Contagion in Complex Financial Networks: Which Network Structure is the Most Stable?

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*Any views expressed are solely those of the authors and so cannot be taken to represent those of the Bank of England.

Outline

Why do we care? (or lessons learnt from recent financial crisis)

The recent financial crisis has revealed:

- 'to safeguard against systemic risk, the financial system needs to be managed as a system' (Haldane, 2009)
- limited knowledge of financial network structure
- importance of understanding the relationship between network structure and financial contagion

Project contributions:

1. study of relationship between contagion risk and
   - **network topology**
   - **shock type**
   - capital adequacy
   - liquidity
   - network size
   - exposures size, etc.
2. measures for assessing/monitoring systemic risk

Literature Review

Theoretical studies: connectedness and diversification impact

- Funding runs
  - Complete networks allow for liquidity risk sharing and are more resilient to contagion than incomplete ones

    Allen & Gale (2000): but for sufficiently large shocks the connections might become contagion channels

    Freixas, Parigi & Rochet (2000): but the risk sharing leads to bad market discipline

- Default cascades
  - *robust-yet-fragile*: Gai & Kapadia (2010)
  - non-monotonic effects: Cont et al. (2010), Elliot et al. (2014), Acemoglu et al. (2015a)
  - clustered networks: Acemoglu et al. (2015a), Elliot & Hazel (2016)

Literature Review

Empirical studies: main findings

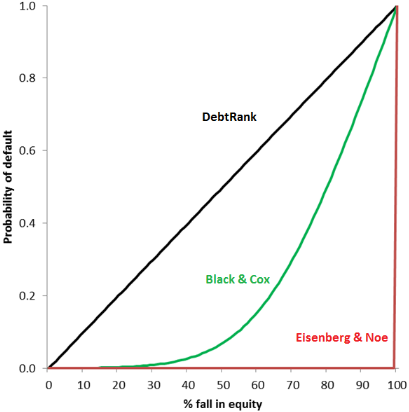
- *maximum entropy* reconstruction approach underestimates the contagion risk
- non-monotonic effect of higher connectivity depending on shock size, capital levels, etc

  - **simulated exposures matrix (ME)** - Upper and Worms (2004) - Germany, Wells (2004) & Elsinger et al. (2006) - Austria, and Degryse & Nguyen (2007) - Belgium;
  - **actual bilateral exposures** - Furfine (2003) - US, Mistrulli (2007) - Italy, Cont et al. (2010) - Brazil, van Lelyveld & Veld (2012) and Craig & von Peter (2014) - Netherlands, Langfield, et al. (2014) - UK.

- **Our paper**:
  - network resilience to solvency contagion channel
  - wide range of network topologies considered
  - comprehensive statistical review of UK banking network

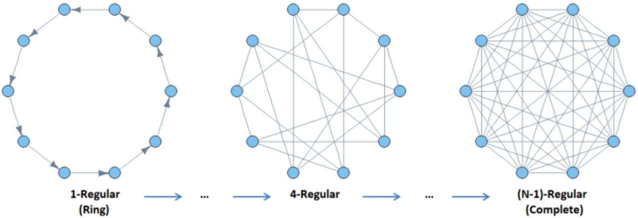
Solvency Contagion model by Bardoscia, Barucca, Brinley Codd & Hill (2017)

- Creditors revalue exposures as counterparties default probabilities change
- Structural credit risk model in a complex network
- Valuation function: Black-Cox first passage model



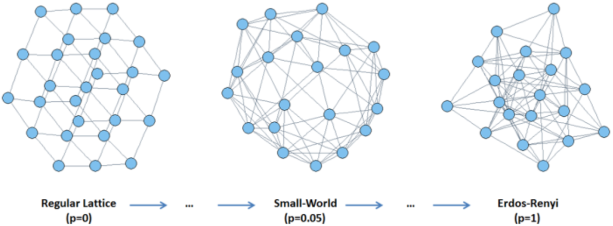
k-Regular Networks

- edges are directed and have same weight
- every node has equal degree k (out and in)
- ring and complete graphs are extreme cases



