Systemic Risk and Stability in Financial Networks

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January 08, 2012

Introduction

- Much recent interest in "systemic risk," partly kindled by the financial crisis of 2007-2008.

"In the current crisis, we have seen that financial firms that become too interconnected to fail pose serious problems for financial stability and for regulators. Due to the complexity and interconnectivity of today's financial markets, the failure of a major counterparty has the potential to severely disrupt many other financial institutions, their customers, and other markets."

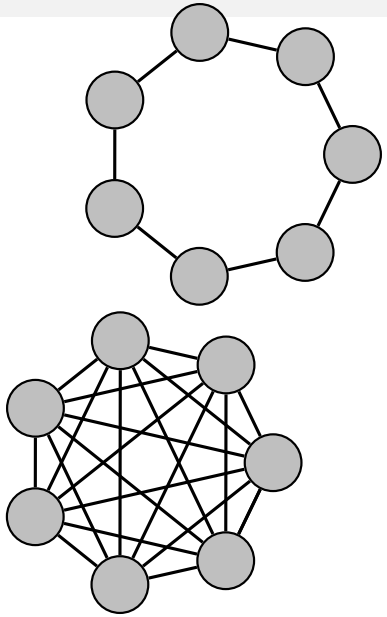
Charles Plosser
President and Chief Executive Officer,
Federal Reserve Bank of Philadelphia,
March 6, 2009

"If any one of the domestic companies should fail, we believe there is a strong chance that the entire industry would face severe disruption. Ours is in some significant ways an industry that is uniquely interdependent – particularly with respect to our supply base, with more than 90 percent commonality among our suppliers. Should one of the other domestic companies declare bankruptcy, the effect on Ford's production operations would be felt within days – if not hours. Suppliers could not get financing and would stop shipments to customers. Without parts for the just-in-time inventory system, Ford plants would not be able to produce vehicles."

Alan Mulally
President and Chief Executive Officer,
Ford Motor Co.,
November 18, 2008

A Common Conjecture

- A common conjecture in economics and finance is that "rings" are more fragile or unstable, and "complete" networks are more stable. [Allen and Gale (2000), Freixas, Parigi and Rochet (2000) and Kiyotaki and Moore (1997)].



- But also the opposite perspective: more densely connected financial networks are more prone to systemic risk. [Battiston *et al.* (2009) and Blume *et al.* (2011)].
- Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2011): with linear (e.g., input-output) interactions, rings as stable as complete networks.
- Which perspective?

This Paper

- The form of intersections and magnitude of shocks crucial for understanding systemic risk and stability in financial networks.
- We consider an economy in which banks engage in inter-bank lending and borrowing, forming the financial network at date $t = 0$, but may have to default on their loans because of negative shocks or indirect effects of negative shocks to their counterparties at date $t = 1$.
- For small shocks, rings are most unstable and complete networks are most stable.
- But for larger shocks, there is a "phase transition:" complete networks become most unstable, and strictly less stable than "weakly connected" networks.
- Intuition: negative shocks remain confined to where they originate.

Interpretation

- This result formalizes a conjecture by Haldane:

> "Interconnected networks exhibit a knife-edge, or tipping point, property. Within a certain range, connections serve as a shock-absorber. The system acts as a mutual insurance device with disturbances dispersed and dissipated... But beyond a certain range, the system can flip the wrong side of the knife-edge. Interconnections serve as shock-amplifiers, not dampeners, as losses cascade. The system acts not as a mutual insurance device but as a mutual incendiary device. Risk-spreading — fragility — prevails."
>
> Andrew Haldane
> April 2009

Other Results

- When returns of long-term assets are partially pledgeable, renegotiation may prevent some of the inefficient defaults.
- In this case, another phase transition: for small shocks, the liquidity of the entire banking system can be used to forestall defaults. Beyond this threshold, local network effects kick in and create cascading defaults.
- At date $t = 1$, excessive incentives to create fragile financial networks because, even with endogenous interest rates, banks do not internalize the systemic risks they create — i.e., the risks they create on the creditors of their creditors.

