Complexity, Concentration and Contagion

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- even complex systems tend to exhibit a basic simplicity
- systems often have a natural hierarchy, comprising nested sub-structures.

**survival of the simplest** non-hierarchical structures should be deselected over time: they are less efficient or less robust relative to simpler, hierarchical structures.
The modern financial system appears to have grown
- more complex, concentrated and interconnected.
- “less modular, less hierarchical and thus less decomposable”

Most balance sheet growth prior to the financial crisis of 2008 was claims by financial firms on financial firms
(See e.g. Shin (2009) on how securitization increased complexity.)
Asset Share of Largest 3 Banks

images/ghk_fig2.png
tipping point  scenarios where a small shock or parameter change produces a large change in outcomes

GHK goal  use network techniques to identify determinants of banking-system tipping points

Especially:  when does a funding liquidity shock become “contagious” (e.g., liquidity hoarding shock: shortening term of interbank loans and holding more deposits with central bank)
- network model of lending in interbank markets
- model of systemic liquidity crisis
A “concrete and practical instantiation of a complex adaptive system in economics.” (Lo 2011 JME)

- focus liquidity management in the face of liquidity shocks
- aspiration demonstrate that interbank network configuration matters for
  - financial fragility
  - the generation of banking crises
Network Configurations

Poisson configuration (ER random graph) thin-tailed: interbank links in the network are distributed roughly evenly across different banks; a small number of banks have many or few links.

Geometric configuration: fat-tailed: interbank links in the network are distributed asymmetrically; a few banks in the network are much more highly connected than the typical bank; many banks have few links.

A fat-tailed configuration is more in keeping with real-world networks. (The Poisson provides a “benchmark”.)
Replication Attempt

Poisson network results: easy to replicate

Geometric network results: not easy to replicate
    had to request their (Matlab) code, which contained some surprises
Two sources of model randomness:

1. network creation is randomized, subject to the distributional assumptions that drive the network structure (network configuration)

2. the initiating shocks are random (which trigger liquidity hoarding)

The randomness over the network and initiating shock imply *ex ante* uncertainty about whether contagion will occur.

Otherwise, the GHK model is entirely non-stochastic: the propagation of contagion is a purely deterministic process which depends on the parameters of the model.
GHK Model: Key Aspects

- unsecured claims
- repo activity
- shocks to the haircuts applied to collateral
Money market instruments: very liquid short-term debt securities (i.e., cash equivalents).

Unsecured bank lending example: federal funds market for (mostly overnight) uncollateralized loans

The Fed Funds market is OTC (often with brokers)
Repurchase Agreements

- secured (collateralized) loan
- borrower/seller sells securities to a lender/buyer, but contract also commits the borrow to repurchase the same (or similar) securities after a specified time, at a given price, and paying specified interest.

The collateral is not just pledged; the title transfers from seller to buyer and then back again. (This means the buyer can re-pledge the asset in another repo transaction.)
Repurchase Agreements (Summary)

Initial transaction (value date):
- cash flows from buyer/lender to seller/borrower
- security ownership flows from borrower to lender

Final transaction (maturity date):
- cash + repo interest flows from borrower to lender
- securities (and any coupon interest) flow from lender to borrower
What is a Haircut?

Repo transactions may be overcollateralized to reduce the likelihood of loss.

**haircut**: percentage subtracted from the market value of an asset that is being used as collateral.

The lender (temporary) ownership of the entire collateral, so the higher the haircut, the safer the loan is for a lender.
Recall that in a repo transaction, security ownership transfers to the lender. The owner rehypothecates (i.e., reuse) this collateral.
Haircuts rise when the perceived risk of lending rises. Why should the credit risk of the repo counterparty affect the size of a haircut? After all, the risk of loss by a non-defaulting party is a function of the collateral and collateral processes, rather than the credit of the counterparty. Still, a default means liquidation costs must be borne. Bottom line: many parties factor in the credit risk of their repo counterparties.
Systemic Liquidity Crises

- haircut shocks -> liquidity hoarding (due to liquidity needs, *not* due to counterparty default risk)
- funding contagion spreads through interbank lending linkages
- complexity and concentration in the financial network may amplify this fragility
- suggests macro-prudential policy measures:
  - tougher liquidity regulation
  - surcharges for systemically important financial institutions
When Is It a “Systemic Crisis”? 

**Systemic Crisis:** 10%+ banks forced to hoard liquidity

Obviously this is an arbitrary cutoff ...
demonstrate (both analytically and via numerical simulations) how the spread of contagion and systemic collapse responds to
- repo market activity
- haircut shocks
- liquidity hoarding in unsecured interbank markets

illustrate the amplification role of collateral (a key systemic risk in repo transactions stems from shocks to the haircuts)

articulate how network contagion effects help us understand the probability and impact of financial crises
Systemic Liquidity Hoarding (One Shock, Poisson Network)
Systemic Liquidity Hoarding (One Shock, Geometric Network)

images/ghk_fig7.png
GHK: “One important reason for the slow up-take amongst economists is that such network techniques are typically silent about behavioral considerations.”