Small-World Networks

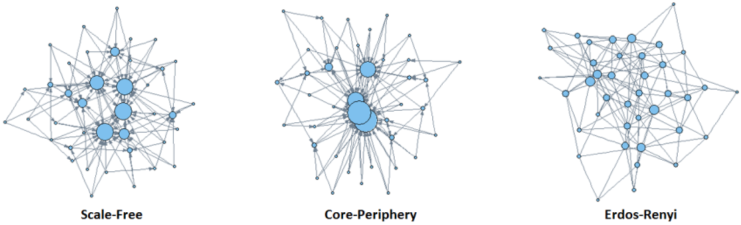
- generation: start with a regular lattice and assign probability p of rewiring the edges
- edges are directed and have same weight
- degree distribution becomes more bell-shaped as p increases
- lattice and random ER graphs are extreme cases



Methodology

Networks Types: Heterogeneous networks[†]

- both degree and link weights are heterogeneous
- density as in the UK interbank network (9% on average)
- marginals (TA and TL) are taken from actual UK data



- Scale-Free and Core-Periphery: robust to random shocks but fragile to targeted attacks

[†] generated following Gandy & Veraart (2015)

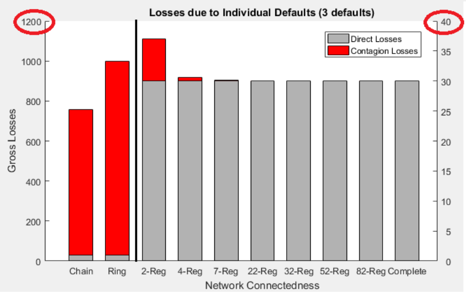
Methodology

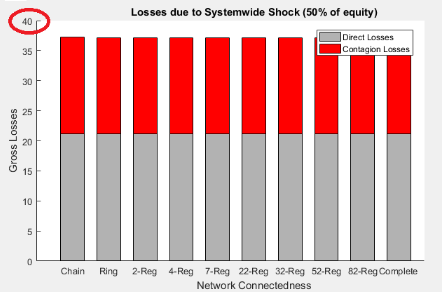
Networks Generation: Initial Conditions

1. N = 100 banks with RWA = 100
2. CET1 requirement = 4.5% of RWA
3. Capital levels
   - CET1 = 12.3% of RWA (FSR, July 2016)
   - actual capital ratios (as robustness check)
4. Exposures size:
   - homogeneous with fixed total exposures (10% of TRWA)
   - also, 15% of CET1 and heterogeneous cases
5. Shocks:
   - system-wide shock of 1%, 5%, 20%, and 50% of buffer
   - individual defaults of 1, 2, and 3 banks.
6. 500 simulations for each network

Preliminary Results: Impact of Connectedness

Regular networks with fixed total exposures

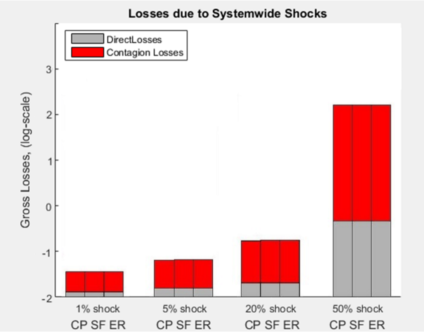


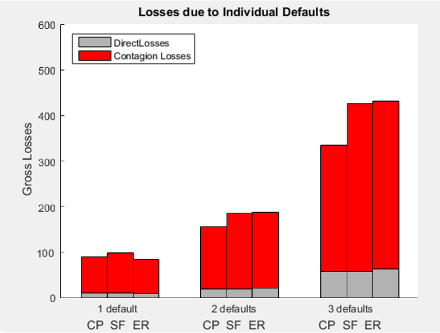


- higher connectedness increases resilience to individual defaults
  - stronger impact at lower connectedness levels
- no impact in case of equal shocks (exposure size reduces proportionally to #exposures)
- exponential increase for growing networks (15% exposures)

