Financial networks and contagion: learning from ecology and epidemiology

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ESRC-Oxford Martin School
International Scientific Symposium on Macroeconomics
Oxford, 2 October 2012

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Overview

• Areas of focus:
  – the causes and dynamics of the global financial crisis
  – appropriate policy responses in the aftermath of the crisis

• What can we learn from ecological and epidemiological examples and techniques?

• Outline
  – Stylised facts
  – Lessons from epidemiology and ecology
  – Applying techniques to modelling contagion in financial system
  – Examples: theory / simulations & quantitative / empirical
  – Policy conclusions
Complexity and Concentration in the Network

Network of large exposures\(^{(a)}\) between UK banks\(^{(b)(c)}\)

Source: FSA regulatory returns.

(a) A large exposure is one that exceeds 10% of a lending bank’s eligible capital during a period. Eligible capital is defined as Tier 1 plus Tier 2 capital, minus regulatory deductions.

(b) Each node represents a bank in the United Kingdom. The size of each node is scaled in proportion to the sum of (1) the total value of exposures to a bank, and (2) the total value of exposures of the bank to others in the network. The thickness of a line is proportionate to the value of a single bilateral exposure.

(c) Based on 2006 Q4 data.
Profile of Intra-financial System Activity

Sectoral breakdown of UK debt, proportion of GDP

Repos & financial market open paper as a % of retail deposits in the US

- Financial corporate debt
- Government debt
- Non-financial corporate debt
- Household debt

Primary dealer repos and financial open market paper
Net repos and financial open market paper

Per cent
Homogeneity

Weighted-average Cumulative Total Returns

Source: Bloomberg, CreditSuisse/Tremont and Bank calculations.
(a) Sample based on banks and insurers in S&P 500, FTSE All Share and DJ EuroSTOXX indices as at March 2009. Excludes firms for which returns not quoted over entire sample period.
Broad Lessons from Ecology (1)

- Complex, concentrated, increasingly homogenous financial system

- Pre-crisis market participant (and economist?) view
  - inevitable by-product of technical progress in finance; completion of markets; improvements in risk management
  - good for stability

- ‘Ecologist’ view
  - Complexity plus homogeneity = fragility
  - Simple and / or modular systems robust: savannas and grasslands (cf tropical rainforests); firebreaks in forests
  - Diversity key: resilience of fisheries, crops to disease, and savannas / grasslands to drought
Broad Lessons from Ecology (2)

• Pre-crisis financial regulation
  – static: no time variation
  – individual institution perspective: no attention paid to potential systemic consequences of failure
Size and Pre-Crisis Capital Adequacy

End-2007 Global Banks’ Size and Capital Ratios

End-2007 Global Banks’ Size and Leverage Ratios
Broad Lessons from Ecology (2)

• Pre-crisis regulation
  – static: no time variation
  – individual institution perspective: no attention paid to potential systemic consequences of failure

• ‘Ecologist’ view
  – System-wide approach to management necessary (eg fishing quotas)
Epidemiology: ‘Tipping Points’ and ‘Super-spreaders’

• When will a disease spread through a population?

• Suppose everyone spreads the disease to 1 in 10 of their friends:
  – If everyone has exactly 9 friends, the disease will die out
  – But if everyone has exactly 11 friends, it will go viral
Epidemiology: ‘Tipping Points’ and ‘Super-spreaders’

• In reality, some are better connected than others.
  – People with more friends spread the disease more widely.
  – But they are also more likely to catch it in the first place, since they have many friends to catch it from.

• So connectivity enters twice. A person with 10 friends is $10 \times 10 = 100$ times important in spreading the disease than someone with 1 friend.

• Highly connected ‘super-spreaders’ are key to the propagation of contagion.

• Policy response: target super-spreaders (eg vaccines, education programmes)
Epidemiology: Behavioural Responses

• ‘Flight’ or ‘Hide’
  – Memphis yellow fever outbreak, 1878
  – SARS and self-quarantining
Why Complex Networks for Finance?

• Examples highlight usefulness of approach:
  – Contagion
  – Nonlinearities (big effects from small shocks)
  – Seemingly Identical Shocks $\Rightarrow$ Different Outcomes
  – Heterogeneity – role of key players (fat tails)
  – Dynamics and Path Dependence
  – Behavioural Feedbacks and Amplifiers

• All key dimensions of systemic risk
Epidemiology and Finance

• Financial systems have particular features:
  – Balance sheets (more complex nodes)
  – Links which are directed and weighted
  – Possibility for risk sharing
  – Local dependence

• Behavioural responses key
  – But may be analogies to ‘hide’ and ‘flight’
Models with Complex Financial Networks

- Overview: Haldane and May (Nature, 2011)

- Default contagion – simulations: Nier et al (JEDC, 2007)


- Liquidity hoarding with richer behaviour, confidence effects, fire sales, default contagion, and differential bank sizes – simulations: Arinaminpathy, Kapadia and May (PNAS, forthcoming)
Network Structure

• Network has $n$ financial intermediaries (‘banks’)

• Each bank is a node; unsecured interbank assets and liabilities define links (directed)

• Average number of links that point into nodes = average number of links that point out. Denote this *average degree*, $z$.

