Systemic Risks and Resilience of Global Financial Networks

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Outline

- Introduction
- Financial Network in Reality
- Simulation Study on Systemic Risk
- Innovation in Finance destabilize markets

  : Automatic trading agents

  : High frequency trading
- Toward more resilient financial networks

Background (1)
The systemic risk of financial systems

- Systemic Risk
  - The risk caused cascading default of financial institution

1997
Asian Financial Crisis

1998
Russian Financial Crisis

1999
Argentine economic crisis

2008
Lehman Shock

Global financial crisis

Background (2)
The systemic risk of financial systems

Between 2000 ~ 2007:
29 banks failed.

Between 2007 ~ present:
469 banks failed.

The importance of understanding banking networks

THE TI

Max 18C, min 5C

Tuesday September 16 2008 timesonline.co.uk No 69430

Lehman collapse sends shockwave round world

hares and oil prices plunge, thousands lose jobs

ry Duncan Economics Editor

rs of a global financial meltdown w yesterday as the world's biggest kruptcy plunged markets into noil.

vestors were left reeling as the pt demise of the Lehman Broth- investment bank sparked the est shake-up on Wall Street in des.

nother of US capitalism's biggest tutions, Merrill Lynch, is to be lowed by Bank of America in a billion takeover to save it from se.

res fell as fear spread through ancial system. Central banks un- urgent measures amid concerns e world economy was entering gerous new phase. The Bank of d injected £5 billion of emer- lending into money markets.

5,000 Lehman staff in Britain

are now estionably in orst financial s since the t Depression'

aletsky, page 24

rticle page 2

ker page 5

Dow Jones industrial average was down 300 points, or 2.6 per cent. Sentiment was also bolstered by steep falls in oil prices, which dropped by more than $5 a barrel to $96, closing under $100 for the first time in six months and raising hopes that cheaper fuel would ease economic stresses on Western nations.

However, by close of trading the Dow had fallen by more than 500 points — its biggest one-day drop since the reopening after the September 11 attacks — as concerns mounted over the world's largest insurer. Shares in American International Group (AIG), which sponsors Manchester United, fell by 45 per cent after it made an unprecedented approach to the US Federal Reserve for $40 billion in emergency funding.

Last night the Fed asked Goldman Sachs and J P Morgan Chase, two of Wall Street's remaining big banks, to head a $75 billion emergency package to keep AIG afloat.

As central banks battled to stabilise the system, the Fed eased its rules for emergency lending further. It announced that it would accept company shares in return for crisis loans for the first time. In Frankfurt, the European Central Bank injected €30 billion in emergency funds into eurozone markets.

A group of ten global banks also attempted to foster calm

Bankruptcy of Lehman in Sept. 2008 caused the global financial crisis.

Focus of financial study shift

- Maximizing returns with minimum risk
- Stabilizing finances **for individual banks**

After financial crisis

- Focus on **banking networks** as complex dynamical systems
- **Systemic risk**

- Asian financial crisis
- Russian financial crisis
- Bankruptcy of Lehman brothers

Contagion, Cascade, Systemic Risk

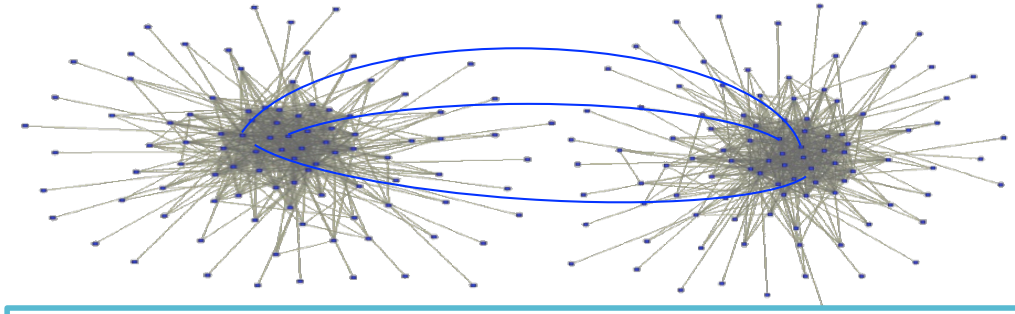
- "Contagion" arise quite generally in biology and social sciences
  - Spread of infectious disease
  - Diffusion of innovations

- "Cascade" arises in social sciences and engineering
  - Cascade phenomena
  - Cascade of failures

- "Systemic risk" arises quite recently in finance
  - Transmission of financial distress
  - Networked risks

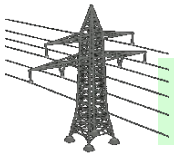
Systemic Risks and Cascading Failures

Systemic risks in financial networks



Cascading failures in engineering networks

Internet



Power grids

congestion and drop in speed

↓

Internet collapse

initial disturbance in some area

↓

Largest blackout

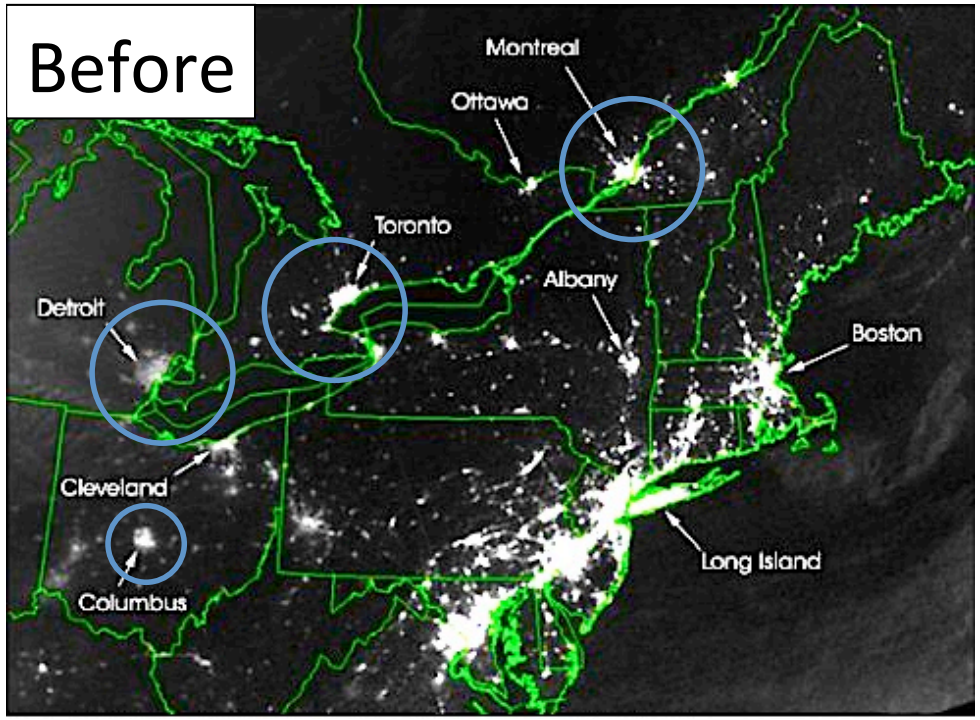
Cascading failure: Blackout

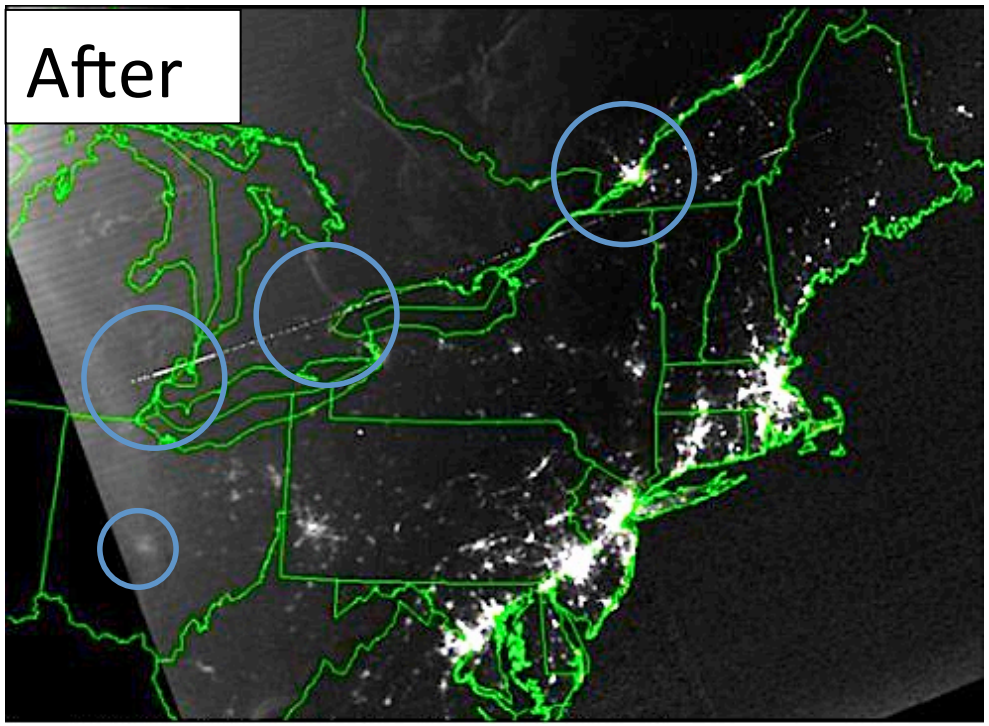
- Concepts of "cascade" arise quite generally in computer science and social sciences
  - ➢ One application component can trigger failures in others.
  - ➢ The down of some sub-systems can make the entire system down.

Failure makes another failure

How about global cascade ?
Initial failure break the system completely.

Blackout Hits U.S. and Canadian Cities Aug. 14, 2003.