Offsetting this, such models deal well with:

- agent heterogeneity
- monitoring shock propagation through a network
- modeling and/or identifying important nonlinearities (e.g., tipping points)
Six Experiments

Poisson Network

- single-bank adverse haircut shock provides a baseline: forces a bank to start hoarding liquidity
- baseline plus: aggregate haircut shock affects all banks (speaks to the collapse of interbank markets)

Geometric Network

- assess how the first two experiments change given a fat-tailed network configuration -> lower likelihood of contagion at low connectivity, higher at higher connectivity
- ‘targeted’ shock: affects the most interconnected interbank lender under both network configurations -> strongly raises systemic risk

Financial Vulnerability

- increase “complexity” (unsecured interbank liabilities rise to 25%) -> increase frequency of contagion
- lower the initial aggregate haircut -> increase risk of contagion
Four Policy Exercises

- impose a uniform increase in liquid asset holdings
- impose an average increase in liquid assets identical to the first policy exercise but this time the increase in liquid assets at each individual bank is positively related to its interbank assets (targeting higher liquidity requirements on key interbank players)
- impose haircut-dependent liquidity requirements
- impose greater network transparency
Description of parameters and calibration in baseline simulation.

<table>
<thead>
<tr>
<th>Param</th>
<th>Description</th>
<th>Baseline calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>Number of banks</td>
<td>250</td>
</tr>
<tr>
<td>$j_i$</td>
<td>Number of bilateral unsecured interbank lending links for bank $i$</td>
<td>Endogenous (depending on network)</td>
</tr>
<tr>
<td>$k_i$</td>
<td>Number of bilateral unsecured interbank borrowing links for bank $i$</td>
<td>Endogenous (depending on network)</td>
</tr>
<tr>
<td>$z$</td>
<td>Average degree or connectivity</td>
<td>Varies</td>
</tr>
<tr>
<td>$LIB_i$</td>
<td>Unsecured interbank liabilities</td>
<td>15% of balance sheet</td>
</tr>
<tr>
<td>$LR_i$</td>
<td>Repo liabilities (i.e. borrowing secured with collateral)</td>
<td>20% of balance sheet</td>
</tr>
<tr>
<td>$LD_i$</td>
<td>Retail deposits</td>
<td>Endogenous (balancing item)</td>
</tr>
</tbody>
</table>
Assumptions

- LIBi evenly distributed over borrowing links for each bank i (the AIBi follow from the LIBi, but a bank may be a net borrower or lender)
- fully liquid assets can be sold without any discount and can be used as collateral for repo financing with no haircut
- fixed assets (AFi) and unsecured interbank assets (AIBi) cannot be used as repo collateral
- collateral assets (ACi) can be repo collateral with haircut (h+hi) with h,hi in [0,1] (see Gorton and Metrick 2010 FRBSLR)
- reverse repo secured with collateral; same aggregate haircut; collateral (ARRi/(1-h)) can be fully rehypothecated (reused as collateral for borrowing (1-h-hi)ARRi/(1-h))
- no new systemic deposit flows; no new equity
- central bank requires same collateral as market
- response to liquidity shortage is liquidity hoarding (stop lending AIBi)
Liability Types

- LIBi Unsecured interbank liabilities
- LRi Repo liabilities (i.e. borrowing secured with collateral)
- LDi Retail deposits (stable; not a focus of the story)
- Ki Capital
- LNi New unsecured interbank borrowing raised after a shock
Asset Types

- AIßi Unsecured interbank assets (lent, but lending withdrawn when liquidity needed)
- AFi Fixed assets (e.g. individual corporate loans or mortgages)
- ACi ‘Collateral’ assets (may be re-used as collateral in “rehypothecated” repo transactions)
- ARRi Reverse repo assets (i.e. collateralised lending) (\(\rightarrow \frac{ARR}{1-h}\) in collateral \(\rightarrow \frac{(1-h-hi)ARR}{1-h}\) in rehypothecated repo funding)
- ALi Unencumbered fully liquid assets
Liquidity Hoarding

Suppose that a fraction, $\mu_i$, of banks connected to bank $i$ in the network ‘hoard’ liquidity from it, withdrawing a portion $\lambda$ of their deposits held at bank $i$. Bank $i$ then loses $\lambda \mu_i LIB_i$ of its liabilities, and it needs to ensure its liquidity condition that its available liquidity (LHS) exceeds its funding needs (RHS):

$$AL_i + (1-h-h_i)AC_i + ARR_i(1-h-h_i)/(1-h) + LNi > LR_i + \lambda \mu_i LIB_i + ei$$

First four terms: available liquidity. Last three terms: funding it needs to cover with collateral, and funding outflows.

Baseline numerical simulations: $\lambda = 1$

Clearly liquidity hoarding by other banks makes it more likely that bank $i$ will need to hoard.
Analytical Approximation

Assume no idiosyncratic shocks. The liquidity condition becomes:

\[ ALi + (1 - h)ACi + AR Ri + LN i > LR i + \lambda \mu iLiBi \]

Assume all banks have identical balance sheets:

\[ AL + (1 - h)AC + AR + LN > LR + \lambda \mu LIB \]

Assume full withdrawal (\( \lambda = 1 \)) and solve for \( \mu \):

\[ \frac{[AL + (1 - h)AC + AR + LN - LR]/LIB}{\mu} > \mu \]
Bank $i$ has $k_i$ borrowing links. So if a single counterparty to bank $i$ hoards, $m_i = 1/k_i$ since interbank liabilities are evenly distributed across counterparties.

Assume that a single bank suffers a haircut or idiosyncratic liquidity shock which is sufficiently large to cause it to start hoarding liquidity. Then, by substituting for $m_i$ in Eq. (1) and rearranging, we see that for contagion to spread beyond the first bank, there must be at least one neighbouring bank for which

$$[ALi + (1 - h - hi)ACi + ARRi(1 - h - hi)/(1 - h) + LN_i - LR_i - ei]/LBI > m_i = 1.$$