The Dynamics of the Interbank Market: Statistical Stylized Facts and Agent-Based Models

Thomas Lux

Department of Economics

University of Kiel &

Bank of Spain Chair in Computational Economics,

University Jaume I, Castellón

Eco**2 Symposium
8-10th September 2014
London School of Economics and Political Science

Part of this research has received funding from the European Union's Seventh Framework Programme under grant agreement no. 612955

Interbank „networks“

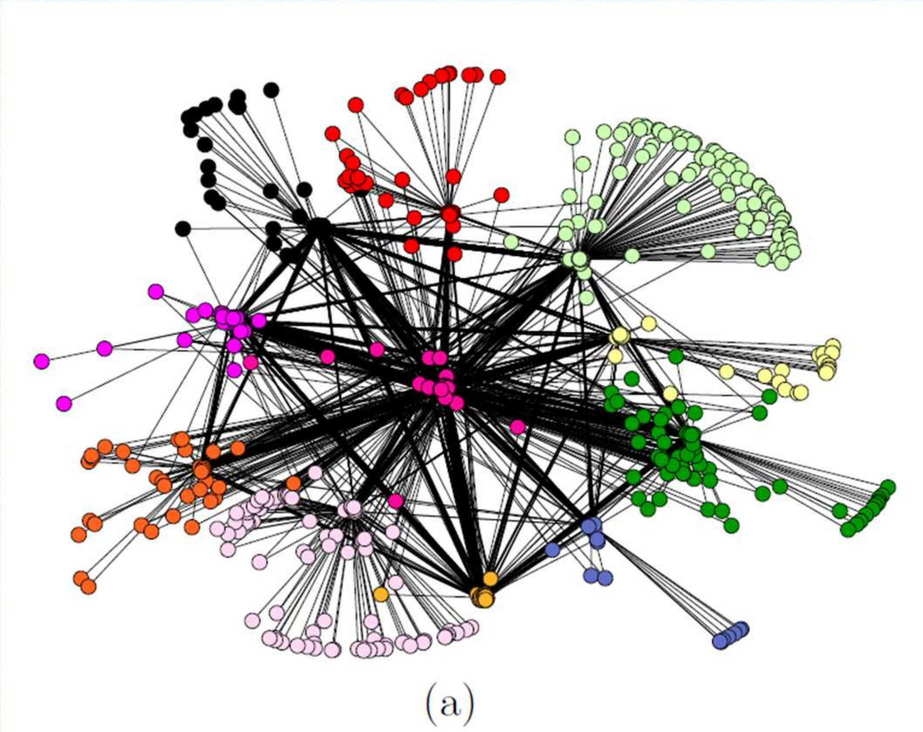
- Networks of banks (nodes, vertices) connected via economic links (edges)
- Mostly: interbank credit, different snapshots of the complete range of connections among N banks
- $D_{\{N \times N\}}$: Matrix of interbank claims, (value of) credit extended from *i* to *j* within a certain period
- $A_{\{N \times N\}}$: Adjacency matrix. Element $a_{ij} = 1$ if $a_{ij} > 0$.

Network links

- Most obvious: Interbank credit
  - Defaults lead to losses of creditor banks
  - Defaults of banks lead to lack of funding
- Price effects: fire sales during stress affect balance sheets of others
- Joint exposures to the same borrowers outside the banking system
- Portfolio overlaps
- Links via derivatives

In principle:
Multiplex networks

Example: The banking network of Austria

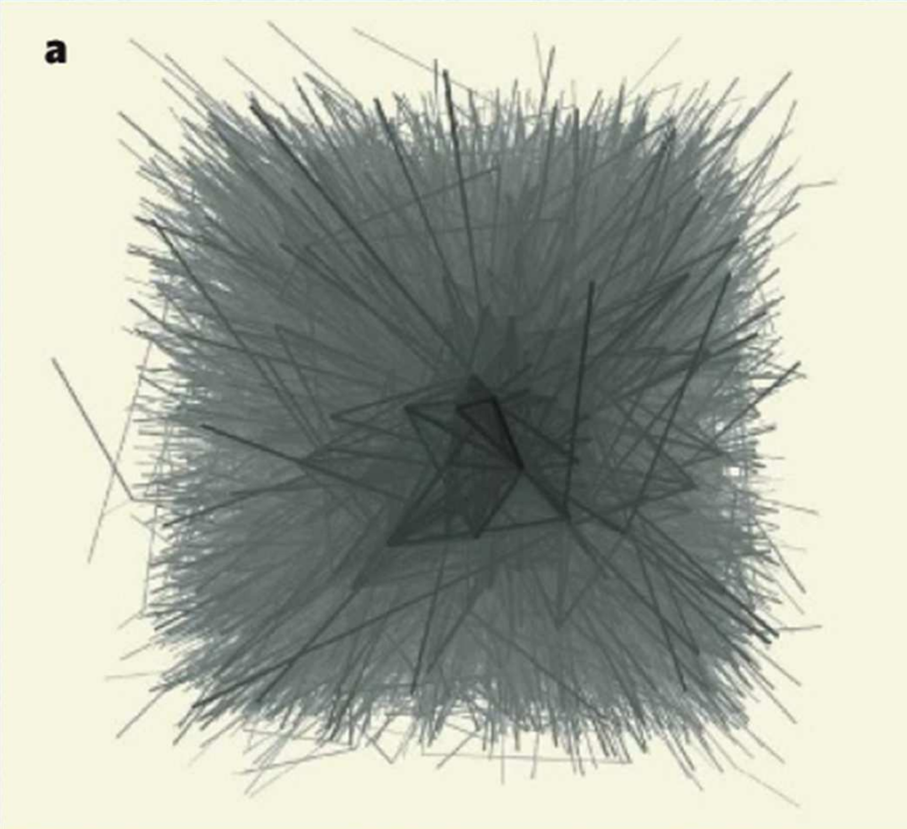


The banking network of Austria (a). Clusters are grouped (colored) according to regional and sectorial organization: R-sector with its federal state sub-structure: RB yellow, RSt orange, light orange RK, gray RV, dark green RT, black RN,

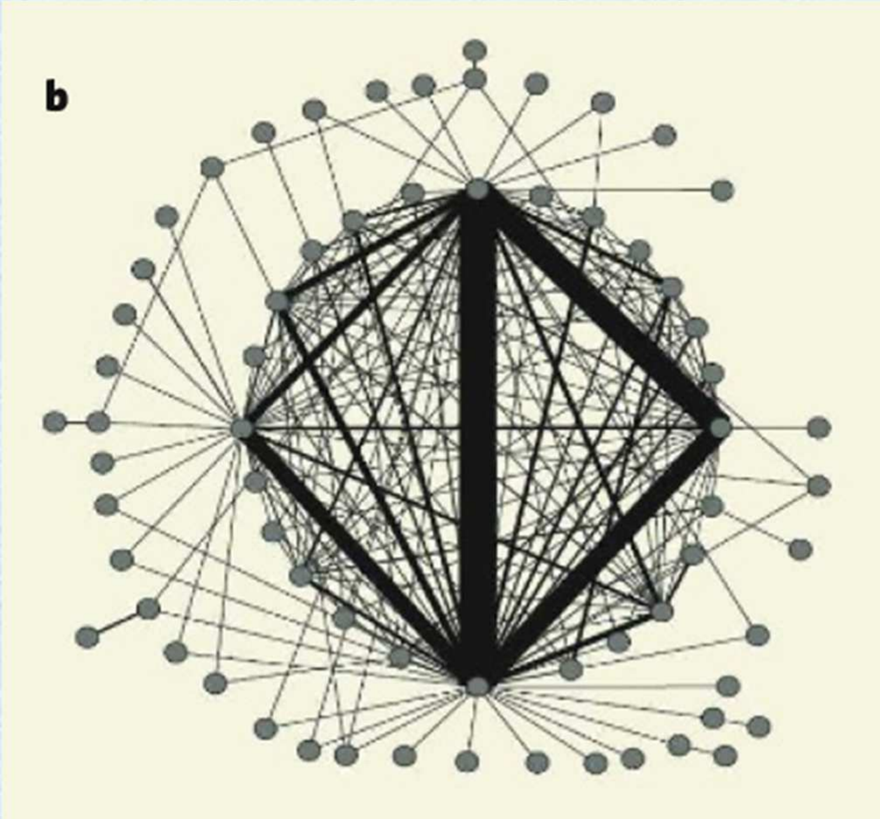
light green RO, light yellow RS. VB-sector: dark gray, S-sector: orange-brown, other: pink.