Publications: Systemic risk to the financial system

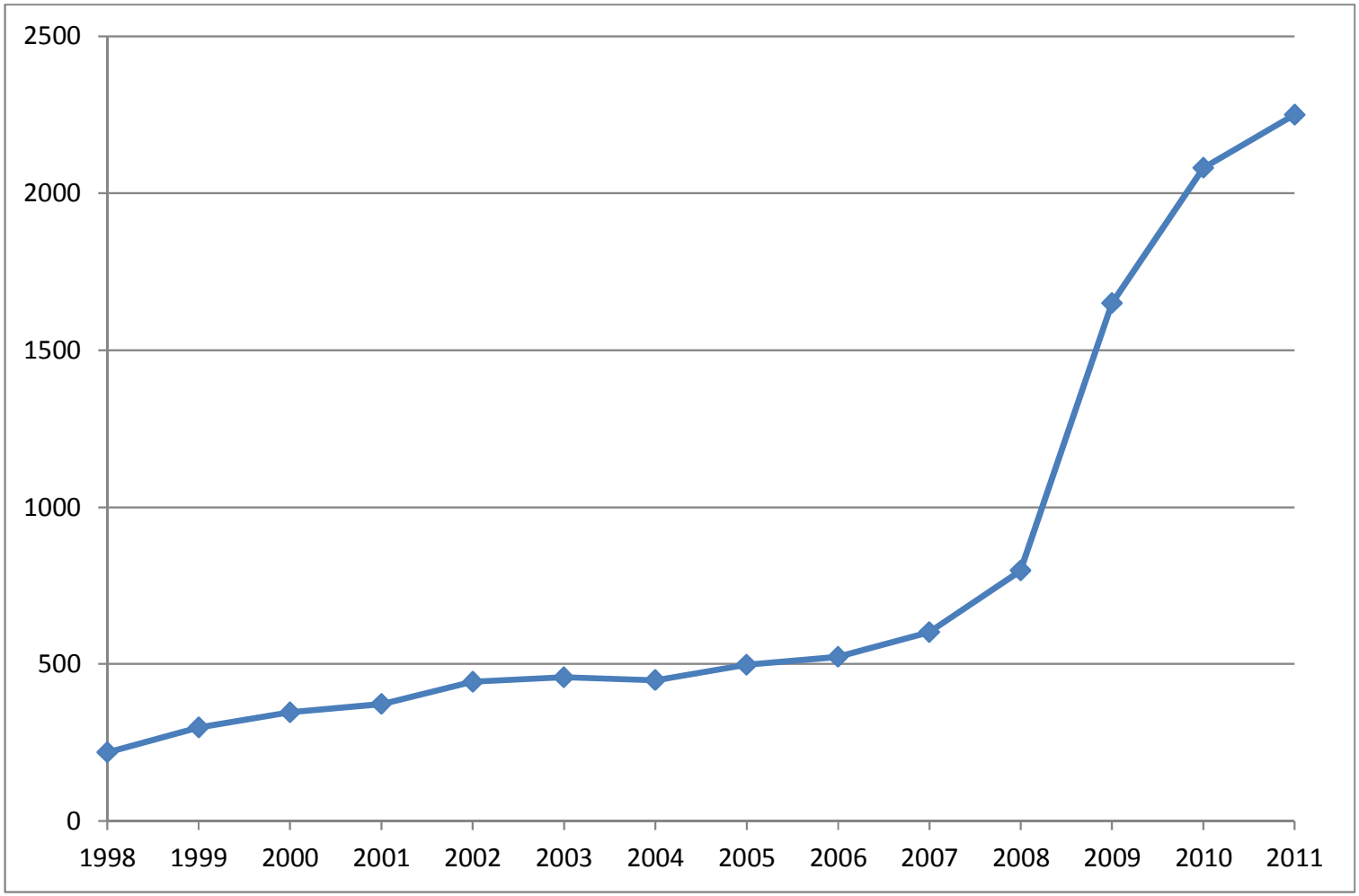


Figure 1. The annual output of publications in the field of systemic risk to the financial system for the period 1998-2011.

Markeloff , R, ”Modeling Systemic Risk to the Financial System” (MITRE, 2012)

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What is known about financial networks?

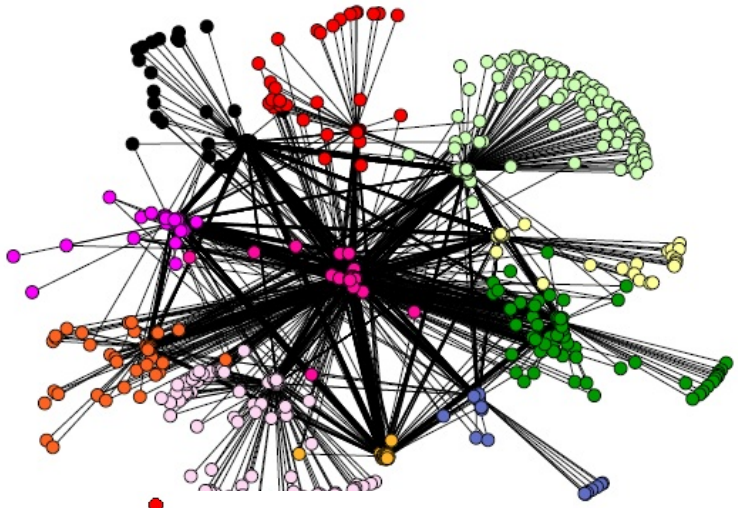
- Contagion models have mostly been studied on Erdos-Renyi random graphs or scale-free networks, while we know from emperical studies that real financial networks are much more complex.

  - G. Iori,, G. De Masi, O. V. Precup, G. Gabbi, G. Caldarelli, A network analysis of the Italian overnight money market, JEBO 32 (2008).
  - M. Boss, H. Elsinger, M. Summer, S. Thurner, The Network Topology of the Interbank Market (Austria), arXiv:cond-mat/0309582v1 (2003)

Network Structures of Real-world Banking Systems

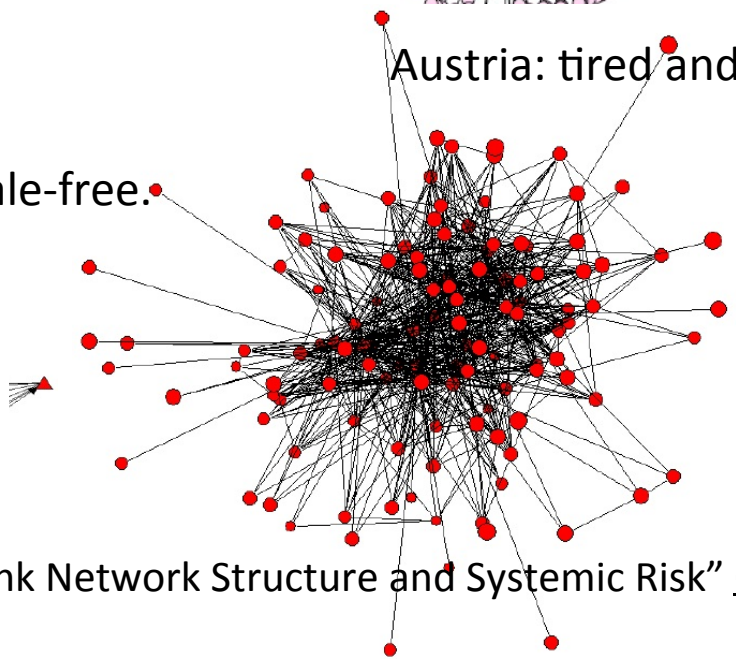
"The network topology of the Interbank market", Boss et al, Quantatitive Finance,4(2006).

Interbank networks are multi-tiered and community structure



Austria: tired and community structure

Interbank networks are roughly scale-free.



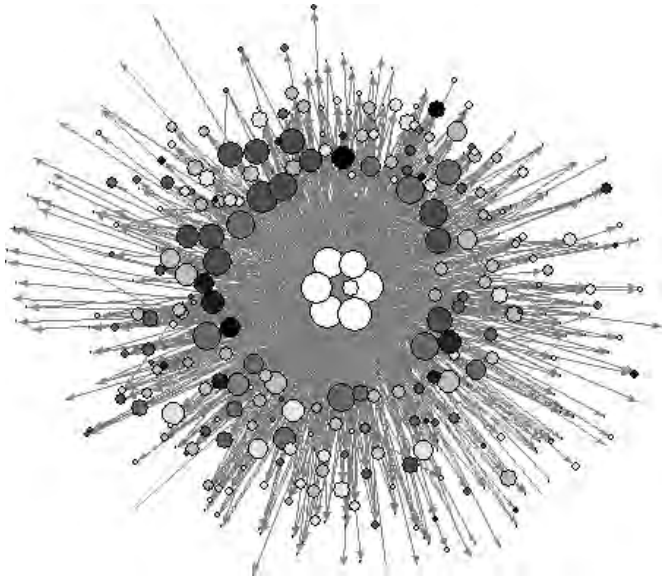
Brazil: scale-free

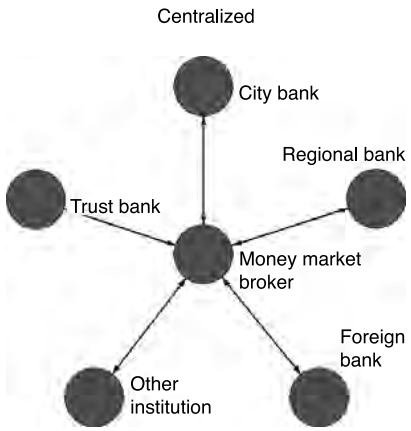
Santos, E, Cont.R, "The Brazilian Interbank Network Structure and Systemic Risk" Central Bank of Brazil working paper, 2010)

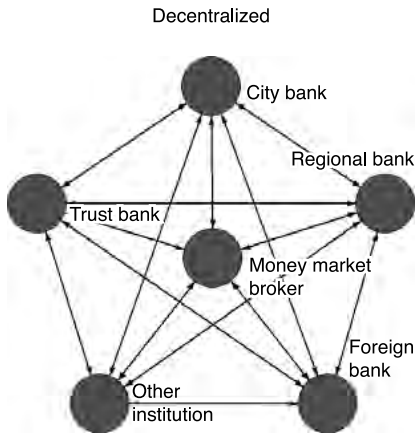
Interbank Transaction Network in Japan

"The Transaction Network in Japan's Interbank Money Markets" Imakubo, K, et al. Monetary and Economic Studies Vol.28 (2010)

