium

- Proposition 1. Every potential lending network T has a weak lending equilibrium.
  - Equilibrium does not allow randomization: each bank gives a deterministic offer, does not withdraw with probability 1, and borrows a deterministic amount.
- Theorem 1. If $G(\cdot)$ is a generic probability distribution over $\mathbf{z}$, then the strong lending equilibrium is essentially unique.
  - Identical Deposits: symmetric Bertrand competition
  - No Trembles: asymmetric Bertrand competition
  - Genericity: Bank 1 has return $\sigma \in (0, 1)$, bank 2 defaults with probability p. Indifferent at $p = p^* = \frac{r^* - r}{r^* - r + \sigma}$.



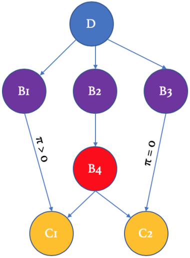
Existence and Uniqueness of Repayment Equilibrium

- If $\tilde{T}$ is a realized lending network from a lending equilibrium, can it have cycles with $x_{i \to j} > 0$?
  - Proposition 2. If $G(\cdot)$ has unbounded support (or generic), no.
- Theorem 2. If $\tilde{T}$ emerges from a lending equilibrium, then for any realization of $\mathbf{z}$, the repayment equilibrium is unique.
  - Can be recursively computed bottom-up!
- Not true for all $\tilde{T}$, in particular, if it has cycles:

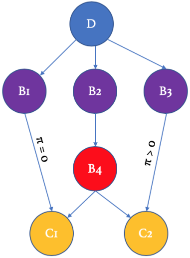


Sensitivity to Order

- Business Lending: The equilibrium flow of funds in $\tilde{T}$ restricted to $\mathcal{C}$, $\mathbf{x}_{\mathcal{C}}$.
- When r, r^{*} are the same for all depositors and clients, respectively, then $\mathbf{x}_{\mathcal{C}}$ is a sufficient statistic for welfare (i.e., gains from trade).
- Proposition 3. Business lending does not depend on the offer order $\mathcal{O}$ or the borrowing order $\mathcal{L}$.
- Does the equilibrium depend on the order?



Bank 1 offers before Bank 3



Bank 3 offers before Bank 1

Intermediation and Liquidity Mismatch

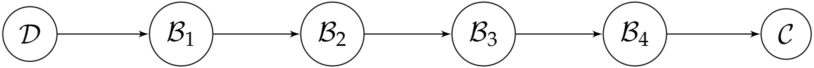


Figure: Chain Network.

- We say that bank j has a credit freeze if $R_{i\to j} = \infty$ for all $i \in \mathcal{N}_{in}(j)$ for some equilibrium realized lending network $\tilde{T}$.
- Proposition 4. If T is a chain, then every bank has a credit freeze or no bank does.
- Theorem 3. (Systemic Credit Freeze)
    - Length: There exists threshold M number of banks such that for $m < M$ there is no freeze and for $m > M$ the whole chain freezes (regardless of risk).
    - Liquidity Mismatch: There exists threshold s^* such that for $(r^* - r) > s^*$ there is no freeze and for $(r^* - r) < s^*$ the whole chain freezes.

Shocks to Asset Values

- In every state of the world, asset $\mathbf{z}'$ pays more than $\mathbf{z}$ for all banks.
  - Say that $\mathbf{z}'$ first-order stochastic dominates $\mathbf{z}$ if $z_i'|\left(\mathbf{z}'_{-i} = \mathcal{Z}_i\right)$ FOSD $z_i|\left(\mathbf{z}_{-i} = \mathcal{Z}_i\right)$ for all banks i and all realization $\mathcal{Z}_i$.
- Two competing effects: systemic risk and risk appetite.
- Need to control for risk appetites. There exists $\bar{F} > 0$ such that for all $F > \bar{F}$:
  - Theorem 4. Whenever $\mathbf{z}'$ FOSD $\mathbf{z}$, there is no systemic credit freeze in $\mathbf{z}'$ if there is no systemic freeze in $\mathbf{z}$.
  - Negative shocks to the distribution of asset returns cause freezes.
- Similar result for a special case of second-order stochastic dominance: see paper.

Portfolio Correlation

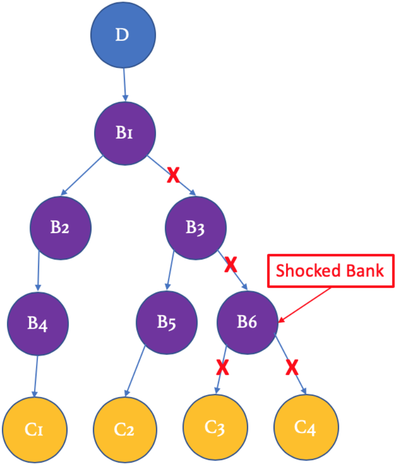
- For simplicity, assume for some $\sigma > 0$ and $\rho \in \left[-\frac{1}{2}, 1\right]$, equity returns $\mathbf{z}$ are given by:

$$\mathbf{z} \sim \mathcal{N}\left(\boldsymbol{\mu}, \begin{pmatrix} \sigma^2 & \rho\sigma^2 & \cdots & \rho\sigma^2 \\ \rho\sigma^2 & \sigma^2 & \cdots & \rho\sigma^2 \\ \cdots & \cdots & \cdots & \cdots \\ \rho\sigma^2 & \rho\sigma^2 & \cdots & \sigma^2 \end{pmatrix}\right)$$

- Proposition 5. For a fixed chain network T, there exists $\rho^* < 1$ such that if $\rho > \rho^*$ there is no freeze.
- As $\rho \to 1$, lending becomes "riskless" because all banks default in the same state of the world.
- As returns become more independent (or anti-correlated), bank i gets a positive return when some other bank might default, which makes lending riskier.