• Joint degree distribution is arbitrary
The Balance Sheet

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A^F$</td>
<td>$D$</td>
</tr>
<tr>
<td>$A^C$</td>
<td></td>
</tr>
<tr>
<td>$A^{RR}$</td>
<td>$L^R$</td>
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<tr>
<td>$A^{IB}$</td>
<td>$L^{IB}$</td>
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<tr>
<td>$A^L$</td>
<td>$K$</td>
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</tbody>
</table>
Contagion (1)

Default contagion and asset fire sales – theory and simulations: Gai and Kapadia (2010); May and Arinaminpathy (2010)
Contagion (1)

Default contagion and asset fire sales – theory and simulations: Gai and Kapadia (2010); May and Arinaminpathy (2010)
Contagion (2)

Liquidity hoarding and repo activity – theory and simulations: Gai, Haldane and Kapadia (JME, 2011)
Example from Gai et al (2011)

Concentrated Network: Random v Targeted Shock
Example from Gai et al (2011)

Microprudential and Systemic Liquidity Requirements

- Targeting liquidity dominates. And may also have a positive incentive effect.
Example from Gai et al (2011)

Time-Varying Liquidity Requirements
Example from Gai et al (2011)

Time-Varying Liquidity Requirements

- Links to broader time-varying macroprudential policy
- Intra-financial system lending key (not just real economy)
Further Behavioural Responses (1)

Liquidity hoarding with richer behaviour and confidence effects: Arinaminpathy, Kapadia and May (PNAS, forthcoming)

• **Individual bank health**: \( h_i = c_i m_i \)
  where \( c_i \) is bank capital as a proportion of its initial level, and:

\[
m_i = \min \left[ 1, \frac{A_i^{ST} + l_i}{L_i^{ST}} \right]
\]

• **System confidence**: \( C = EA \)

  \( E \) – proportion of interbank loans not withdrawn
  \( A \) – total value of all remaining assets in the system (at current market price) as a proportion of its initial level
Further Behavioural Responses (2)

- Banks shorten the maturity of their long-term IB loans if:
  \[ h_i h_j < (1 - C) \]
- This improves their own health at the expense of the system
Further Behavioural Responses (2)

- Banks shorten the maturity of their long-term IB loans if:

\[ h_i \cdot h_j < (1 - C) \]

- This improves their own health at the expense of the system

- Banks withdraw loans altogether if either:

\[ h_i \cdot h_j < (1 - C)^2 \]

or if they are forced to because they do not have sufficient liquid assets to meet funding withdrawals by other banks
Example from Arinaminpathy et al (2012)

- Model also integrates asset fire sales, default contagion and differential bank sizes
Example from Arinaminpathy *et al* (2012)

Bank size, capital ratios and failure
Macroprudential Policy Implications

• Capital and liquidity surcharges for SIFIs
  – aim to make key nodes more resilient
  – and incentivise banks to become less systemically important

• Time-varying policies to mitigate effects of the cycle
  – risk weights on intra-financial system exposures;
  – time-varying liquidity requirements;
  – adjusting haircuts on secured financing
Broader Policy Implications

• Better Data and Greater Transparency
  – cf real-time management and mapping of SARS

• Netting and Central Clearing
  – simplicity and modularity

• System Structure (eg ICB ring-fencing, Volcker rule, living wills)
  – diversity and modularity
Quantitative Models with Complex Financial Networks

- Quantitative systemic risk / stress testing models with networks and systemic feedbacks:
  - OeNB SRM model (2006); BoE RAMSI model (Aikman et al, 2009, BoE WP 372; Kapadia et al, 2012, BoE WP 456)

- Calibrated network models (link to agent-based modelling):
RAMSI

Macroeconomic and financial shocks

Credit, market and income risk

Individual Banks’ P&L
Feedbacks in RAMSI

- **Shock**
  - Funding problems at one or more banks
  - Confidence effects

- **Confidence effects**
  - Failure of a bank
  - Counterparty credit risk (Network)
  - Funding problems at other banks

- **Failure of a bank**
  - Reduction in Interbank Lending (Liquidity Hoarding)

- **Reduction in Interbank Lending (Liquidity Hoarding)**
  - Asset fire sales

Feedback arrows:
1. Shock → Funding problems at one or more banks
2. Funding problems at one or more banks → Failure of a bank
3. Failure of a bank → Reduction in Interbank Lending (Liquidity Hoarding)
4. Counterparty credit risk (Network) → Funding problems at other banks
5. Reduction in Interbank Lending (Liquidity Hoarding) → Asset fire sales
Example from RAMSI

Total System Assets, Q12: With and Without Liquidity Risk, Network Effects and Feedbacks

- **Core**: 17 UK banks; **Middle**: 120 foreign banks; **Periphery**: 50,000 firms.
- Use FSA and BIS data to calibrate the distributions of interbank loan sizes.
  - distributions look fat-tailed, so use log-normal distribution
- Use Bankscope data to ascertain general structure of the balance sheets
Concluding Comments

• Network approaches drawing on epidemiology and ecology can parsimoniously capture key features of financial systems and contagion.
  – Important insights and policy conclusions often not evident in standard economic models

• Key challenges / areas for future work:
  – Introducing a stronger / more developed role for behavioural considerations (eg for the formation of links)
  – Stronger role for uncertainty
  – Endogenous shocks
  – Greater empiricism
  – Integration into agent-based models
  – Role of diversity and modularity?