From: Boss *et al.*, *Quantitative Finance* 4, 2004

The Fedwire interbank payment network



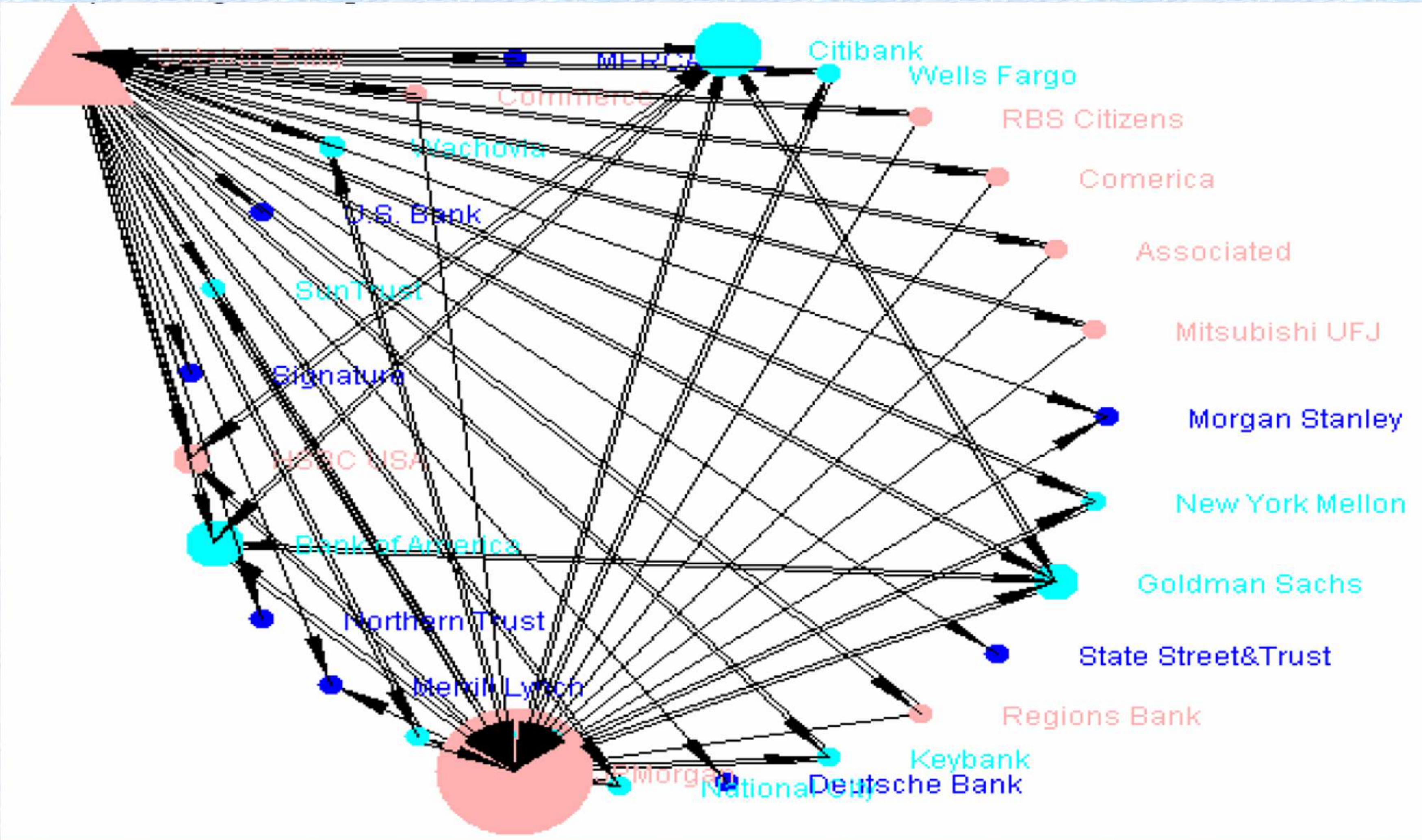
The entire system



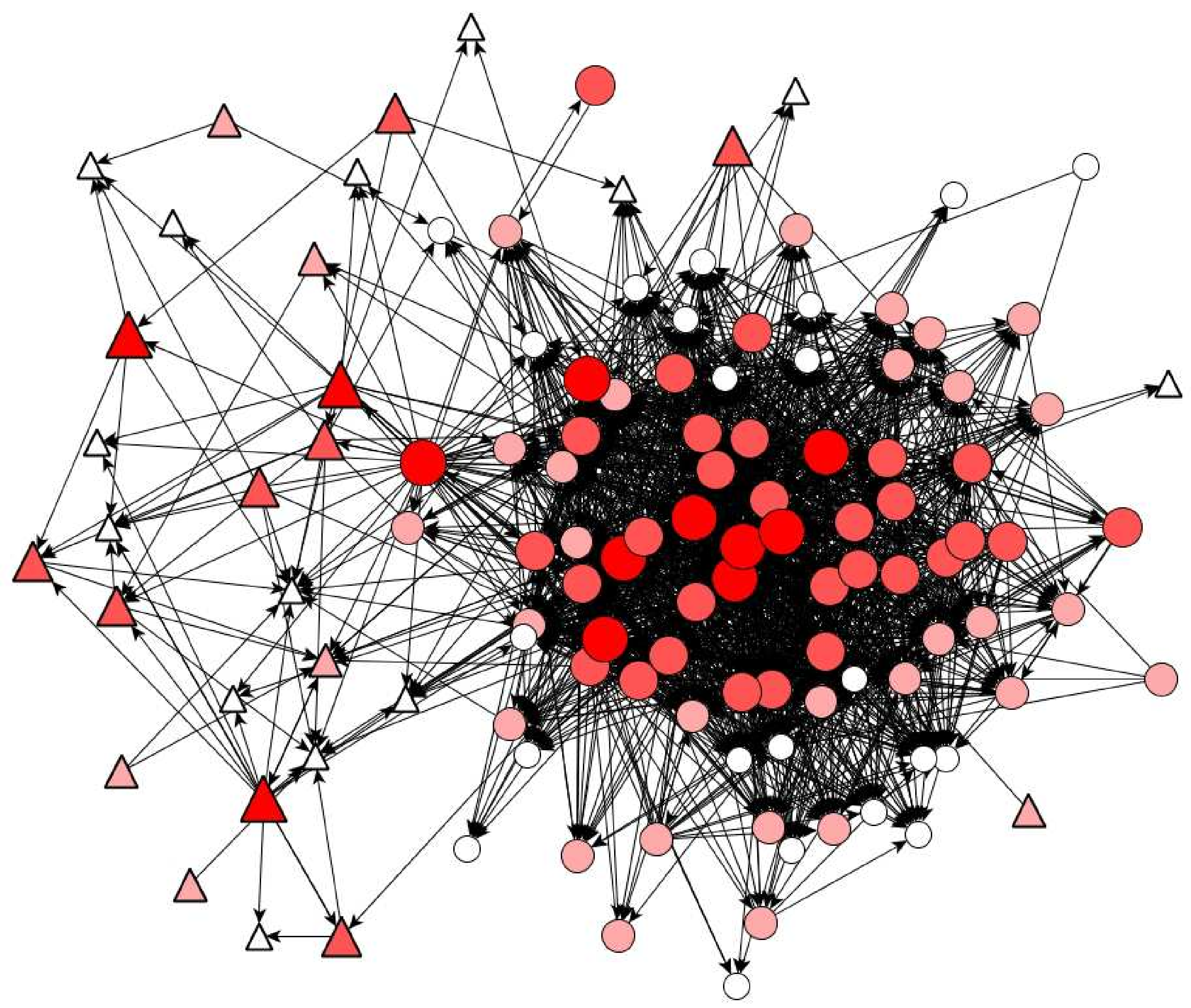
The core: 66 banks with 75% of daily value of transfers

May, R. et al., Ecology for Bankers, *Nature* 451, 2008

The Hypothetical CDS Network for US Banks



From: Markose et al., *Too Interconnected to Fail*. Working Paper, Univ. of Essex, 2009



Snapshot of the e-MID network at 2010/4

Triangles: foreign banks (20)

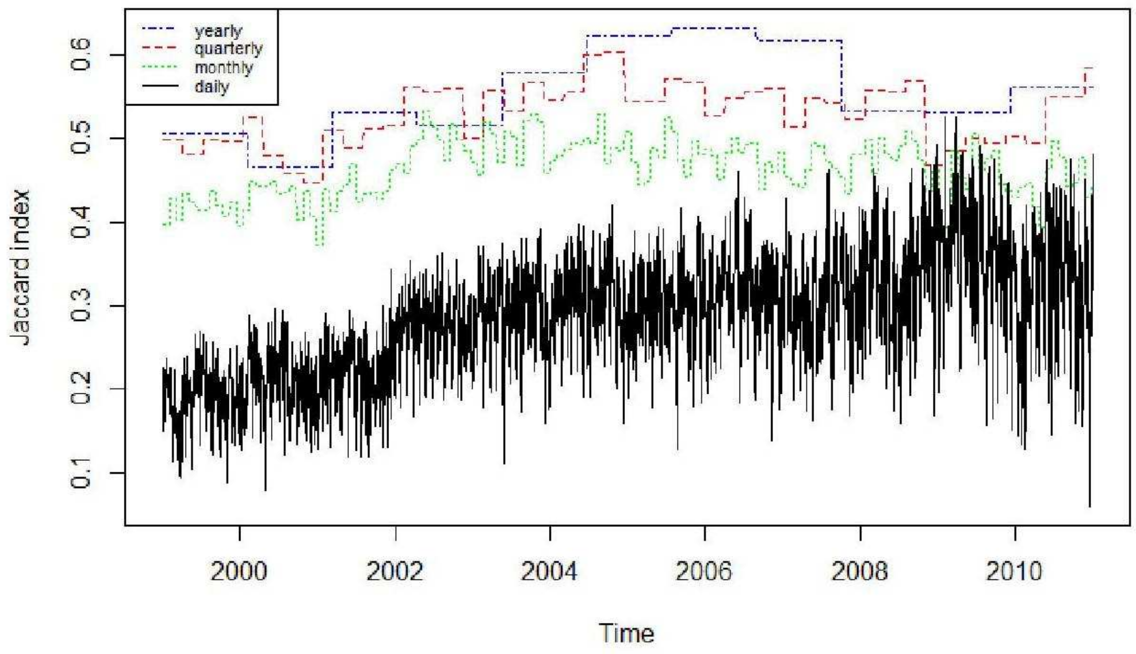
Dots: Italian banks (89)