December 1997



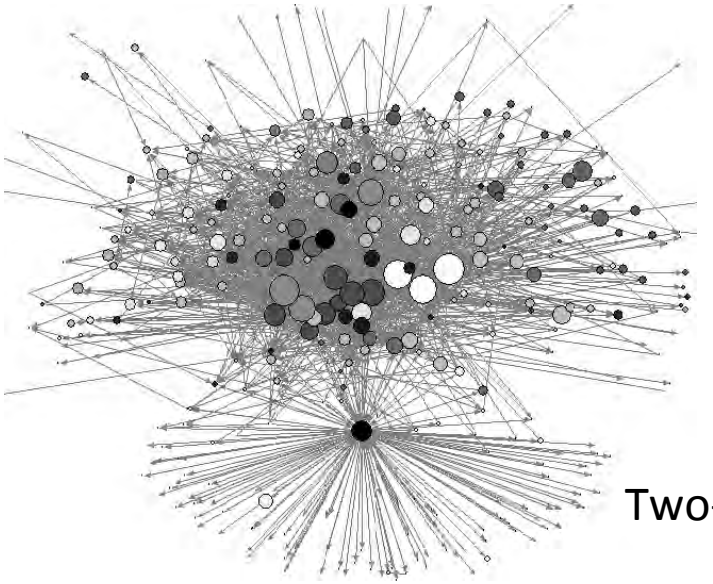


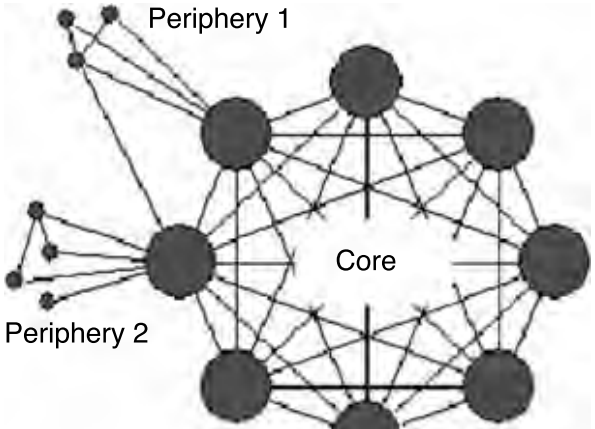


Single core(centralized) (1997)

Multi- core (decentralized, 2005)

December 2005

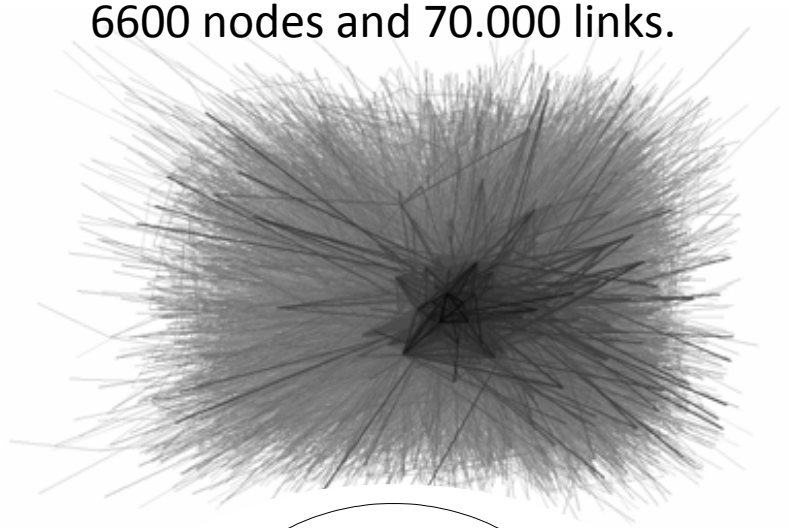




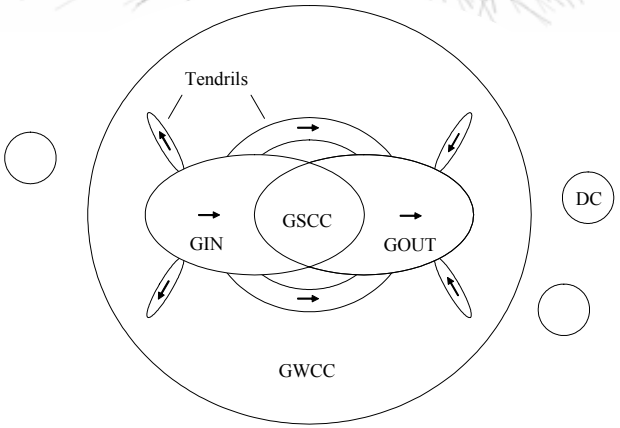
Two-Tier Structure with Core-Periphery (2005)

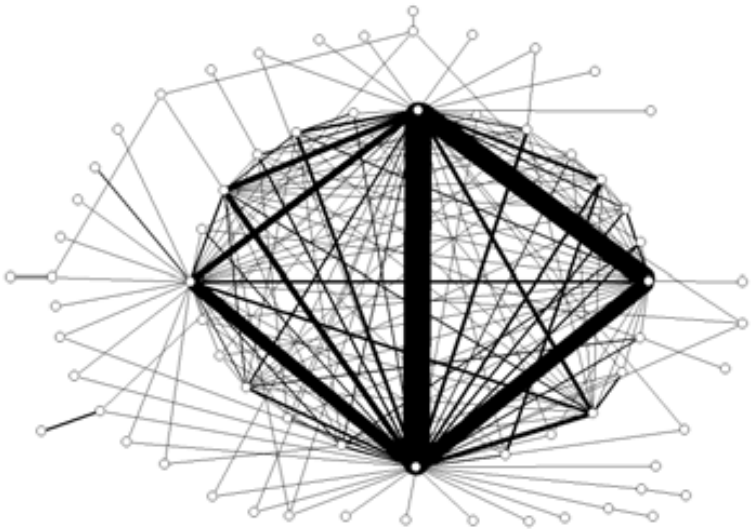
Federal Reserve Wire Network: existence of cores

Fedwire interbank payment network.
6600 nodes and 70.000 links.



GSCC , the undirected links that comprise 75 percent of the value transferred in Fedwire. This network consists of only 66 nodes and 181 links. The prominent feature of this network is that 25 nodes form a densely connected sub-graph





GSCC: Core of Fedwire Interbank Payment Network

GWCC = giant weakly connected component, DC = disconnected component,
GSCC = giant strongly connected component, GIN = giant in component,
GOUT = giant out component.

"The topology of interbank payment flows", Soramaki, K, M.L. Bech, J. Arnold, R.J. Glass and W.E. Beyeler, Physica A, Vol. 379, pp 317-333, 2007.

The global financial networks

- Minoiu, et al. construct a global banking network using cross-border banking data for 184 countries for the period 1978-2007.
- Hale constructs a global banking network of 7938 banking institutions from 141 countries using interbank lending data from a database of international syndicated bank loans.

: This is the first study in which bank-level network is analyzed in a global scale.

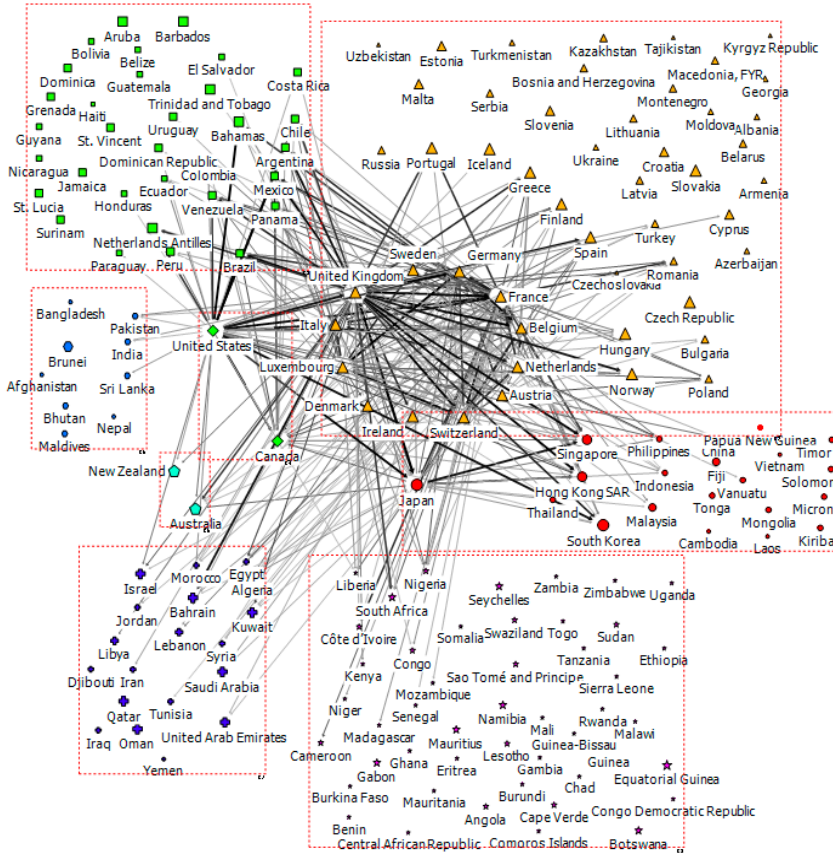
"A network analysis of global banking", Minoiu, IMF working paper, (2012)

"Bank Relationships, Business Cycles, and Financial Crises", Hale, Federal Reserve Bank, (2012)

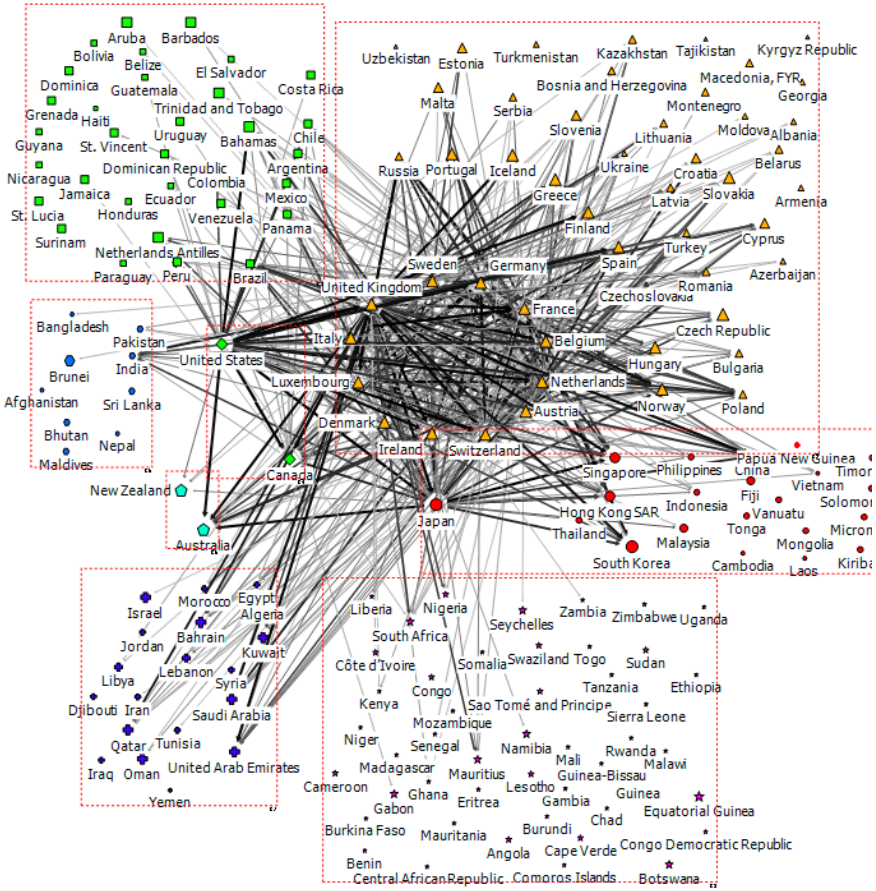
Network View of Cross-border Banking (1980 and 2007)

Minoiu et al. (2012) calculate network statistics with the goal of understanding how the flow of global capital changes over time.