Related Literature

- Financial networks
  - Allen and Gale (2000), Freixas, Parigi and Rochet (2000), Furfine (2003), Dasgupta (2004), Leitner (2005), Babus (2009), Zawadowski (2011), Blume et al. (2011).
- Input-output networks
  - Jovanovic (1987), Durlauf (1993), Gabaix (2011), Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi (2011).

A Minimalist Model of Financial Networks

- There are three dates, $t = 0, 1, 2$.
- The first date is subdivided to n periods, $j = 1, 2, \ldots, n$.
- The economy consisting of n risk-neutral banks (financial institutions), where bank j has k unit of funds at period j.
- Each bank can invest k units in a project, with a stochastic short-run return z_i and long-run return A (if it is continued).
- The returns of i's project are realized only if it continuously invests over the course of date $t = 0$.
  - In period j bank $i \neq j$ has to invest k_{ij} (where $\sum_{j=1}^{n} k_{ij} = k$).

A Minimalist Model of Financial Networks (continued)

- Long-term returns of the project have limited pledgeablity, only a fraction κ of which can be pledged at $t = 1$.
- Each bank needs to meet an outside obligation $v > 0$ at $t = 1$ which has seniority over its other obligations.
- If the bank cannot meet its obligations, it defaults: it needs to liquidate its assets before their long-run returns, A, are realized in which case their returns are ζA.
- Outside financiers endowed with n units of capital and have access to a linear technology with return r at $t = 1$.
- Bank j can raise funds from other banks or outside financiers, using standard debt contracts at interest rate $R_j > 0$.
- Face values of the bilateral contracts, $\{y_{ij}\}$, define a financial network.

Summary: Timing and Description of Events

- Three dates:
- $t = 0$:
  - in period j bank j has one unit of funds,
  - in subperiod j bank $i \neq j$ has continuing investment needs of k_{ij},
  - these continuing investment needs can be met by borrowing from other banks or from outside financiers at the interest rate R_i
  - this leads to an endogenous financial network—as a function of the lending decisions of bank j in subperiod j.
- $t = 1$:
  - the z_j's are realized,
  - banks have to pay their outside obligations v, the outside financiers and their interbank loans,
  - any shortfall forces liquidation of the asset, losing the long-run returns.
- $t = 2$:
  - remaining assets have their long-run returns realized.

Payment Equilibrium

- v: outside obligation; z_j: shock; y_{ij}: face value of debt obligation; c_j: additional cash at hand.
- x_{ij}: payment of bank j to bank i at $t = 1$ given $t = 0$ contracts

$$x_{ij} = \begin{cases} y_{ij} & \text{if } \; c_j + z_j + \sum_s x_{js} \geq v + kR_j \\ \frac{y_{ij}}{kR_j}(c_j - v + z_j + \sum_s x_{js}) & \text{if } \; v \leq c_j + z_j + \sum_s x_{js} < v + kR_j \\ 0 & \text{if } \; c_j + z_j + \sum_s x_{js} < v, \end{cases}$$

- A payment equilibrium is a fixed point $\{x_{ij}\}$ of the above set of equations.

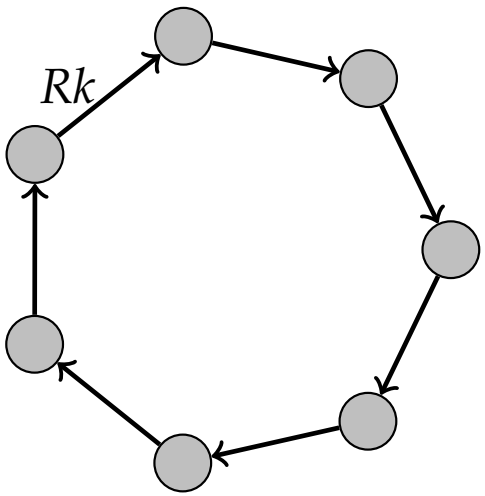
Proposition

A payment equilibrium exists and is generically unique.