Simple Freezes in Trees

- Shock: parallel shift in the distribution of z_i, set $z_i' = z_i - \epsilon$ for some shock size $\epsilon > 0$.
- Assume there is a credit freeze. Recall that simple freezes satisfy: (i) bank i loses credit, (ii) all banks which lose credit are connected to bank i through banks with frozen credit.
- Proposition 6. If T is a directed tree, then any shock induces only simple freezes.



Complex Freezes: Before Shock

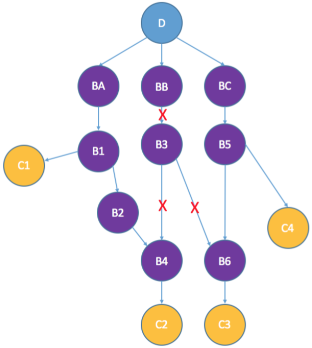


Figure: Network A.

- Each bank has independent returns: **G** or **B**
- **B**: toxic asset wipes the bank out
- Banks 1, 2, 4, and 6 are always safe (realize state **G** with probability 1)
- Small chance banks 3 and 5 get **B** return. Assume bank 5 is slightly riskier.
- Branch A to client 2 is riskless so is more competitive than branch B.
- Branch C has two clients as opposed to one, so as long as bank 5 is not *much* riskier than bank 3, branch C can compete with branch B over client 3.

Complex Freezes: After Shock

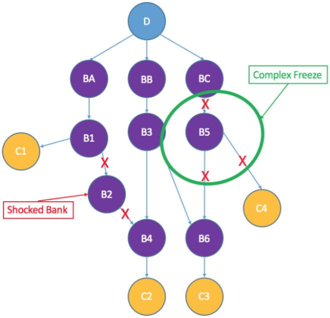


Figure: Network B.

- Shock bank 2: realizes state **B** with probability (for simplicity).
- Clearly bank 1 will not lend to bank 2.
- Branch B has monopolistic access over client 2.
- Bank 3 is less risky than bank 5, and both branch B and C have access to two clients.
- Branch B is now competitive for client 3, so branch C can only have access to client 4.
- Profits from client 4 not sufficient to compensate for bank 5's risk.

Central Bank Policy

- Central bank has a budget B and can implement asset purchases (positive shock) or discount window (lender-of-last-resort) policies.
- Space of feasible policies $(\boldsymbol{\epsilon}, \mathbf{B})$ at discount rate $r_{CB} > 1$:

$$\sum_{i=1}^{n} (\epsilon_i + B_i) \leqslant B$$

- Untargeted policy: Use the entire budget and set $\epsilon_i = \epsilon_j$ and $B_i = B_j$ for all banks i, j.
- Targeted policy: No restriction on $(\boldsymbol{\epsilon}, \mathbf{B})$ except the budget constraint.
- Optimal policy: maximize total business lending.

Main Policy Findings

- Proposition 7. For freezes in the chain, an untargeted policy does no worse than a targeted policy.
  - Lending in the chain is cooperative, use the interest rates to redistribute liquidity in a way that makes everyone content to borrow/lend.
- Proposition 8. After a shock, we see business lending decrease by $\Delta > 0$ from a simple freeze, want to implement an inexpensive policy to restore lending:
  - Always set $\epsilon_i = 0$ and $B_i = 0$ if bank i did not lose credit.
  - This policy is relatively cheap (i.e., $B \leqslant \Delta$) and strictly cheaper than untargeted policy (if not in the chain).
- When the freeze is complex, may be better to target banks unaffected by freezes.

Policy Examples (Ongoing)

- An untargeted policy will work with a large budget, but if the resources of the central bank are limited (i.e., the budget is bounded), could cause business lending to fall.
- If policymakers are misinformed of the financial network, targeting policies can exacerbate the problem.
- Evidence for a policy of decreasing some asset prices, which would lower interest rates.

Conclusion

- Extend current work on financial networks: link between ex-post defaults and ex-ante lending considerations.
- Lack of short-term funding because of uncertainty of future solvency:
  - Bear Stearns was in trouble (March 2008) months before the collapse of Lehman Brothers (September 2008).
  - Interconnectedness of financial system caused tightening of credit. Affected large financial institutions and small business alike.
- Extent of credit freeze is highly sensitive to the structure of lending.
- Monetary policy can be effective if the cause of the freezes is well-understood. Policy becomes increasingly more complex as financial system becomes more complex.
- Future work: investigate credit freezes in repo or interbank lending market, can we characterize optimal policy?