1980



2007



"A network analysis of global banking", Minoiu, IMF working paper, 2012)

The Value of Derivative Contracts
600 Trillions US$ (10^{16})

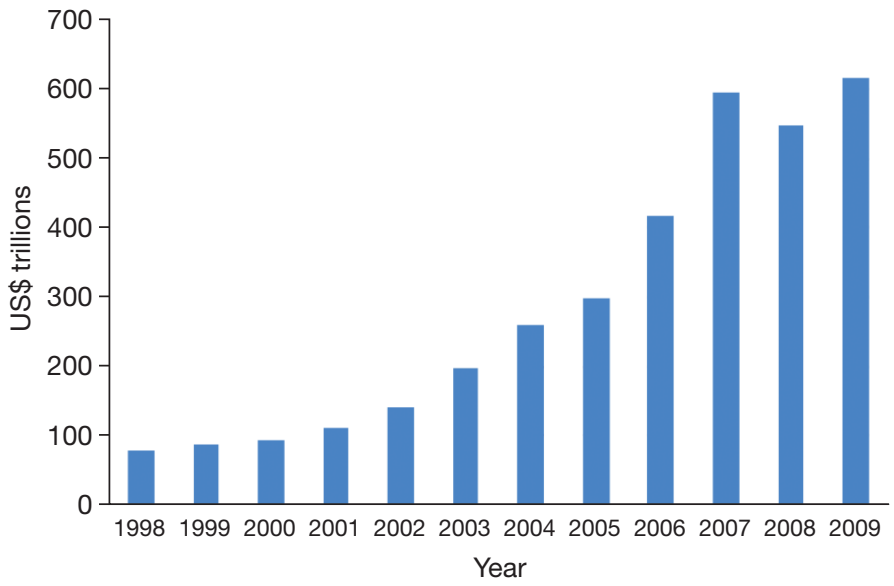
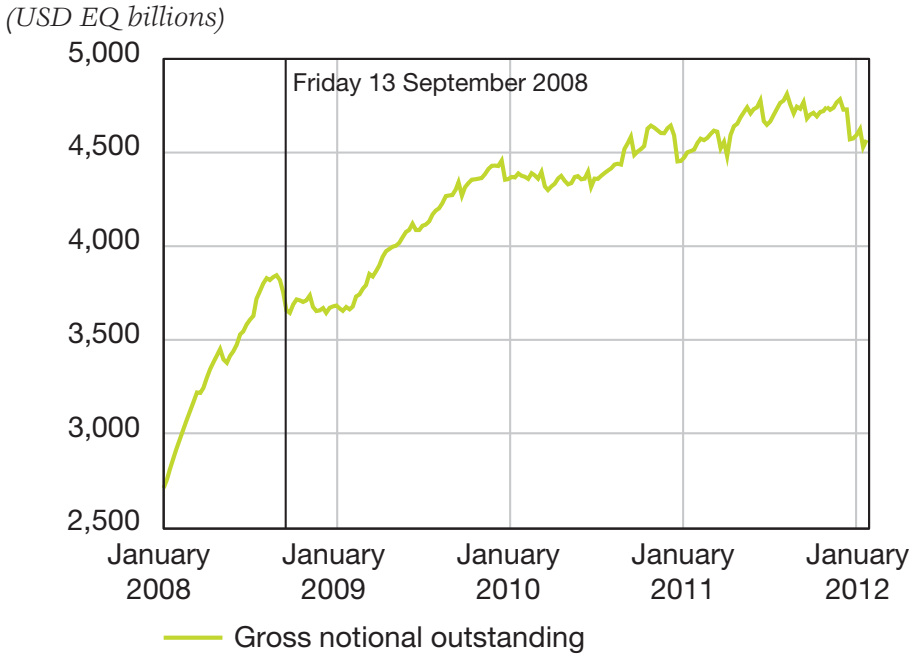


Figure 1 | Notional principal value of outstanding derivative contracts, as recorded at year end. These include foreign exchange, interest rates, equities, commodities and credit derivatives. Data from UK Department for Business, Innovation and Skills, International Monetary Fund and Bank of England calculations.

Evolution of the EU CDS market since 2008



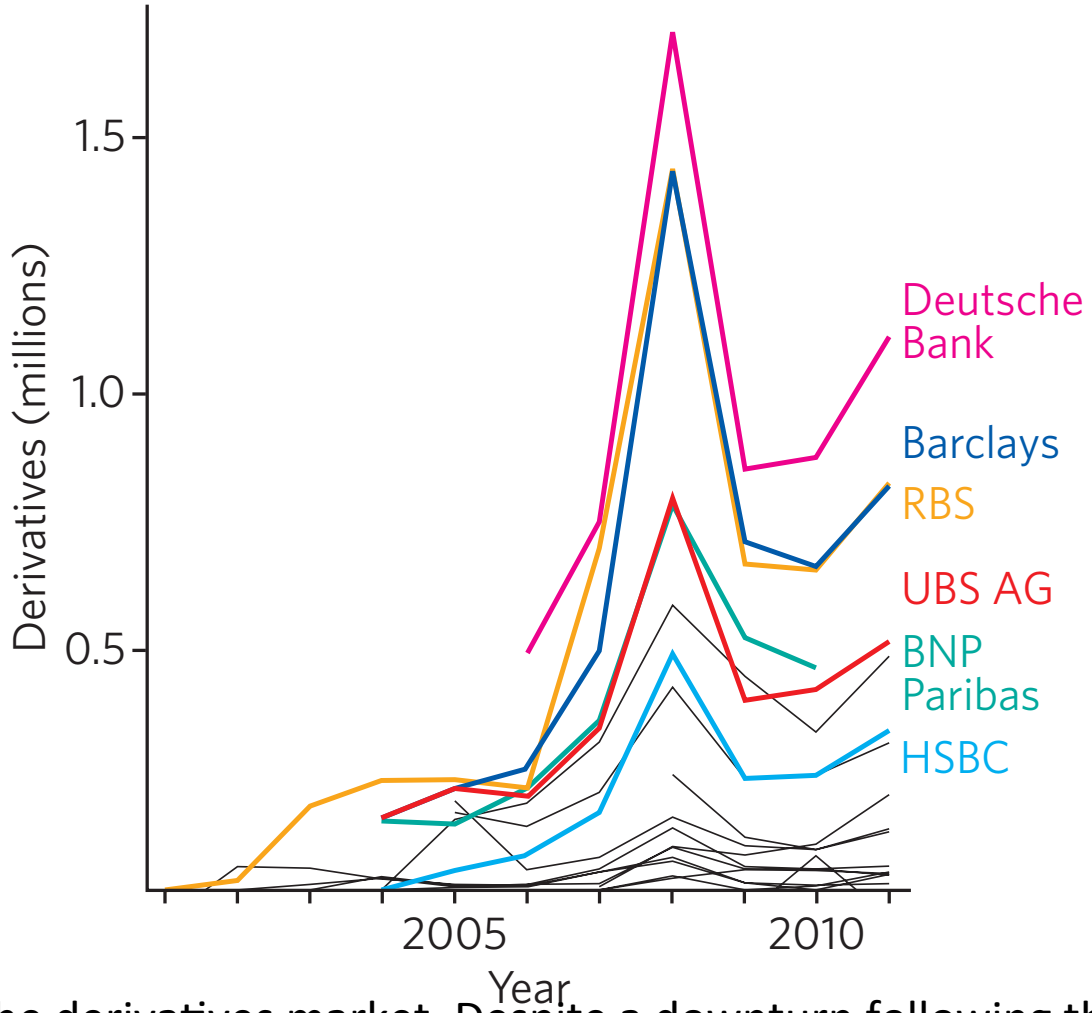
Sources: ESMA, DTCC.