Size and brightness indicate size as lender

e-MID: electronic market for interbank credit, only publicly available data set

Issue of choice of data and time horizon: daily networks behave very erratically, they are incomplete samples from an underlying dormant network, of which only few links are activated, more stability for monthly, quarterly networks

data:e-MID electronic platform for interbank credit

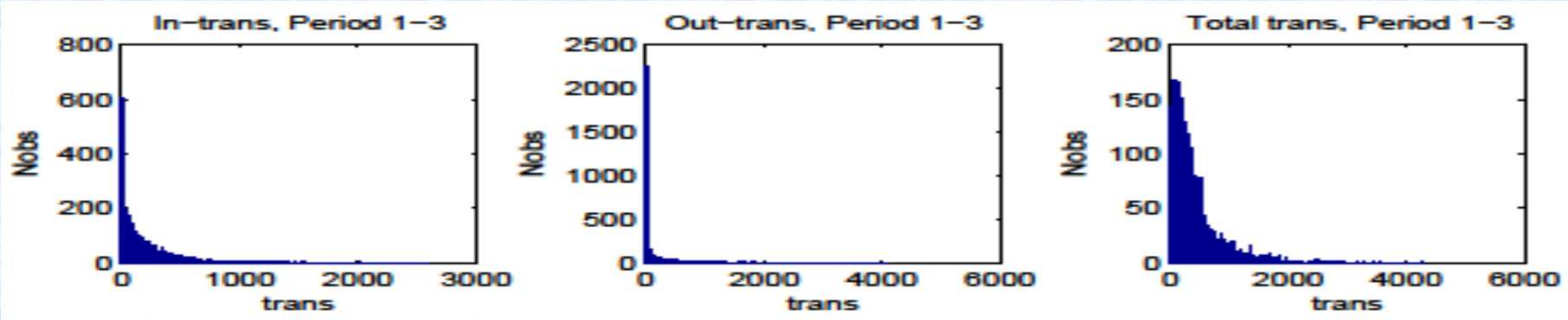


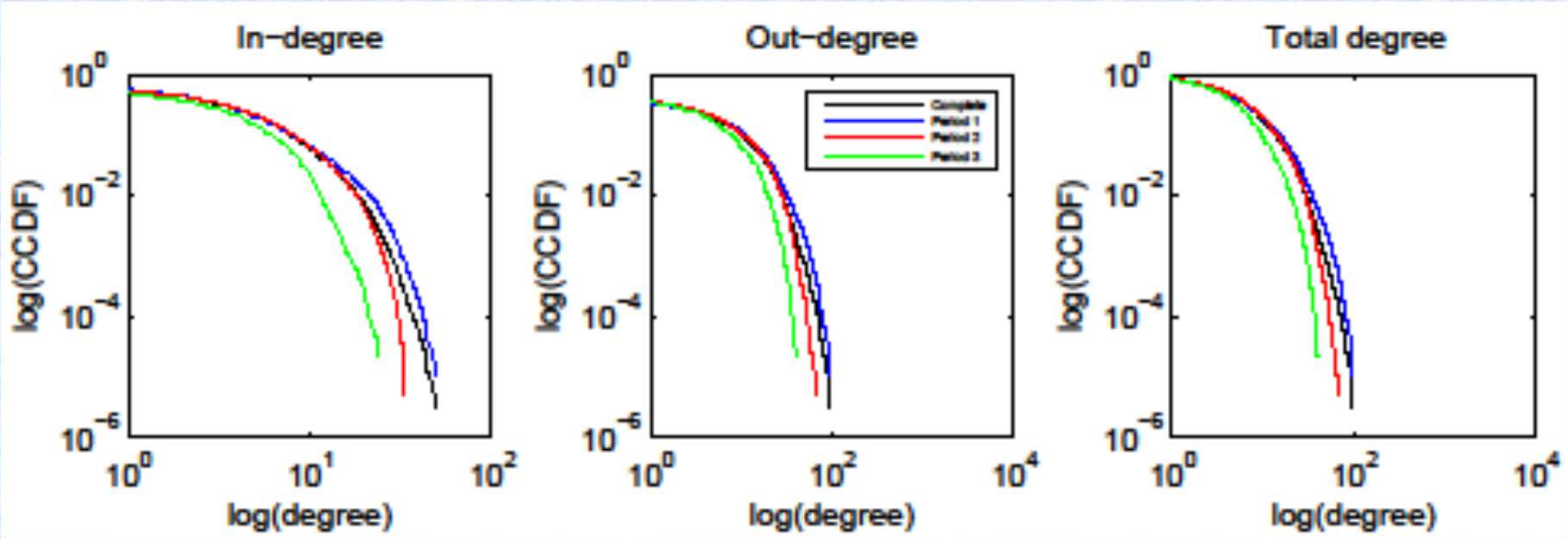
Jaccard Index for daily (black), monthly (green), quarterly (red) and yearly (blue) networks.

$$Jaccard\ index: J = \frac{M_{11}}{M_{01}+M_{10}+M_{11}},$$

Stylized Facts

- ***High persistence of links:*** relationship banking
- ***High dependence*** on creditor, much less on borrower
- ***Disassortative mixing***: high-degree nodes are more likely to have associations with low-degree nodes
- A ***core-periphery*** structure provides a somewhat better fit than alternative network models
- ***Distribution of links:*** Scale free or not?
- Ensemble of stylized facts cannot be reproduced by standard network mechanisms



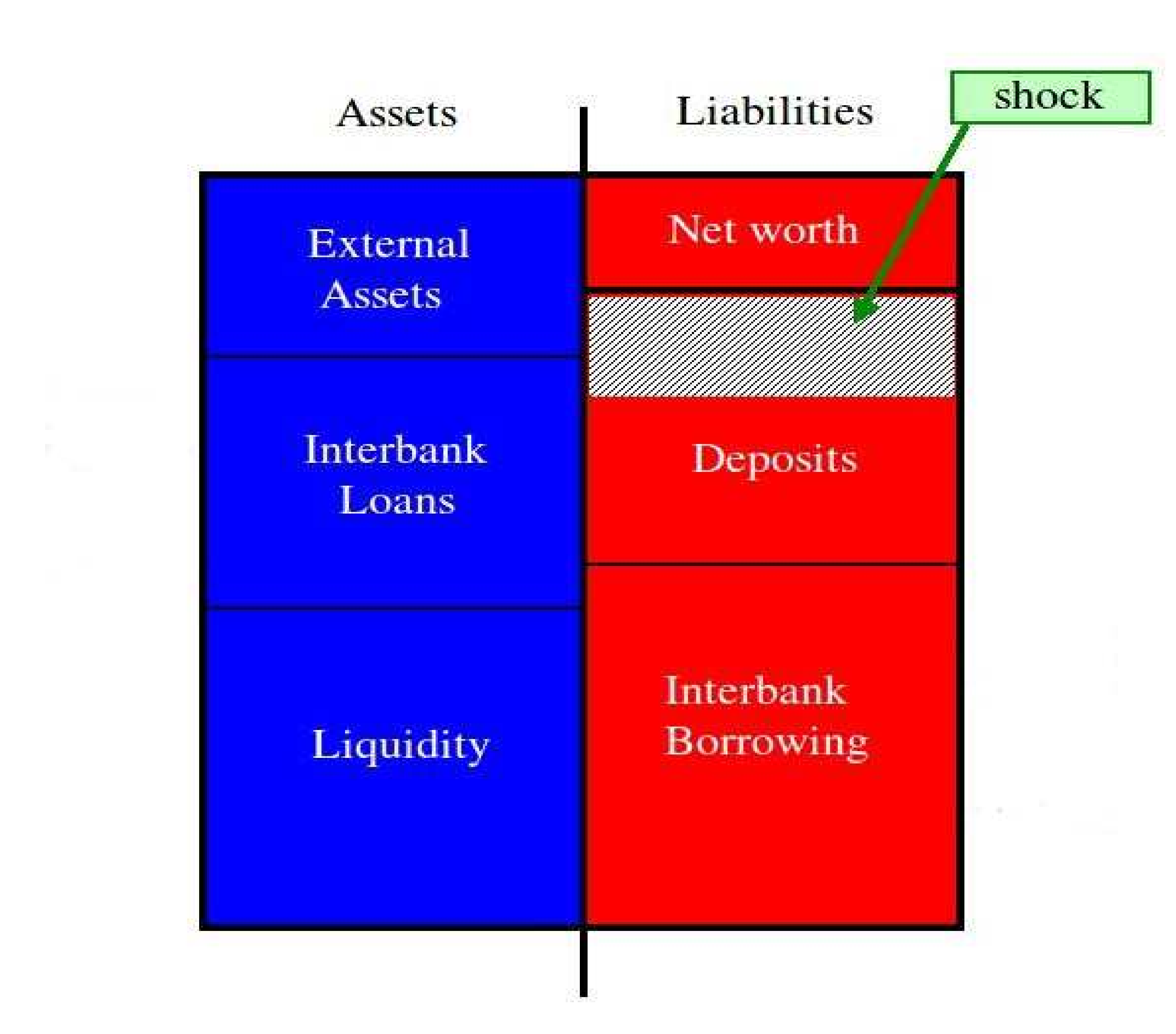


Degree distributions for interbank overnight credit in e-MID platform: exponential rather than power-law decline of cdf, best fits by negative Binomial, Weibull, Gamma, Exponential distributions, same for no. of transactions, volume

Network Approaches to Interbank Activities

- Mostly studes of default contagion
- Counterfactual simulations: disaggregation from macro data, maximum entropy approach, mostly at central banks, e.g. Upper and Worms (EER, 2004)
- Stylized theoretical models, e.g. 4-bank model by Allen and Gale (JPE, 2000)
- Simulation models using one of the well-known classes of networks for link formation, e.g. random network s etc (Nier et al, JEDC 2007, theoretical approach: May and Arinaminpathy, 2010)