Resilience, Stability and Systemic Risk

- Suppose that
  - $z_i \in \{a, a-\epsilon\}$ where, $0 < a - \epsilon < v$.
  - $m < n$ financial institutions receive the negative shock, $-\epsilon$.
  - $\zeta \approx 0$ and $\kappa = 0$.
  - "Regular financial network", where all banks' liabilities are equal to Rk.
- Resilience: what is the worst case performance of a particular financial network (with respect to the m realizations)?
- Stability: what is the average performanceof a particular financial network (with respect to the m realizations)?
- Systemic Risk: likelihood that many banks fail as a result of negative shocks to a few — i.e., m — financial institutions.

The Ring Is Least Resilient and Stable



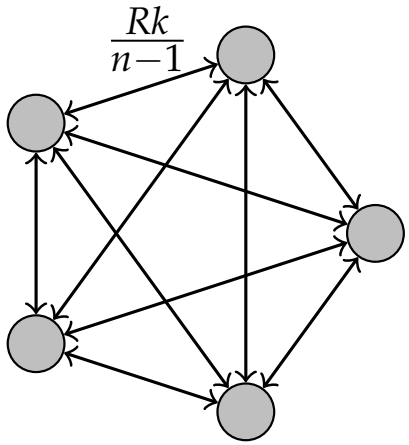
Proposition

- *The (directed) ring is the least resilient financial network.*
- *The (directed) ring is the least stable financial network.*

- Why so different from input-output economies?
  - with linearity, what matters is the average, this makes networks with equal degrees robust and stable;
  - but with nonlinearity, "failures" cannot be averaged out by successes.

Complete Network Is Resilient and Stable

- The complete network refers to the situation in which each bank invests equally in all other banks.



Proposition

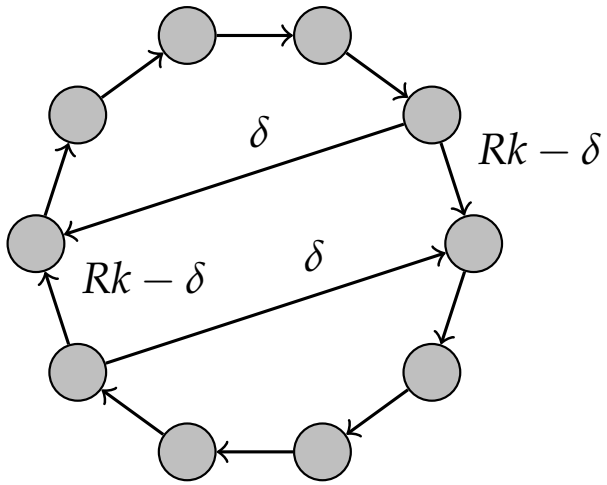
For any $m < n$ and for $\epsilon < \overline{\epsilon}(m)$,

- *The complete network is the most resilient financial network.*
- *The complete network is the most stable financial network.*
- *No other network has the same resilience or stability as the complete network.*

- Intuition: the complete network reduces the impact of a given bank's failure on any other bank.

Comparisons of Financial Networks

- A compressing rewiring is swapping an amount δ of the assets and liabilities of two pairs of banks such that the distribution of assets and liabilities of all four banks are more similar after the rewiring.
- We can go from a ring network to a complete network by a series of compressing rewirings.



Proposition

If $\epsilon < \hat{\epsilon}$, then starting from any non-complete regular network, rewiring assets and liabilities increases resilience and stability.