- 1. A. Haldane, R.May ”Systemic risk in banking ecosystems” Nature

2. Banque de France • Financial Stability Review • No. 17 • April 2013

The Value of Derivative Contracts: Key players

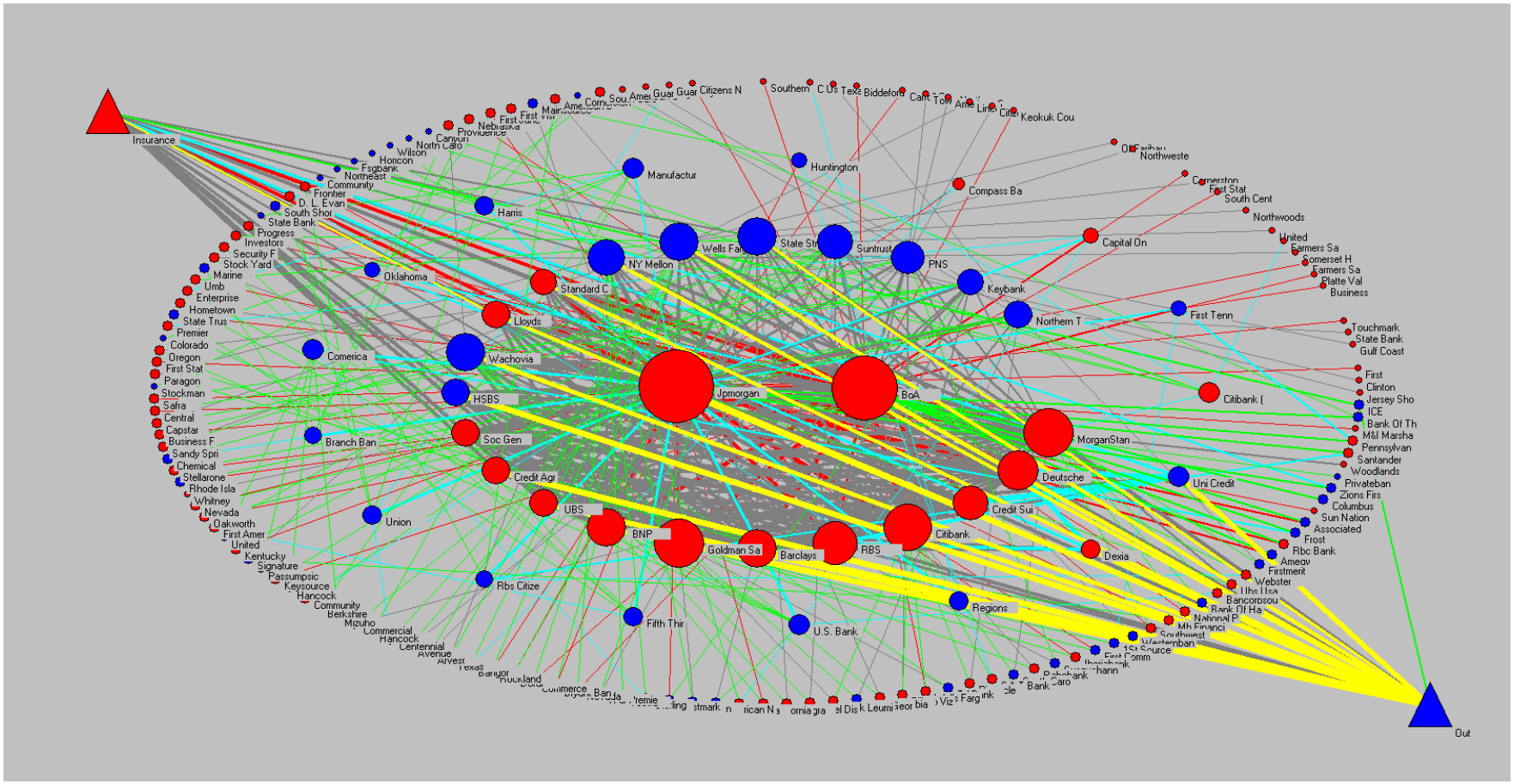
S. Battiston, et al. Complex derivatives , NATURE PHYSICS, 2013.3



The largest players in the derivatives market. Despite a downturn following the 2008 financial crisis, the volume of derivative contracts for 30 top market players continues to increase, with the 7 biggest labelled in colour. Data from Bankscope © 2013 Bureau van Dijk.

Global Derivatives Market

: JP and BoA central Tier; 22 other banks in Tier 2 all banks in the top tiers will fail if any other fails of this group



(Sheri Markose, 2012)

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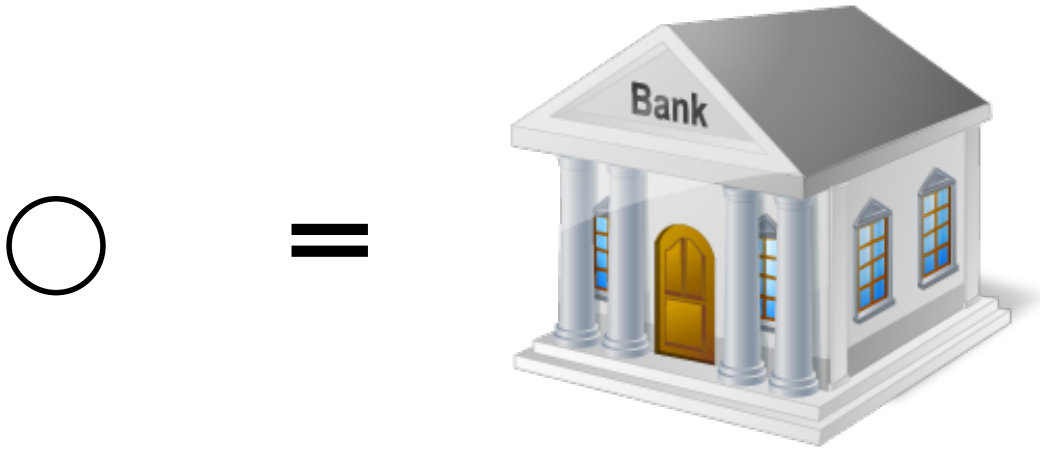
Modeling of Financial Network (1)

- Node: Bank



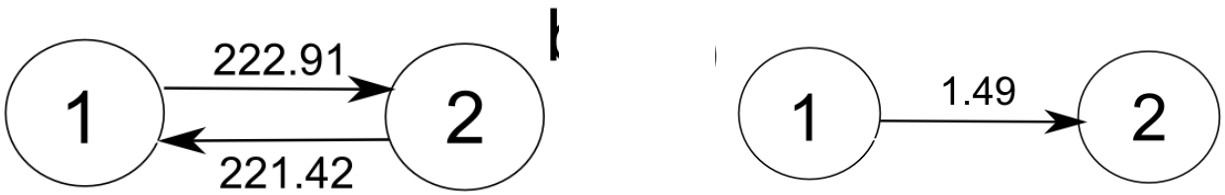
- Links: Interbank liabilities

Liability Relations among Banks

The matrix of bilateral exposures

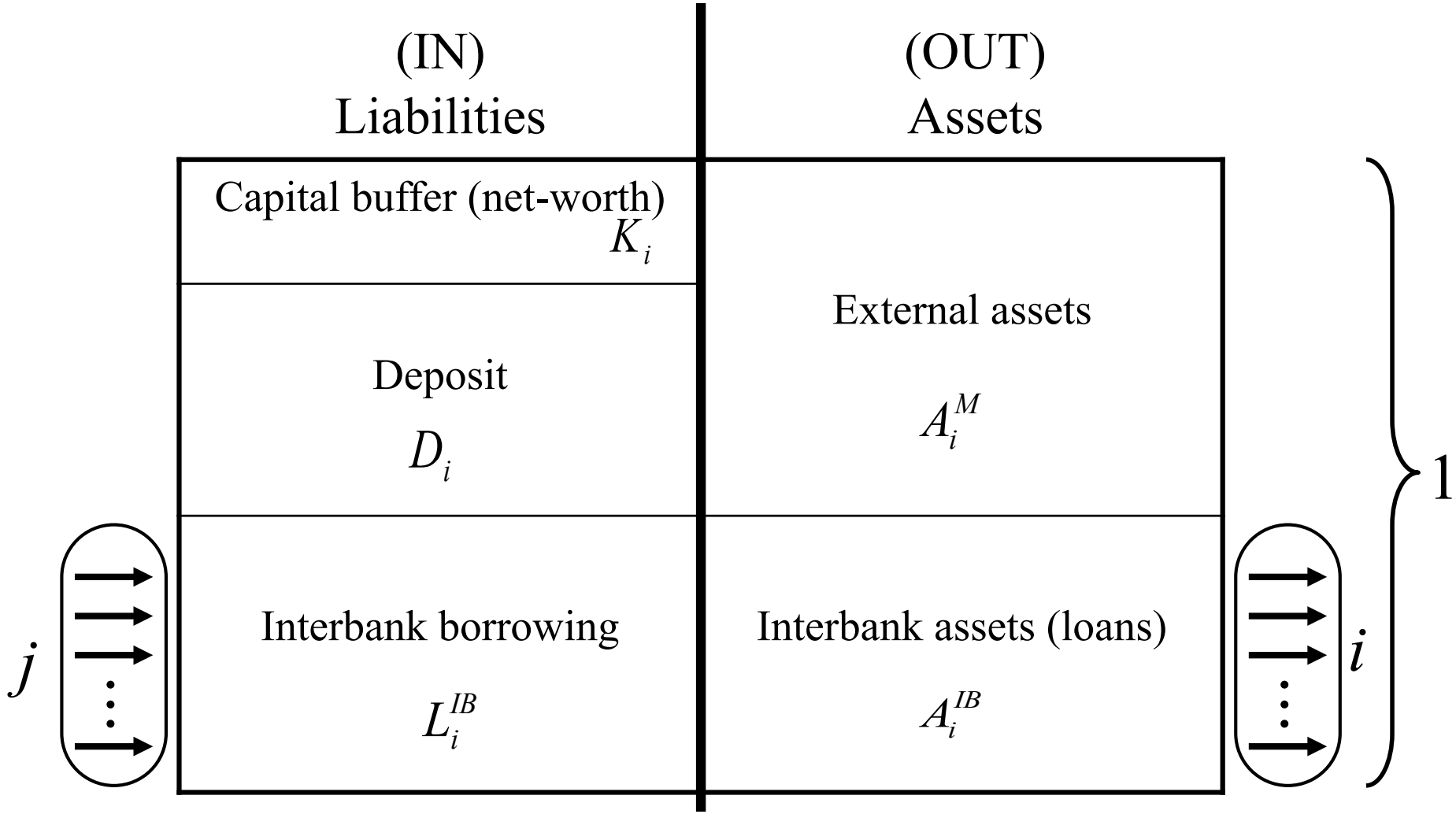
$$X = \begin{vmatrix} 0 & 222.91 & 138.37 & 129.28 & 109.64 & 105.29 & \dots \\ 221.42 & 0 & 124.15 & 116.34 & 104.96 & 100.80 & \dots \\ 126.66 & 122.08 & 0 & 70.80 & 60.04 & 57.66 & \dots \\ 118.78 & 114.48 & 71.07 & 0 & 56.31 & 54.07 & \dots \\ 105.10 & 101.29 & 62.88 & 58.74 & 0 & 47.84 & \dots \\ 95.87 & 92.40 & 57.36 & 53.58 & 45.44 & 0 & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \end{vmatrix}$$

Arrows indicate flow of debt settlement



Node 1 is the debtor, node 2 the creditor

Schematic model for a node with interbank network (Balance sheet)



q : resale price of the illiquid asset

K_i : net-worth (capital buffer)

$$K_i = A_i^M + A_i^{IB} - L_i^{IB} - D_i$$

Solvency Condition (1)

$$(1\text{-p})\,A_i^{IB} + qA_i^{M} - L_i^{IB} - D_i > 0$$

A_i^{IB} : Intterbank asset (loans)

L_i^{IB} : Interbank liabilities

D_i : Customer deposit

p: the fraction of banks with obligations to bank i have defaulted

q : the resale price of the illiquid asset.