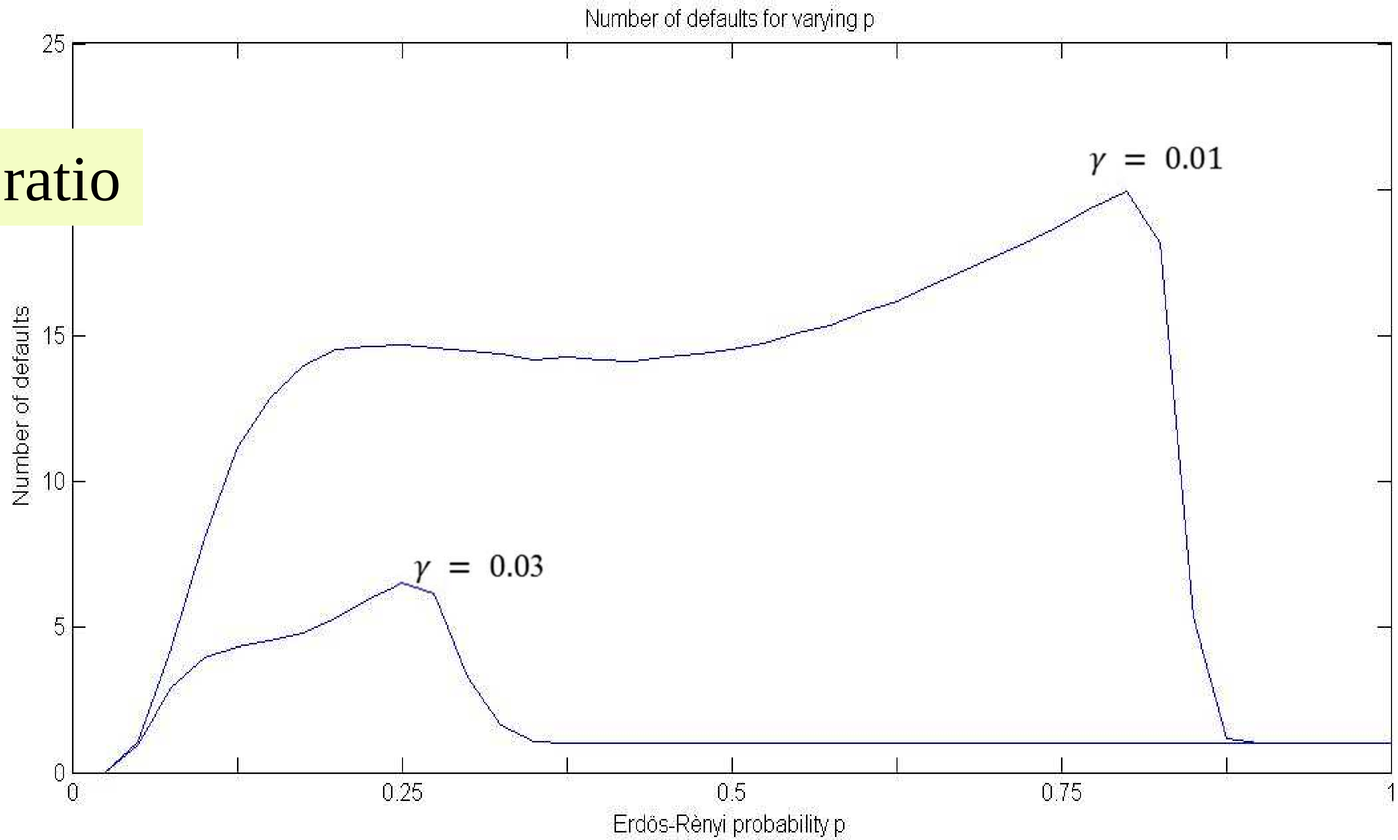
The basic framework: Banks‘ balance sheet structure



Stylized Contagion Exercise

- Set up a banking system with consistent balance sheet structure and interbank credit
- Shock the system: one bank defaults
- Compute the knock-on effects: default on interbank loans might lead to defaults of other banks via direct or indirect channels (price effects)
- Count the overall sum of subsequent defaults or loss of capital
- Investigate how results depend on parameters/assumptions

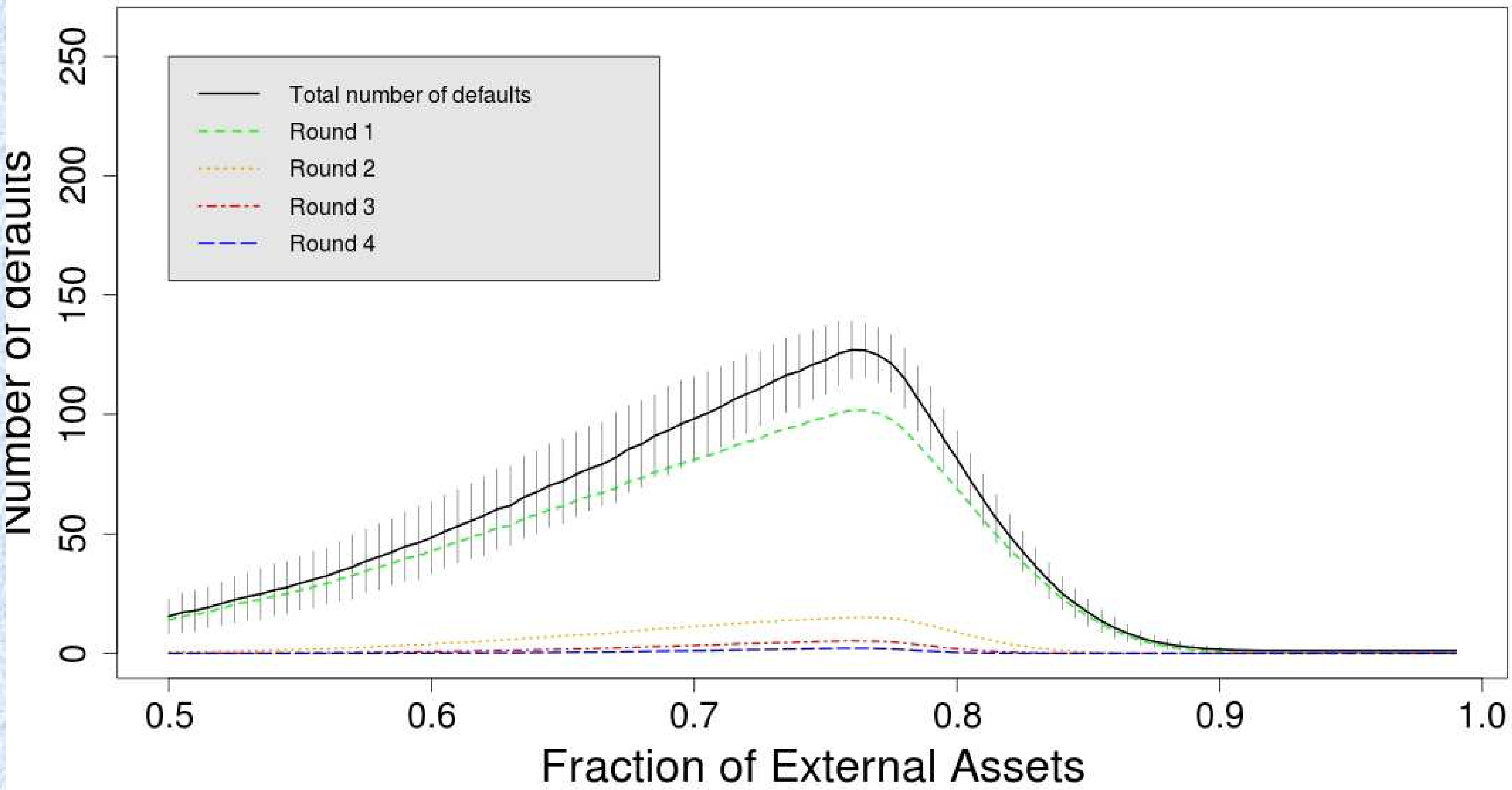
Replication of Nier et al.: identical bank sizes, random network of interbank credit



γ: equity ratio

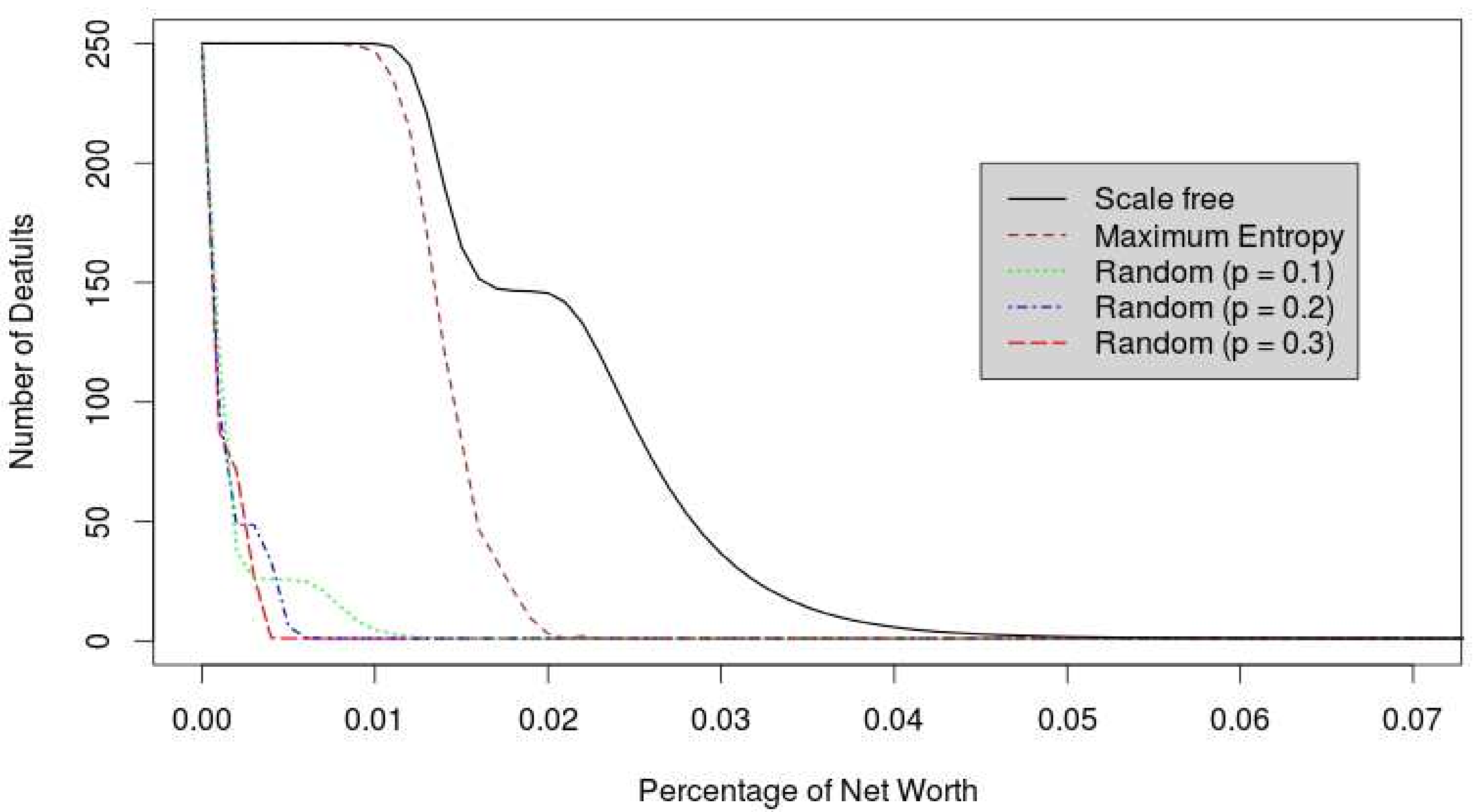
First important insight: Trade-off between stabilizing ***risk sharing*** and higher ***risk propagation*** through interbank links