Resilience and Stability with Large Shocks

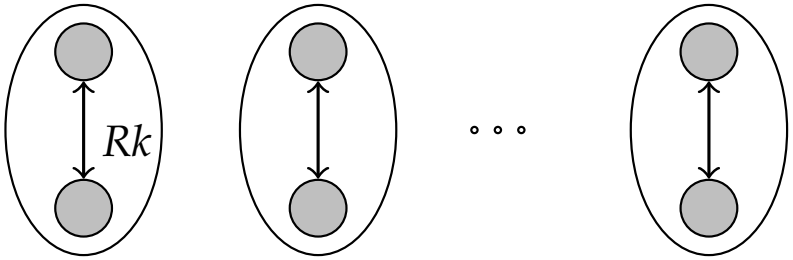
Proposition

If $\epsilon > \overline{\epsilon}(m)$, then

(a) *the complete network is the least stable and least resilient network structure.*

(b) *any collection of $n/2$ "weakly linked" pairs of banks are the most resilient and most stable financial networks.*

- "Phase transition" for large shocks: the complete network is as unstable as the ring, while "weakly connected" networks are more stable.



Resilience and Stability with Large Shocks

- Intuition: The presence of dense connections imply that "large" negative shocks propagate to the entire financial system. In contrast, with weak connections, shocks remain confined to where they originate.

- This also formalizes Haldane's conjecture:

> "Interconnected networks exhibit a knife-edge, or tipping point, property. Within a certain range, connections serve as a shock-absorber. The system acts as a mutual insurance device with disturbances dispersed and dissipated... But beyond a certain range, the system can flip the wrong side of the knife-edge. Interconnections serve as shock-amplifiers, not dampeners, as losses cascade. The system acts not as a mutual insurance device but as a mutual incendiary device. Risk-spreading — fragility — prevails."
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Renegotiations and Network Effects

- Suppose banks can pledge a fraction $\kappa \in (0,1)$ of their long-term returns A at $t = 1$.
- Also suppose that
  - liquidation generates positive returns $0 < \zeta < 1$.
  - funds from liquidation will not become available until $t = 2$.
  - banks can make renegotiation offers at the end of $t = 1$.
  - Bank j pledges amount $A_{ij} \geq 0$ to bank i:

$$\sum_{i \neq j} A_{ij} \leq \kappa A.$$

- Another "phase-transition" result:

Proposition

Suppose that the financial network is connected and that only one bank is hit with negative shock $\epsilon < n(a - v)$. Then there exists $\overline{\kappa}$ such that if $\kappa > \overline{\kappa}$, then there are no defaults. When $\kappa < \overline{\kappa}$, then defaults are unavoidable, and local network effects emerge again.

Network Formation

- Now consider date $t = 0$.
- A full equilibrium is a collection of interest rates $\{R_i\}$ and bilateral lending decisions by the banks at $t = 0$ such that banks maximize their expected profits and the outside financiers are willing to lend to bank i at rate R_i.
  - The focus is no longer on a regular financial network.
- Corresponds to the endogenous formation of the financial network.

Proposition

A full equilibrium exists.

Inefficient Networks

- Are equilibrium financial networks insufficiently resilient and stable relative to what a social planner wishing to maximize net surplus will choose?
- Consider the full model, where banks can choose whether to lend to other banks or not.
- Endogenous interest rates: given the equilibrium financial network, the cost of capital for each bank is such that outside financiers are indifferent between lending and not lending to it.
- Suppose that $k_{i,i+1} = k$.

Proposition

There are $\underline{r}$ and $\bar{r}$ such that the ring financial network formed in equilibrium is inefficient, if $r \in (\underline{r}, \bar{r})$.

- Intuition: with endogenous interest rates, banks internalize the risk they create on their creditors, but not on their creditors' creditors.

Concluding Remarks

- A framework for studying the relationship between the structure of financial networks and the extent of contagion and cascading failures
- For small shocks, rings are most unstable and the complete network is the most stable.
- For larger shocks, there is a phase transition result: complete network is the most unstable, and strictly less stable than weakly connected networks.
- If the long-term returns are partially pledgeable, there is another phase transition: tor small shocks renegotiations can prevent inefficient defaults. Beyond a certain threshold, local network effects kick in and create cascading defaults.
- Financial networks that emerge in equilibrium may be inefficient.