Binary rule of each node i

$$\textit{Bank i suvives if}:\ (1\text{-p})\,A_i^{IB} + qA_i^{M} - L_i^{IB} - D_i > 0$$

$$\textit{Bank i defaults if}:\ (1\text{-p})\,A_i^{IB} + qA_i^{M} - L_i^{IB} - D_i < 0$$

Solvency Condition (2)

Default condition: (1-p) $A_i^{IB} + qA_i^M - L_i^{IB} - D_i < 0$

$$\frac{A_i^{IB} + qA_i^M - L_i^{IB} - D_i}{A_i^{IB}} < p$$

$$\frac{(A_i^{IB} + A_i^M - L_i^{IB} - D_i) - (1-q)A_i^M}{A_i^{IB}} < p$$

$$\frac{K_i - (1-q)A_i^M}{A_i^{IB}} < p \qquad (K_i = A_i^{IB} + A_i^M - L_i^{IB} - D_i \text{:capital buffer})$$

Threshold rule

$$p > \frac{K_i}{A_i^{IB}} \equiv \phi \qquad (\text{ if we set } q = 1) \text{ Bank i defaults}$$

p: the fraction of default

K_i: the capital buffer

A^{IB}: Interbank loan

Windows to Cascade Failure

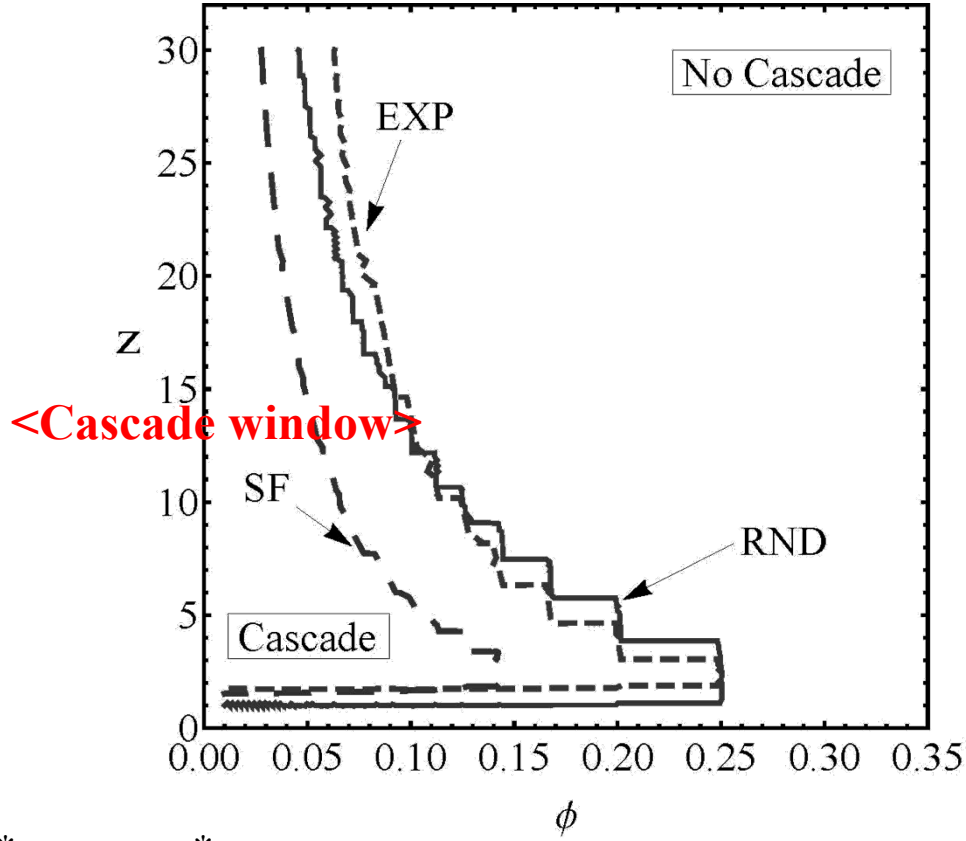
[Lopez, Watts, 2006]

$$\phi^* = \arg\min_{\phi\in[0,1]} \frac{1}{z}\sum_{k\geq 1}^{\lfloor 1/\phi \rfloor} k^2 P(k)$$

$$\text{s.t.} \quad \frac{1}{z}\sum_{k\geq 1}^{\lfloor 1/\varphi \rfloor} k^2 P(k) > 1$$

P(k): degree distribution
z: average degree,
ϕ:threshold,

Cascade can occur at some region of threshold and average degree



<Cascade window>

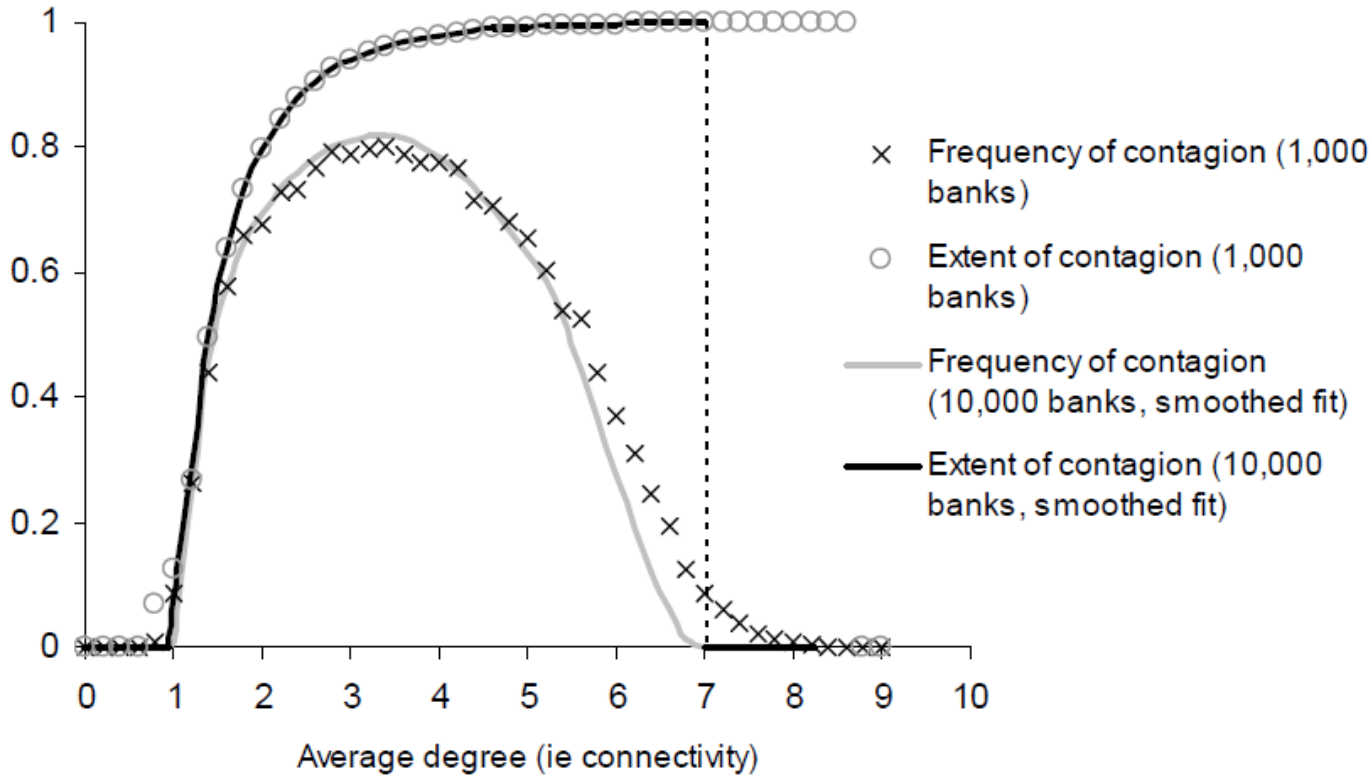
$$?? < \phi^*_{Homo} < \phi^*_{RND} < \phi^*_{SF(BA)} < ??$$

Least susceptible network

Most susceptible network

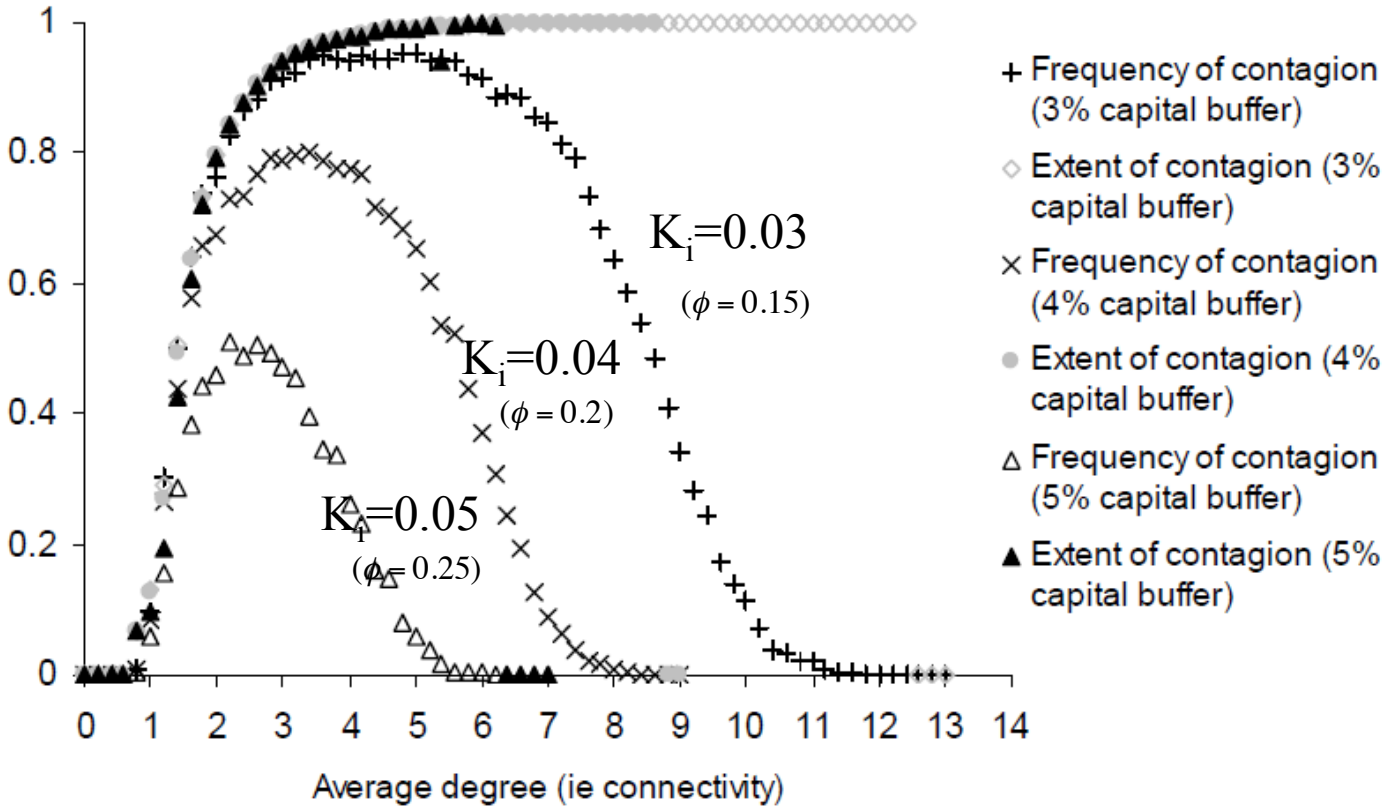
Simulation Results (1)
(Benchmark and analytical solutions compared)