Survives in more realistic settings: Pareto distribution of bank sizes, disassortative network structure with broad link distribution (Montagna and Lux, submitted)



<- fraction of interbank assets

Comparison of number of defaults for disassortative, random and max entropy networks



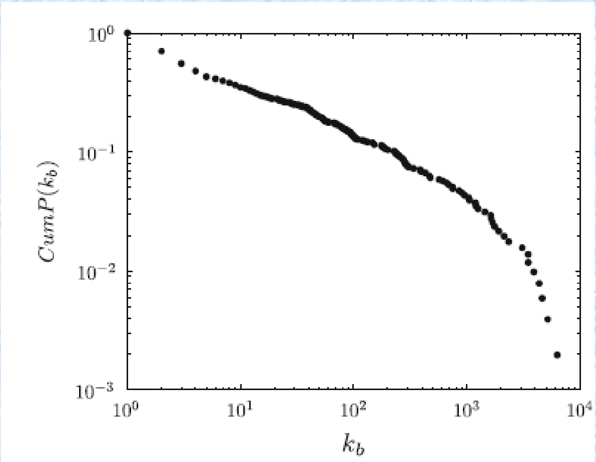
Adding Other Channels of Contagion

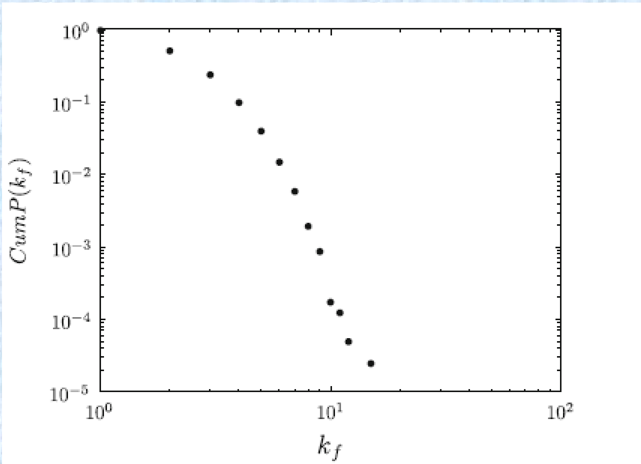
- Funding risk (Halaj and Kok, 2013)
- Portfolio overlaps and valuation effects (Huang et al., 2012, Montagna and Kok, 2013)
- Joint exposure via derivatives
- Joint exposures via loans to same counterparty

New Features: Bipartite or tripartite network structures

What do we know about the firm-bank credit network?

- Banks typically have more links and a broader link distribution than firms
- From Italian data: mean degree of firms = 1.8, for banks = 149, maxima are 15 and 6699, respectively
- While not monotonic, there is a tendency of the no. of links to increase with size for both banks and firms





Modelling the Firm-Bank Network

- Following Zipf's law, we assume a fat-tailed size distribution for both banks and firms (or their loans)
- To capture size dependence and heterogeneity, the number of links per bank and firm follow Poisson distributions with size-dependent parameter

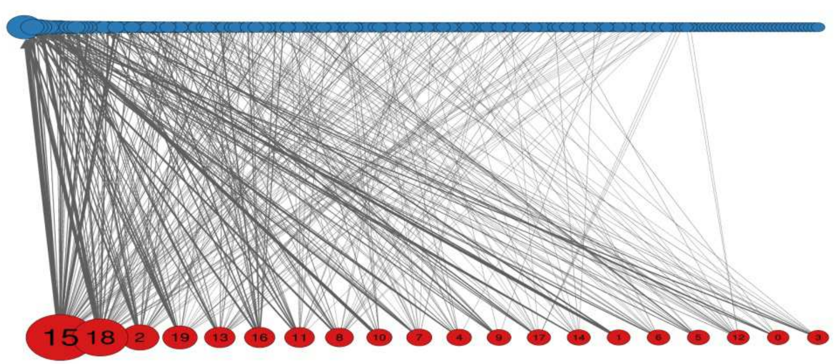
$$\lambda_{i,(j)} = \overline{\lambda_{(j)}}\, A_{i,(j)},\ j \in \{b, f\}$$

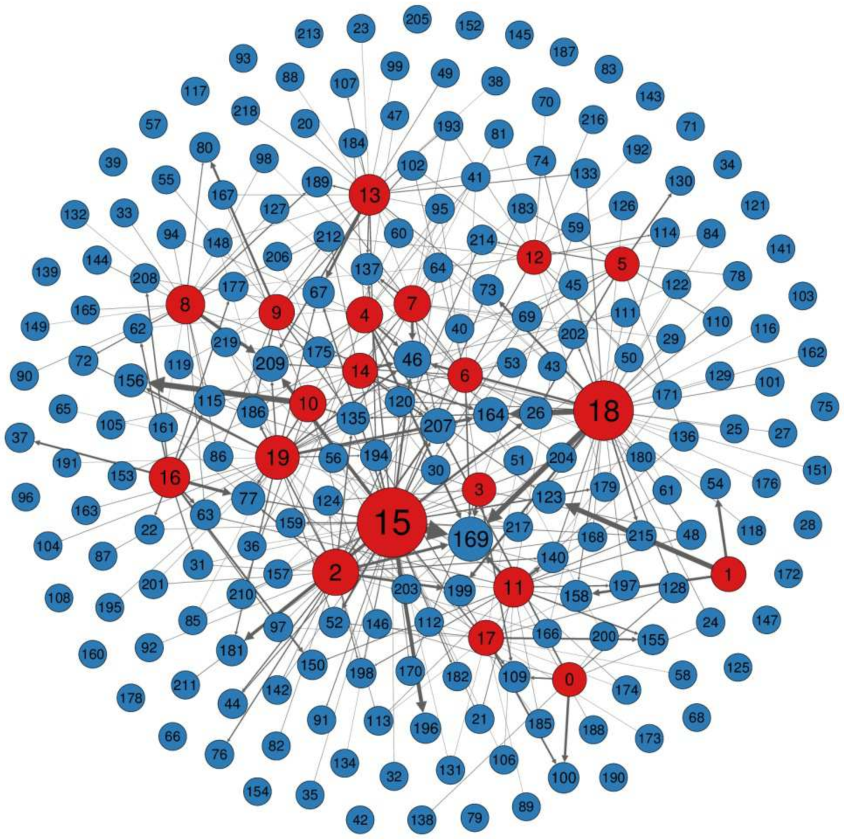
- Links are then matched randomly until either the aggregate links of banks or firms are exhausted

$$\overline{\lambda_f} = 2, \overline{\lambda_b} = 20$$

A bipartite network of firm and bank connections,

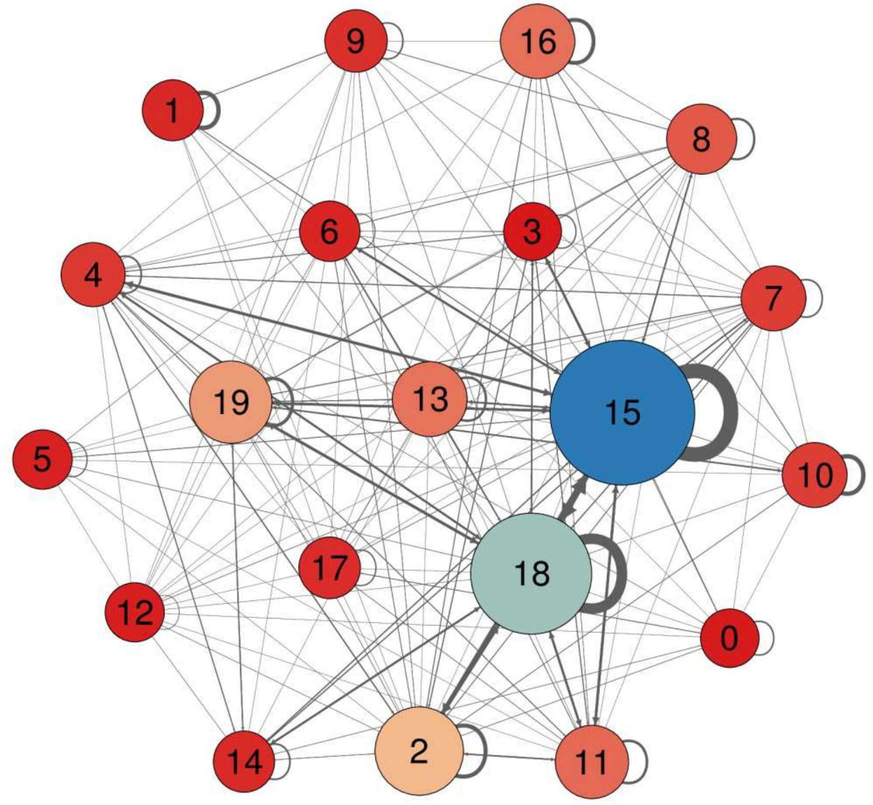
$N_b = 20$, $N_f = 200$



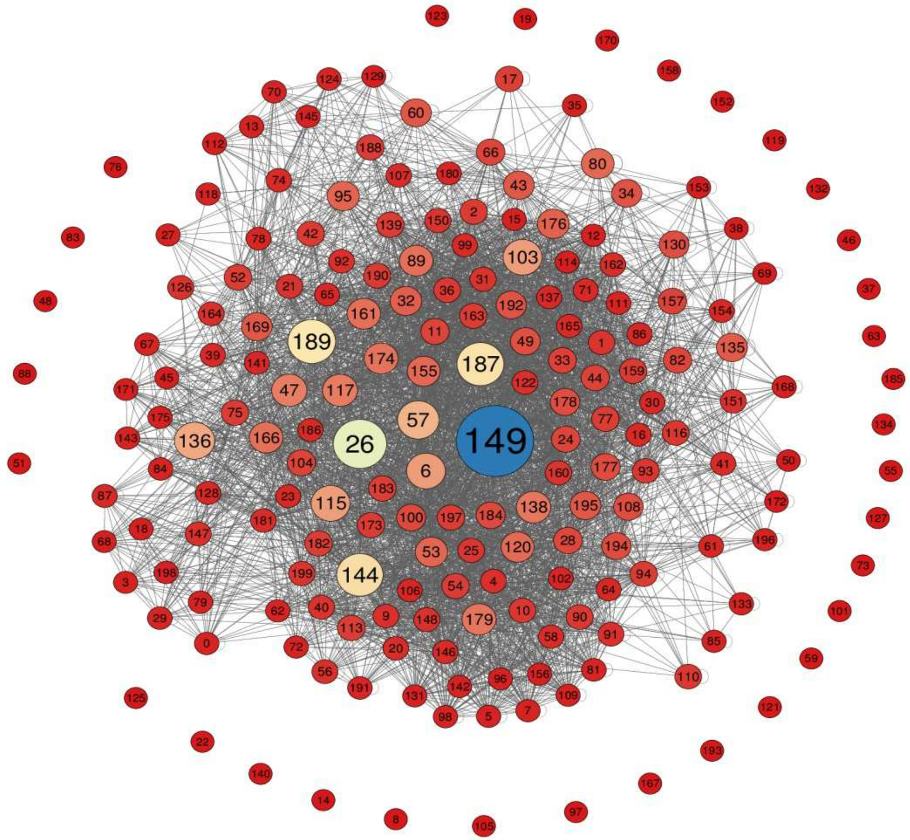


The resulting connections between ***banks*** via joint exposures, given by $M\,M^T$