Preliminary Results: Impact of Heterogeneity

Heterogeneous Networks: core-periphery, scale-free, erdos-renyi

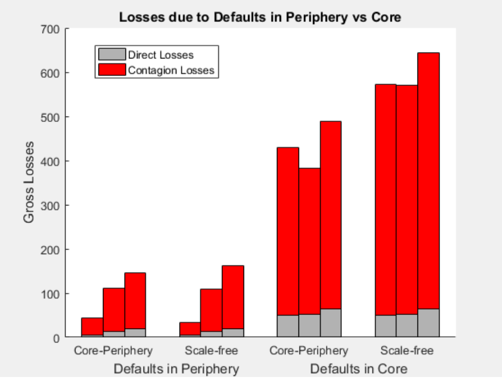




- System-wide shocks: similar for 3 networks (negligible for small shocks)
- Individual defaults: magnitudes larger than system-wide shocks and than homogeneous networks
- Scale-Free is the most susceptible

Preliminary Results: Impact of Heterogeneity

Defaults in the Core



- average across shock realizations where at least 1 core bank defaults
- as expected, more prone to the shocks in the core
- larger losses (especially, amplification) for SF than CP:

Preliminary Results

Regression results (dependent variable - Gross Losses, shock = 1 default)

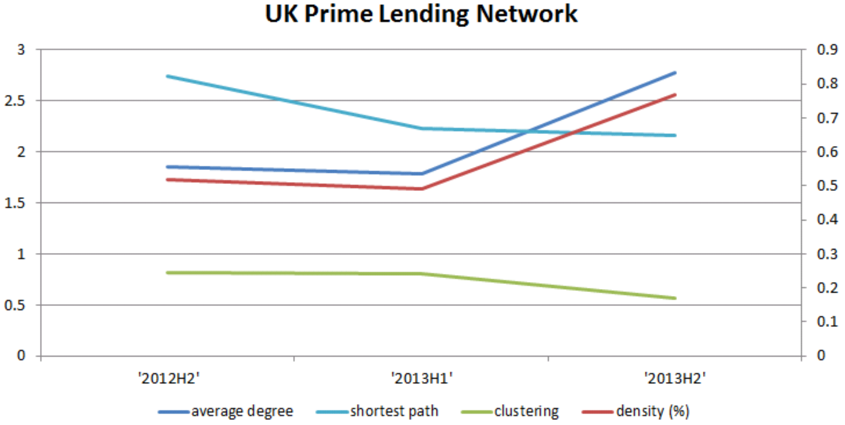
Network	Cluste-ring	Assorta-tivity	N of Defaults	Contagion dist (out)	Contagion dist (in)	Contagion dist (out)	Contagion dist (in)	Degree (out)	Degree (in)	Close-ness	Between-ness	KNN
	(network level)					(node level)						
Core Periphery	**-7.47*** **	**1.500** **	**34.61*** **	**-49.83** **	**64.65*** **	-0.204	**1.783** **	-0.135	**1.006** **	-22.58	0.021	0.121
Scale-Free	**-2.678** **	**-1.697*** **	**38.43*** **	90.51	-69.088	**-0.582** **	0.657	**0.747** **	-0.28	**-142.3***	**0.017** **	-0.030
Erdos-Renyi	**3.564***	0.318	**32.93*** **	-1.970	9.416	0.017	-0.648	0.141	0.885	-42.26	-0.048	-0.229

- node-level characteristics do not seem to explain contagion losses
- contagion distance highly significant at network level
- #defaults $\uparrow$ losses $\uparrow$ $\Rightarrow$ not due to 1 large bank default
- very small and insignificant coefficients for density and average degree (by construction)