Chart 4: Benchmark and analytical solutions compared



Simulation results (2)
:Effects of increasing K_i (the capital buffer)

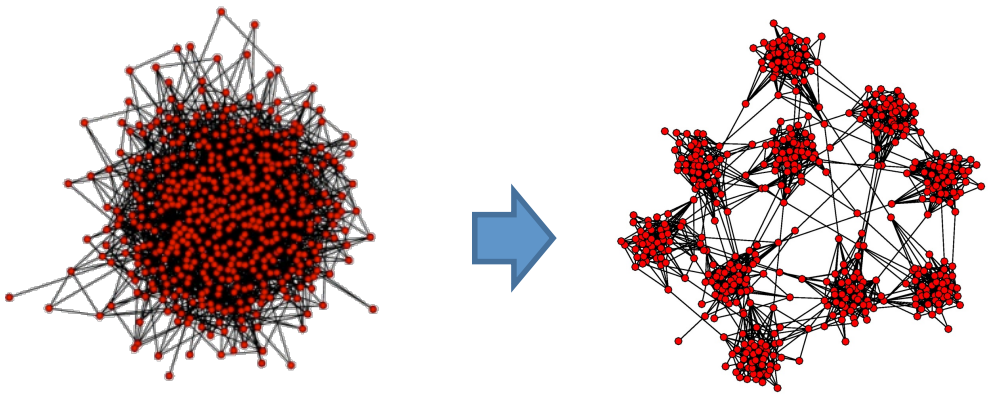
Chart 5: Varying the capital buffer



$$\phi \equiv \frac{K_i}{A_i^{IB}} = \frac{K_i}{0,2} \qquad A_i^{IB} = 0.2,\ \ A_i^{M} = 0.8,\ A_i^{IB} + A_i^{M} = 1$$

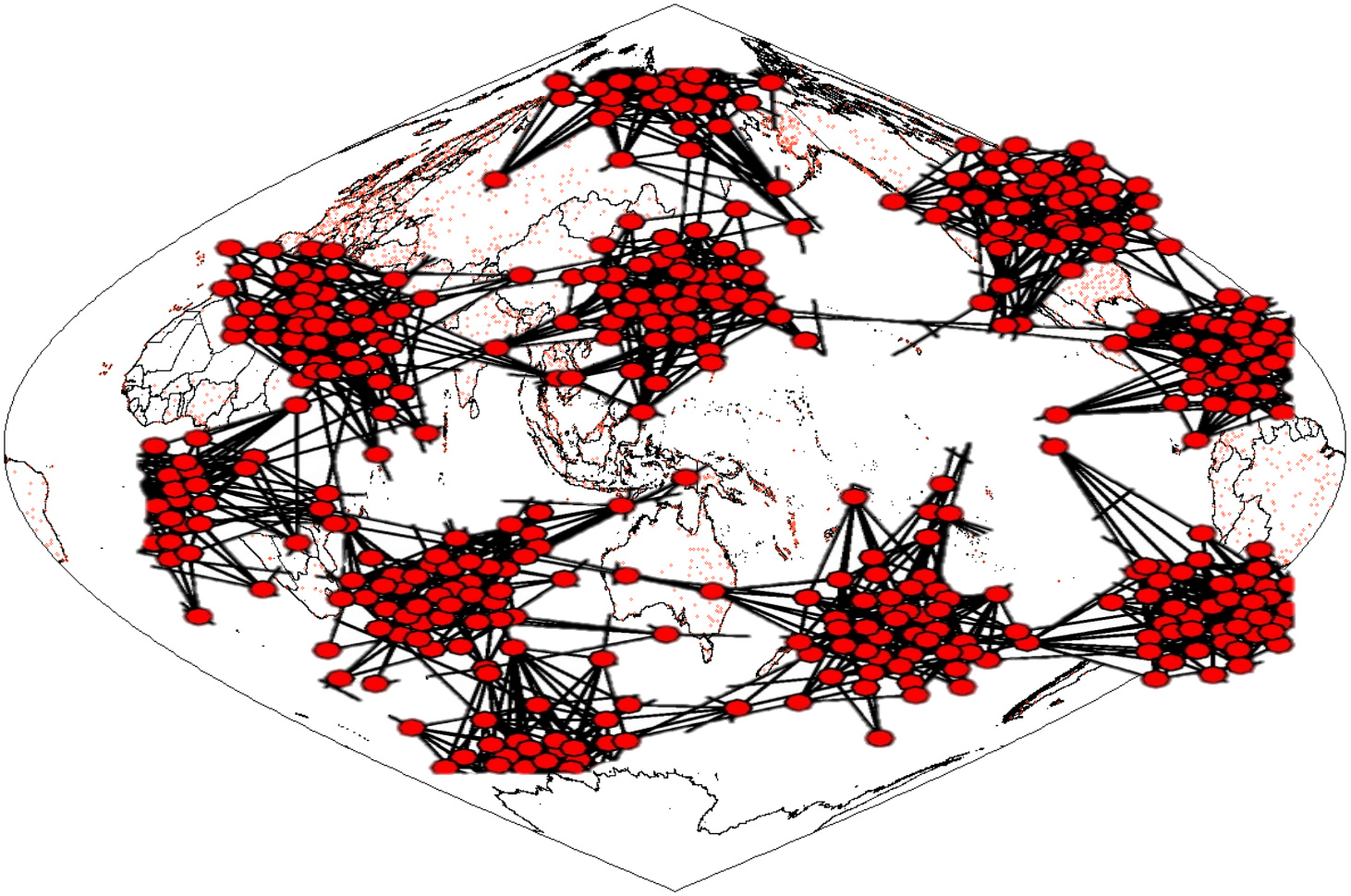
Systemic Risks on Modular Networks

- Contagion process was investigated using the percolation method, which basically assumes uncorrelated networks.
- Concentration and complexity may be key amplifiers of the fragility.
- Real financial networks are correlated and fragmented into modules.



Global Financial Networks

Global financial risks can be drastically reduced if we can reconstruct them properly



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Algorithms Take Control of Wall Street

Share of automatic trading: 70% of US stock markets, 50% of Europe and Japan, 70% of foreign exchange markets

Wired January 2011

Computers (algorithms or trading agents) help prospective buyers and sellers of stocks find one another. Trading agents tend to follow a fairly simple set of rules. High-frequency traders, flash traders, execute deals so quickly, and on such a massive scale, that they can win or lose a fortune if the price of a stock fluctuates by even a few cents. The result is a system that is more efficient, faster, and smarter than any human. However, it is also harder to understand, predict, and regulate. They respond instantly to shifting market conditions, taking into account thousands or millions of data points every second.

TED Global Conference

Kevin Slavin: How algorithms shape our world

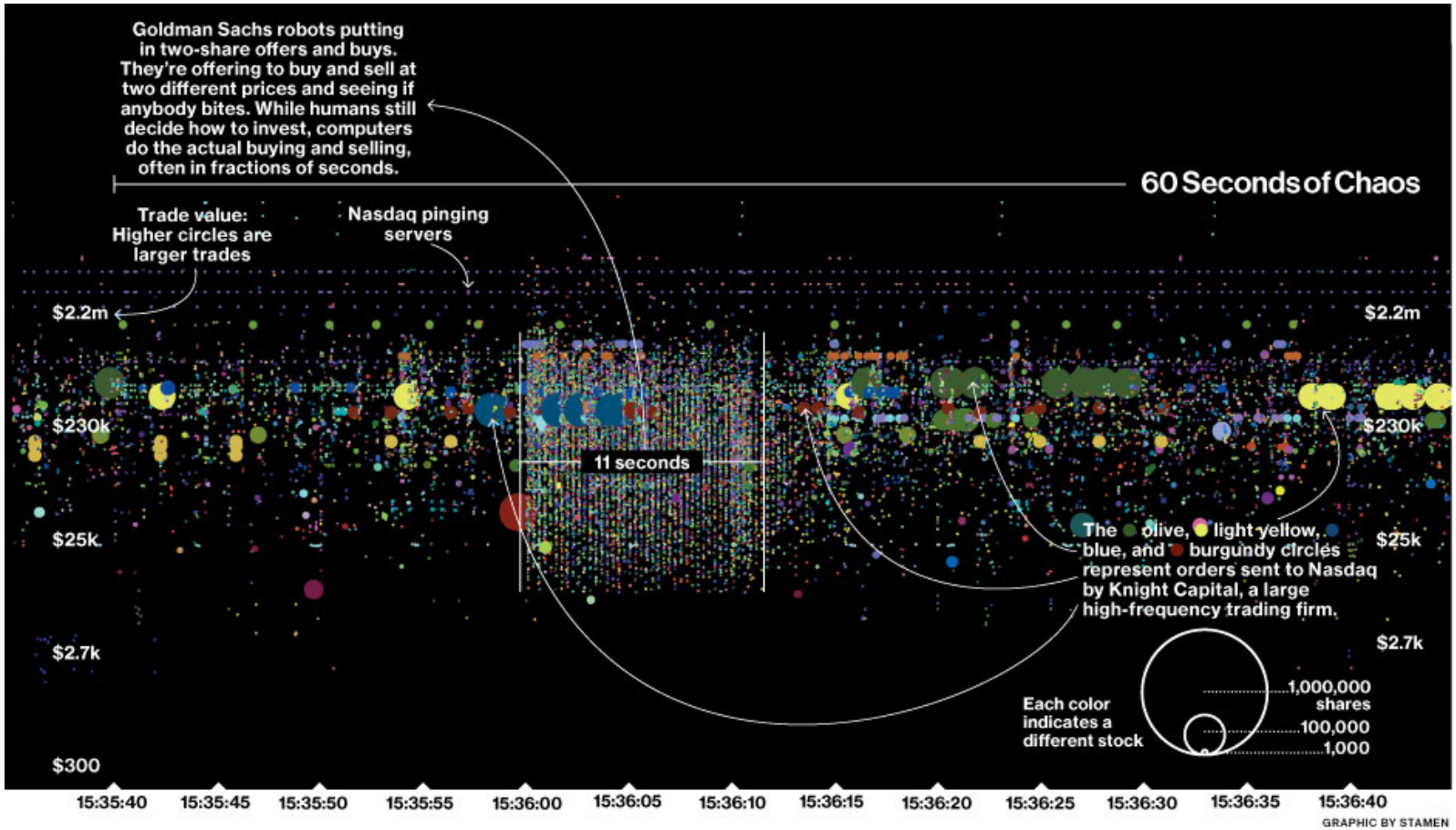
Kevin Slavin argues that we're living in a world designed for -- and increasingly **controlled** by **algorithms**.