M: incidence matrix of dimension N_b x N_f



The resulting connections between ***firms*** via joint exposures, given by M^TM



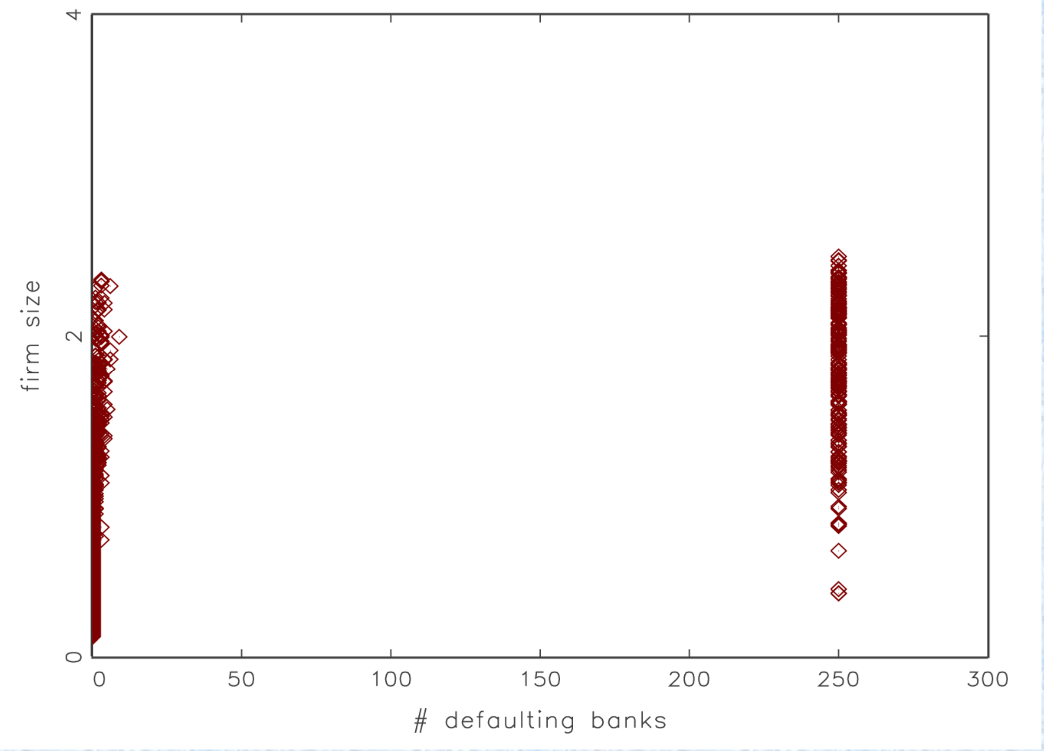
Application: We now consider as external shocks the failure of a specific company

- Initial default: any one of the N_f firms
- Knock-on effects (I) through interbank contagion (as before)
- Knock-on effects (II) through lack of funding for firms (minimum remaining funding required)

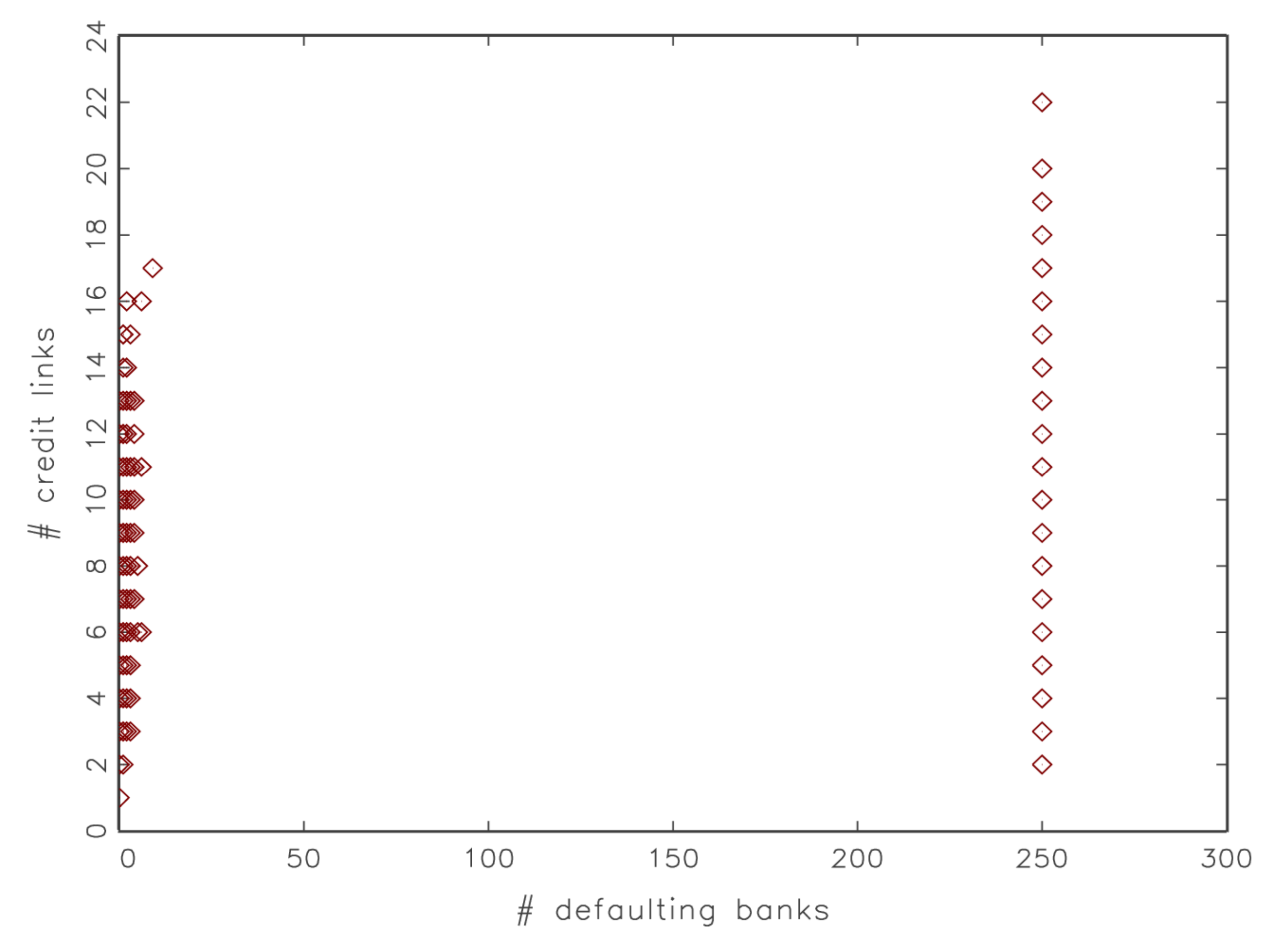
Cumulative Defaults vs. Size of Initial Disturbance

- Huge heterogeneity of no. of defaults
- almost uncorrelated to size of firm, but dependent on exact position in the network