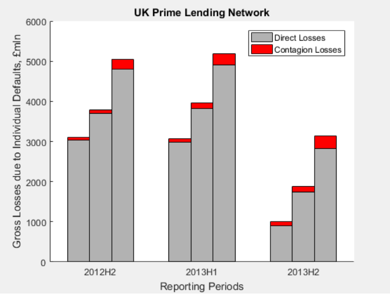
Preliminary Results: UK interbank Network

RRP Interbank Exposures Data

- exposures to top 20 bank counterparties + UK6 (if not in 20)
- around 180 banks, highly granular, semi-annual (2011, H2 - 2013, H2)
- incomplete network



Preliminary Results: UK interbank Network



Contagion losses due to individual defaults.
Columns within each time period correspond to 1, 2 and 3 defaults, respectively.

- Negligible direct losses and no contagion in case of small system-wide shock
- Magnitudes (10^3) larger direct and contagion losses in case of default of individual banks
  - significantly decreased over time though

Summary

1. Are more connections good/bad?
   - GOOD for fixed total exposures (individual defaults)
   - NO IMPACT for fixed total exposures (system-wide shocks)
   - BAD for 'growing' network
2. Heterogeneous heavy-tailed degree networks:
   - robust to small equal shocks
   - prone to individual defaults (especially in the core)
3. node-level characteristics do not seem to have relationship with contagion losses to the whole network, while
4. network-level measures tend to explain those losses

Work in Progress and Next Steps

- Reverse stress testing
- Different connectedness levels for heterogeneous degree networks
- Relationship between solvency contagion losses and other contagion & systemic risk measures
- Network structure before shock and after final round of contagion

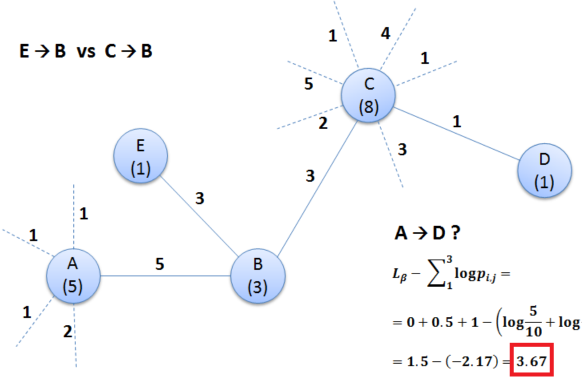
Appendix. Contagion Distance (Abduraimova, 2017)

Definition: **Contagion distance** $d_{cont}(u,v)$ from v to u minimizes the path distance composed by the **length** $L_\beta(\gamma_{u,v})$ and maximized **log path probability** along the path $\gamma_{u,v}$, i.e.,

$$d_{cont}(u,v) := \min_{\gamma_{uv}} \left[L_\beta(\gamma_{uv}) - \left(\sum_{(u_i u_{i-1}) \in E_\gamma} \log p_{u_i u_{i-1}} \right) \right] \qquad (1)$$

where $L_\beta(\gamma_{uv})$ is sum of link costs along the path and link cost of each step is the exposure size mapped to [0,1] using β-distribution.

- short d_{eff} $\rightarrow$ close to others $\rightarrow$ likely to infect $\rightarrow$ strongly contagious
- long d_{eff} $\rightarrow$ distant $\rightarrow$ not likely to propagate $\rightarrow$ weakly contagious



A → D ?

$$L_\beta - \sum_1^3 \log p_{i,j} =$$

$$= 0 + 0.5 + 1 - \left(\log\frac{5}{10} + \log\frac{3}{11} + \log\frac{1}{20}\right) =$$

$$= 1.5 - (-2.17) = \boxed{3.67}$$

- *contagiousness* of node based on its network properties (importance, positioning, interconnectedness), not damage
- increases with #steps on the path (and link costs of those steps)
- decreases with connectivity of nodes on the path

Some more plots. Impact of Connectedness