September 15, 2012

Kevin Slavin is the co-founder of gaming company Area/Code.

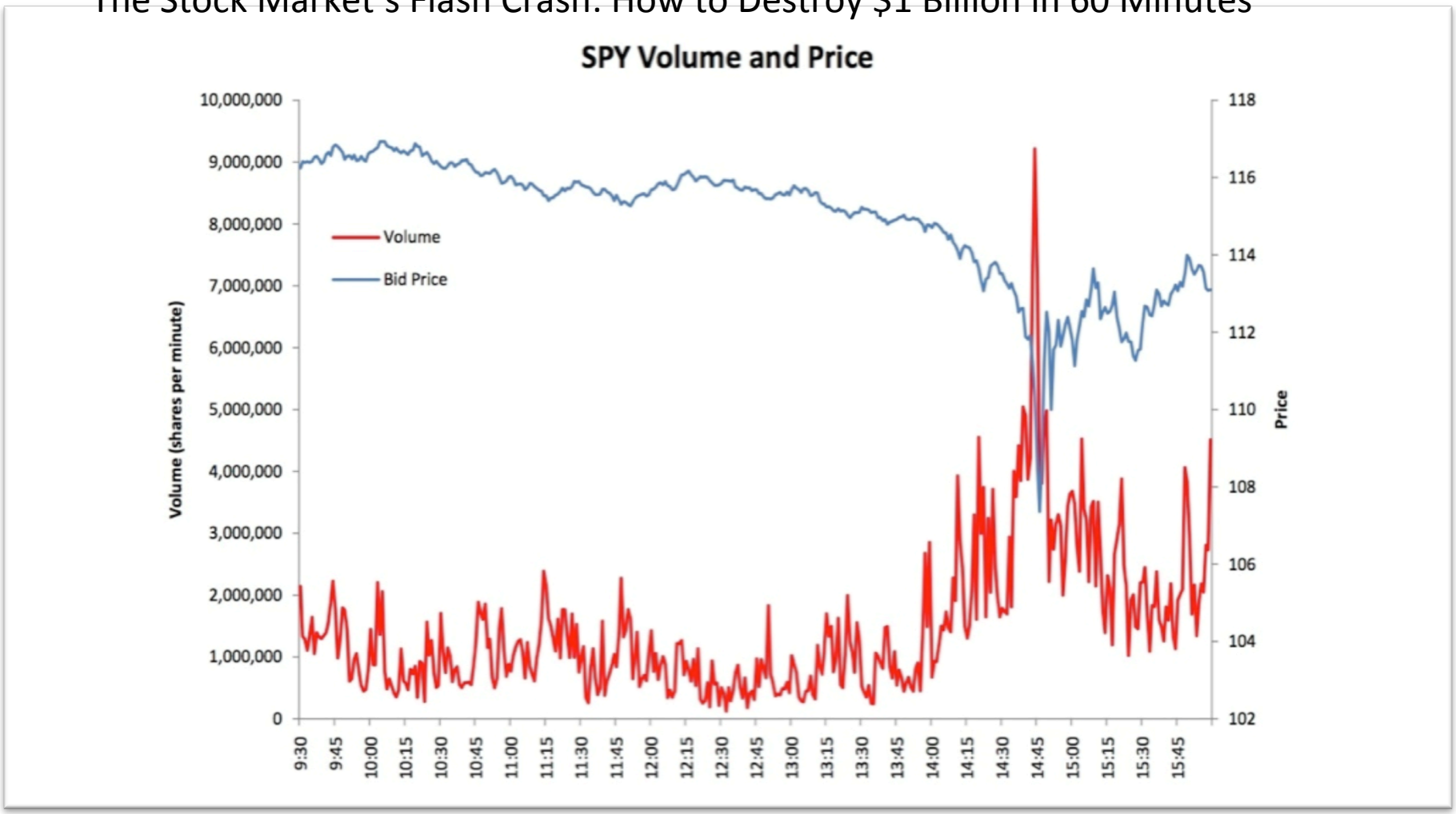
High Frequency Trading with Trading Agents

San Francisco design firm Stamen teamed up with Nasdaq to visualize the frenzy of automated trading. This is one minute of bids and offers on March 8, 2011.



Flash crash, May 6th 2010

The Stock Market's Flash Crash: How to Destroy $1 Billion in 60 Minutes



How a flash crash happens?

- When **a very large market sell order** is placed, it can execute against all of the limit buy orders, which makes the buy order curve disappear and the price plunge. This is what happened in the May 2010 flash crash.
- Even if a single order is not quite large enough to deplete all the buy orders, traders might *panic* if the price of a security is going down rapidly and add more sell orders, resulting in a flash crash.

Market Instability: Why Flash Crashes Happen Vedant Misra, Yaneer Bar-Yam NECSI Report #2011-08-02

Relaxed static stability

- The new domain in fact made possible **a new generation of military aircraft** designed to be *inherently unstable* (in technology jargon, to have "**relaxed static stability**"). This gave an advantage. Just as you can maneuver an unstable bicycle more easily than a stable tri-cycle, you can maneuver an inherently unstable aircraft more easily than a stable one.
- The new controls could act to stabilize the aircraft much as a cyclist stabilizes a bicycle by offsetting its instabilities with countering motions.
- **A human pilot** could not react quickly enough to do this; under the earlier manual technology, an inherently unstable aircraft would be unflyable.
- (Arthur 2009, 73)

F-35 Lightning II (Lockheed Martin)

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- Introduction
- Financial Network in Reality
- Simulation Study on Systemic Risk
- Innovation in Finance destabilize markets

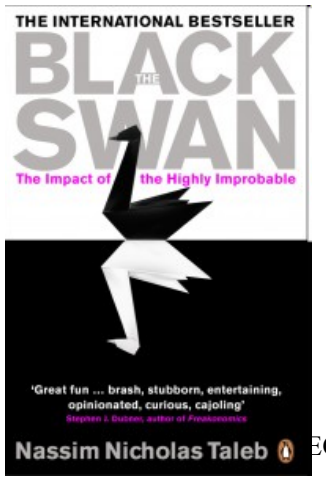
  : Automatic trading agents

  : High frequency trading
- Toward more resilient financial networks

“Unknown unknown”, “Black Swan Event”

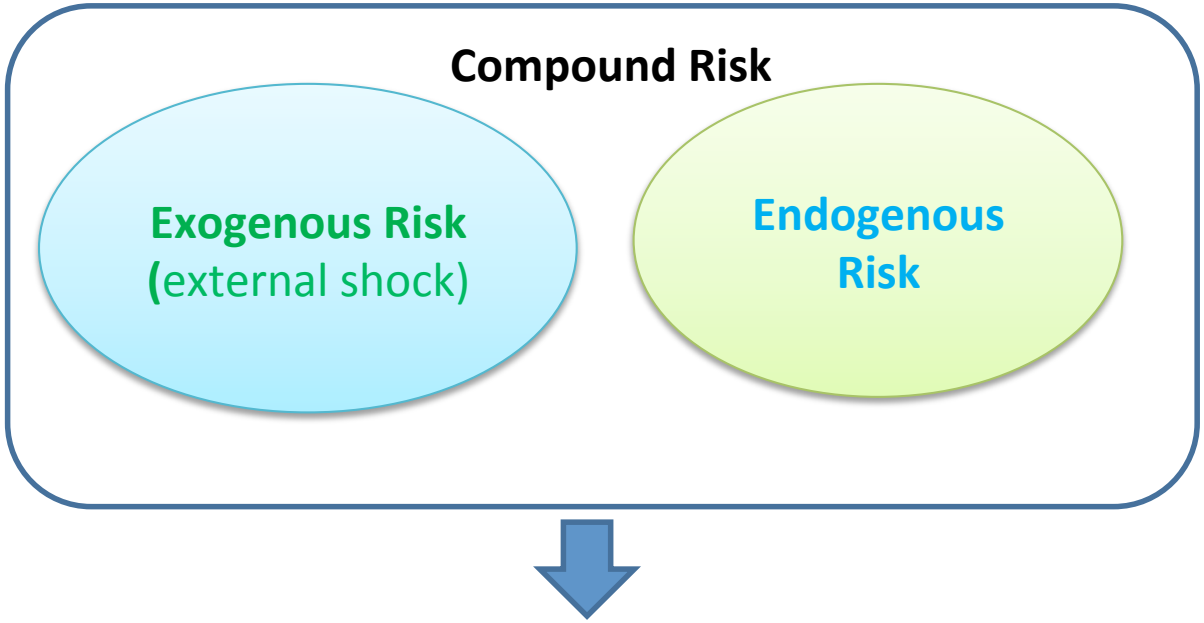
1. The event is a surprise (to the observer).
2. The event has a major impact.
3. After its first recording, the event is rationalized by hindsight, as if it could have been expected.

Black Swan (2007)
Developed by N. Nicholas Taleb



Compound Risks

- In most cases, failures due to a combination of both exogenous and endogenous risk



- We need to consider both exogenous and endogenous risks
- Endogenous risk is amplified by the interactions among agents

Classification of Extreme Events

J. Casti “Four faces of Tomorrow” (OECD, 2011)

	Data	No data
Model	Known Knows ・dynamical system theory ・ network analysis	Unknown Knows ・simulation
No Model	Known Unknown (Gray Swan) ・statistical techniques	Unknown Unknown (Black Swan) ・scenarios thinking

ASIAN ECONOMIC OBSERVATORY NETWORK

A Data-Driven Approach to Finance

CHEONG, Ann
(Nanyang Technological University, Singapore)

44GECSS Phuket(26.1.11-12)

Why Network of Observatories?

(b)

Each observatory sees a difficult cultural facet of Asian economy

Difficult & unethical to perform experiments

Each observatory sees a different facet of night sky

Impossible to perform experiments

Thank you for listening!!

Question Time