All firms have at least one connection to a bank

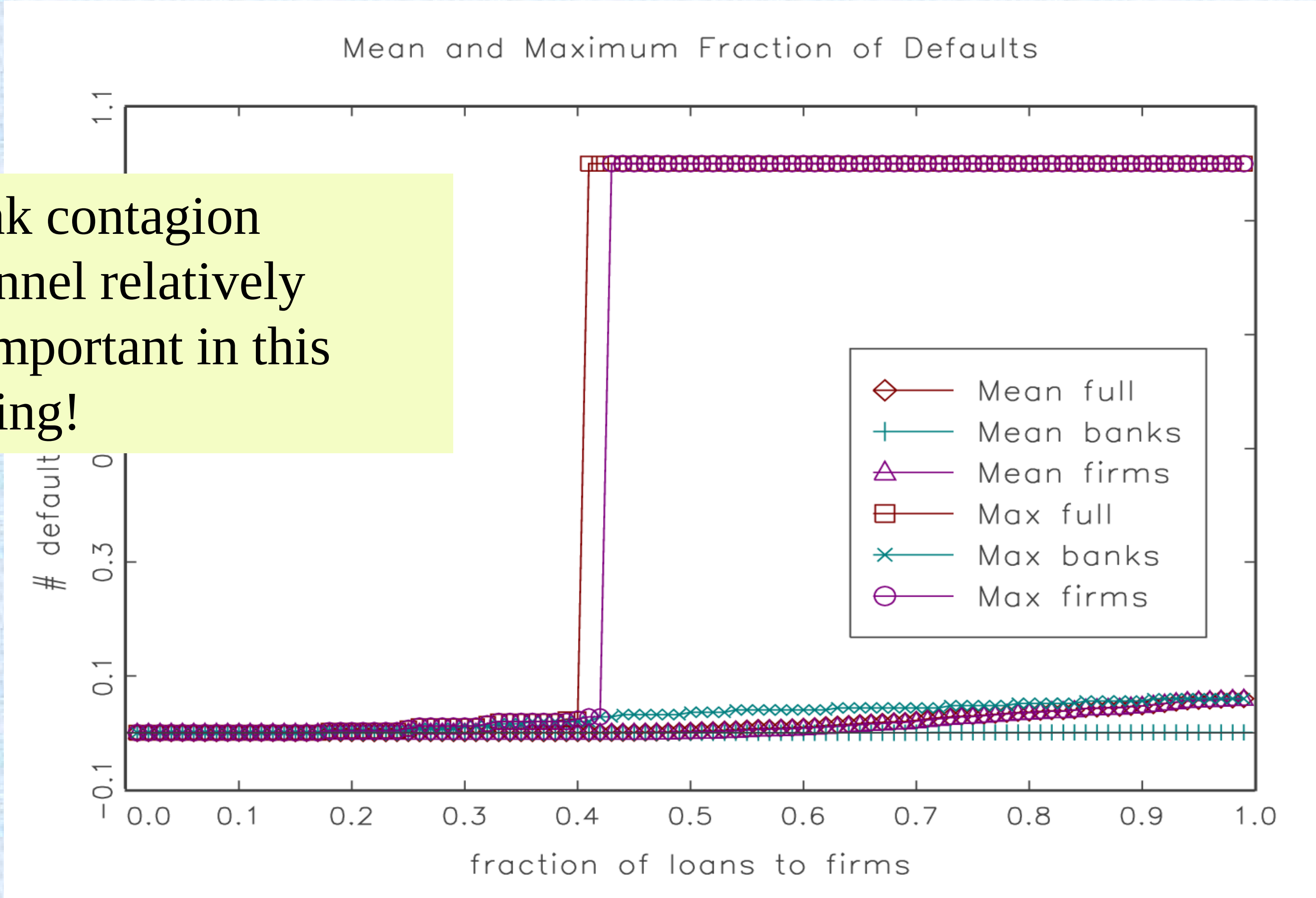


also independent of no. of links



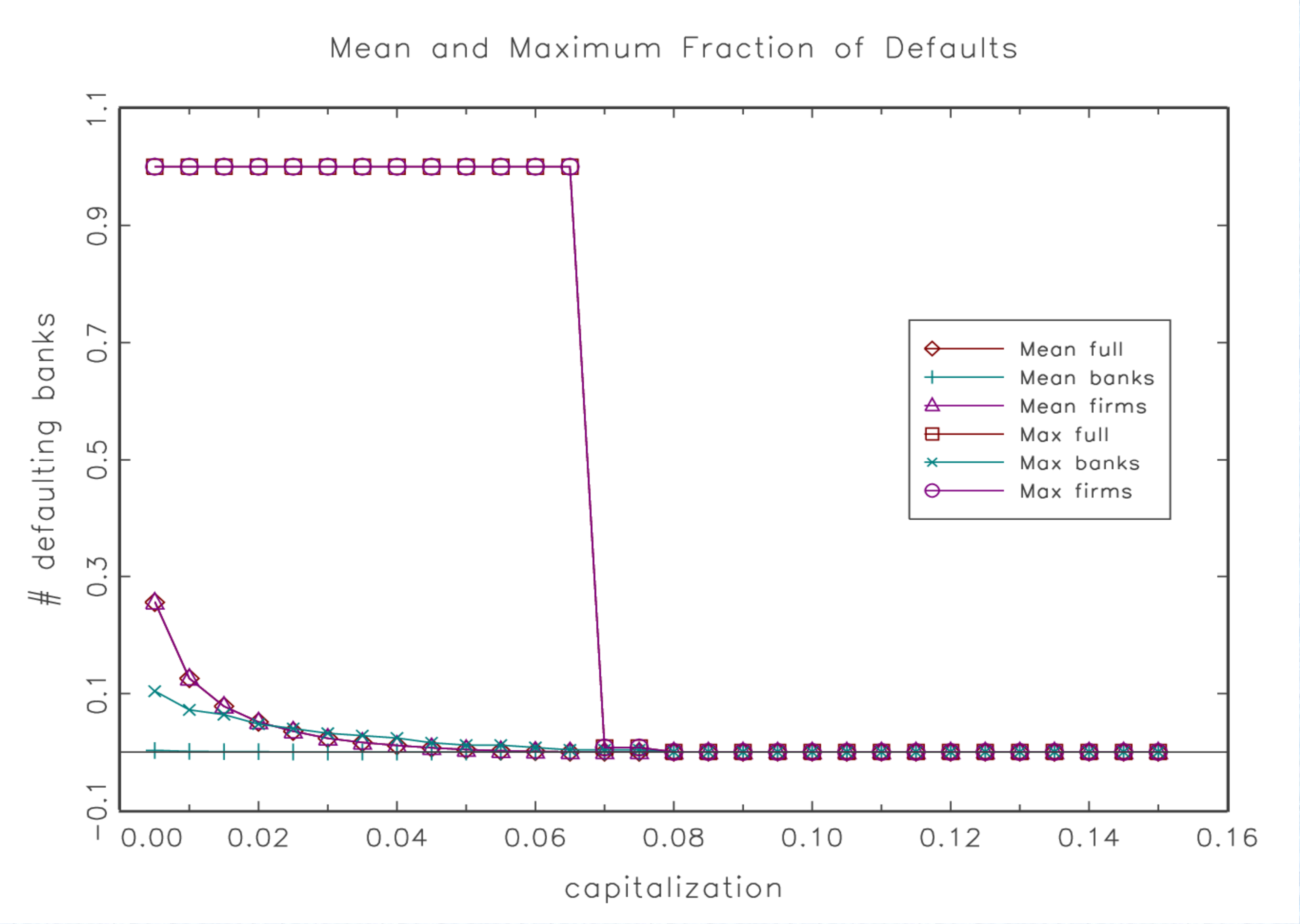
Probit model shows significant coefficients for size and degree, but forcasting is dismal.

Firm-Bank vs Bank-Bank Channel of Contagion



Bank contagion channel relatively unimportant in this setting!

Role of Capitalization



System is „robust, yet fragile“, why?

- With given numbers for average links of banks and firms, and their size dependence, the system will have a *giant connected component*
- Stress *can* propagate throuhout the entire system
- Whether an entity is dangerous depends on its exact position, its size and degree alone do not provide good predictions on systemic aftreeffects

Towards A Dynamic Model of the Interbank Market

- Ensemble of banks with *power-law distribution* of balance sheet size
- Banks are facing liquidity shocks that are mean-reverting and have mean zero
- Liquidity is reallocated in the system through borrower-initiated trades in interbank market
- Banks decide about potential lender via a trust function depending on past experience

Dynamic evolution

- Banks are hit in every period by liquidity shocks:

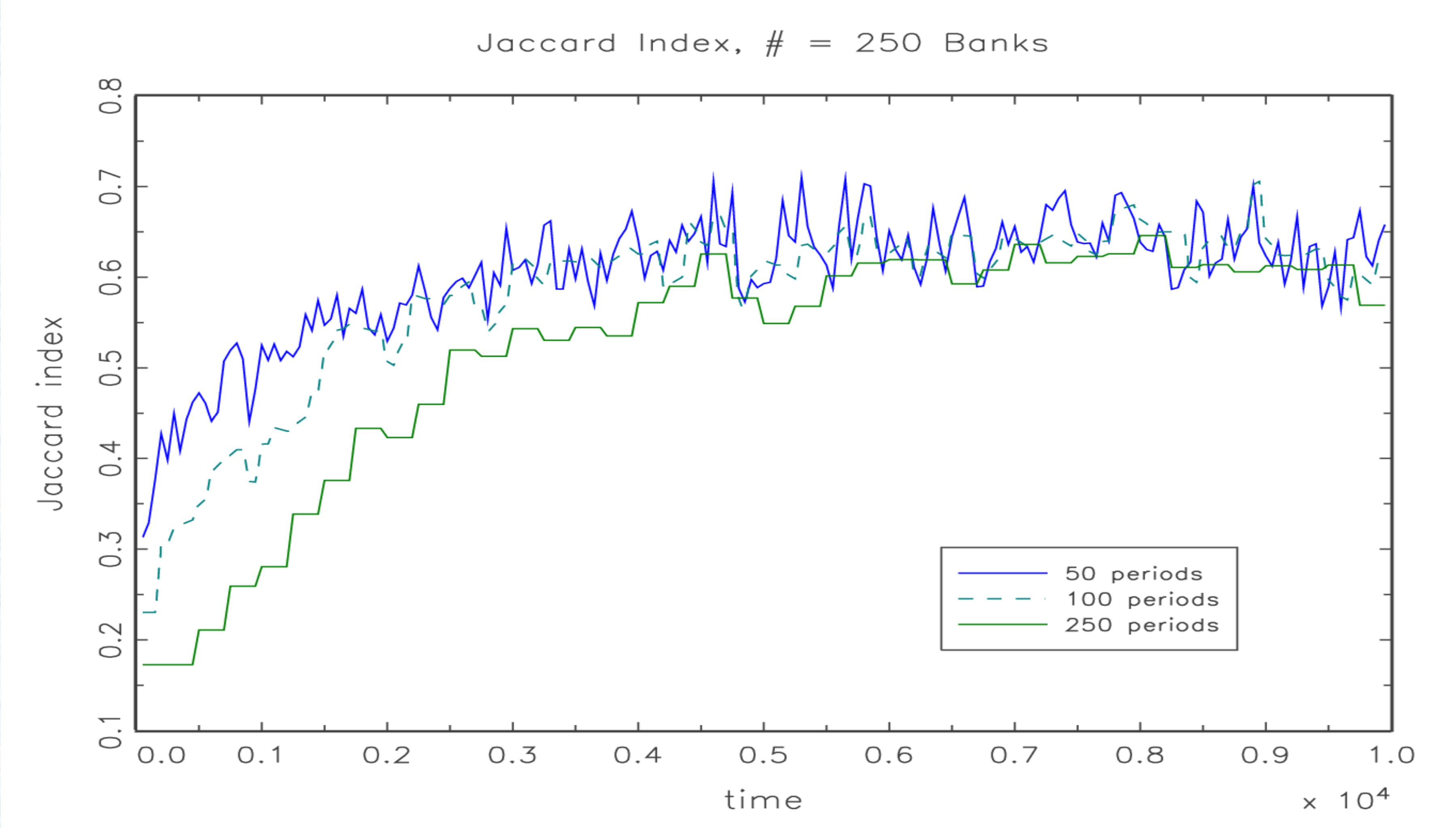
$$shock_{i,t} = \beta(\overline{d_i} - d_{i,t}) + \sigma_i \varepsilon_{i,t}$$

- …mean-reverting to bank-specific mean, with bank-specific size of random shock

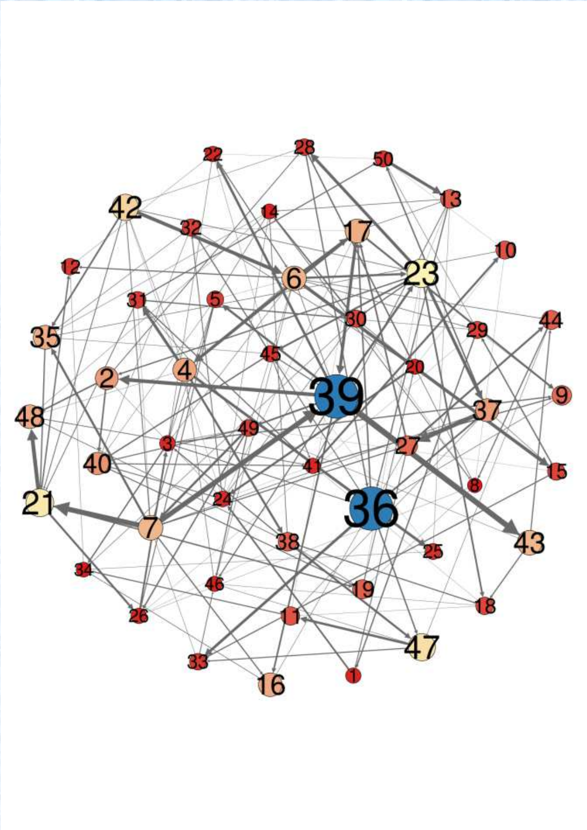
- If *shock <0*: bank asks for credit at other banks choosing creditor according to a „trust“ function

- If credit is provided, trust increases, if not, it declines.

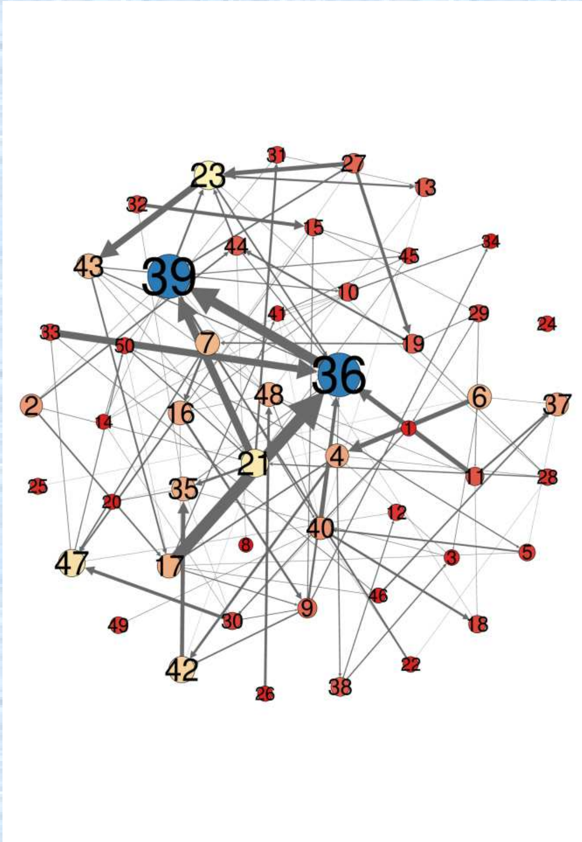
Results: The system converges to a statistical equilibrium, e.g., for persistence



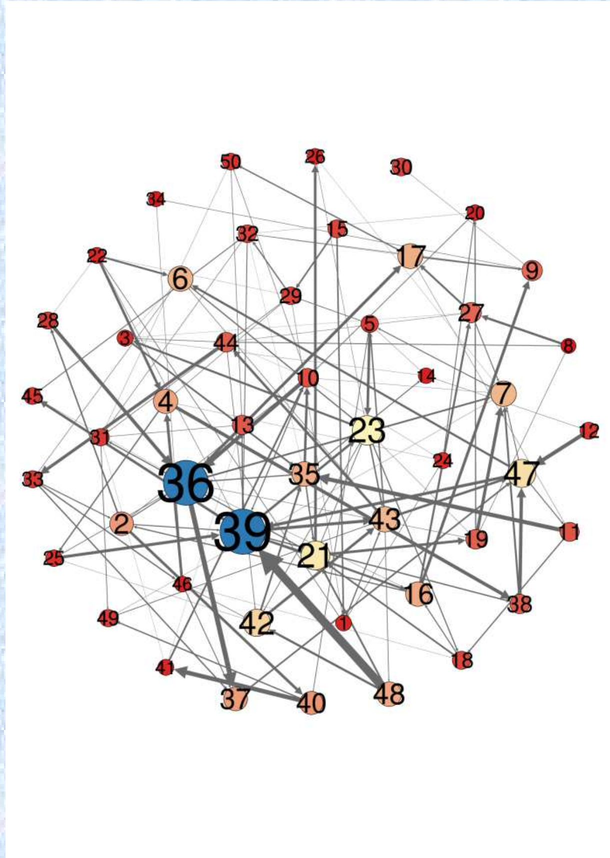
Development of Network Structure towards core-periphery



t = 100



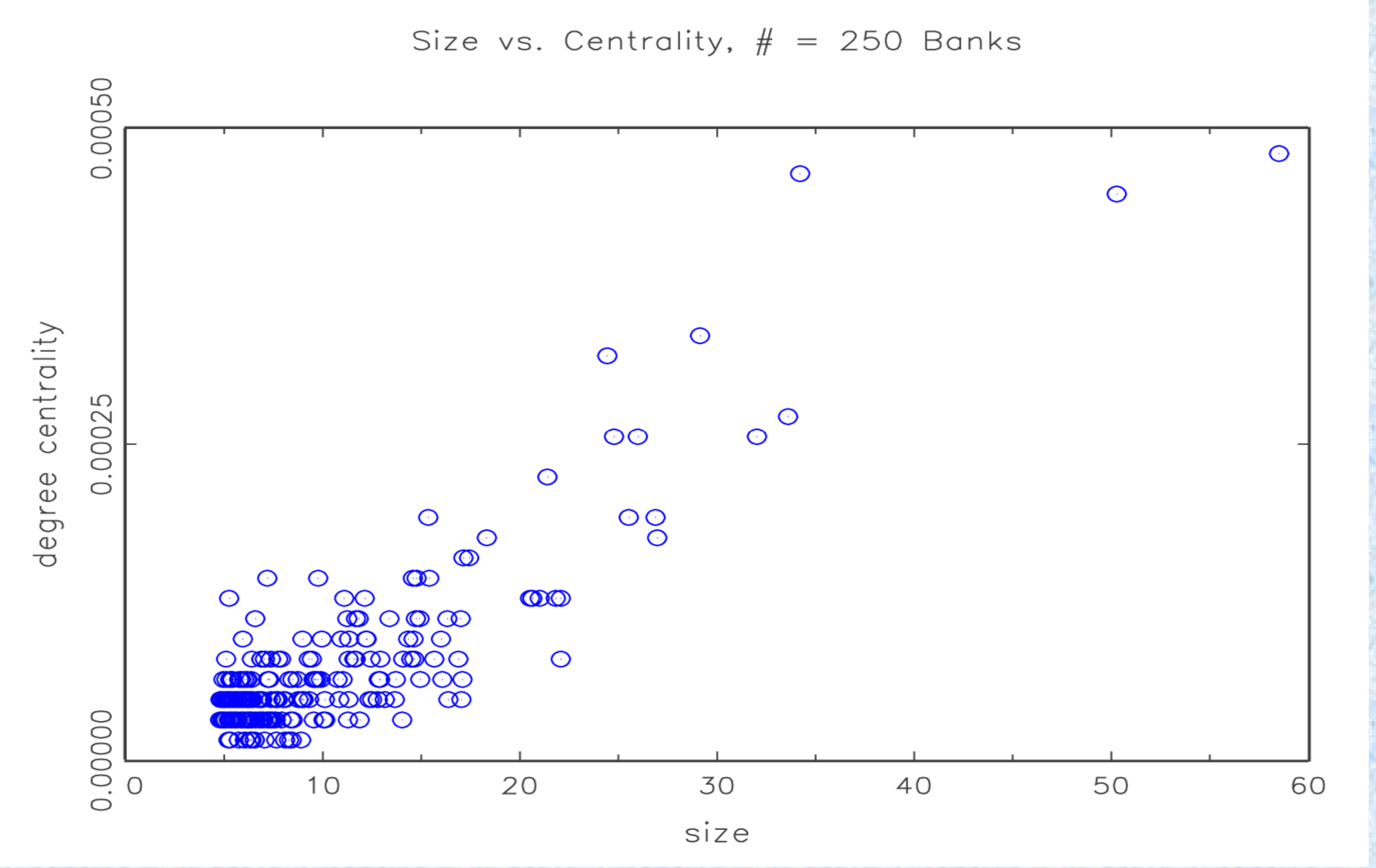
t = 5000



t = 10000

Development of core-periphery structure as documented by Craig/ von Peters, Fricke/Lux and Lelyfeld/in`t Veld

Size versus centrality



Model replicates the CP structure and other important stylized facts as emergent phenomena

Conclusions

- Certain scenarios have been explored for various channels of contagion
- Mostly good quality data are missing, so policy conclusions have to remain tentative
- Mostly single channels have been investigated in isolation: however, joint activation of multiple channels might lead to superadditive cumulative effects (Montagna and Kock, 2013)
- Policy recommendations: regulatory details or overall tendencies?