# Systemic Risk Measurement Challenges and Opportunities

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# Outline

Background

    Recent history

    Relevant concepts and literature

Data

    Interbank exposures' data

    Payment system's data

Network theory

    Topological and other measures

    Centrality measures

Results

Extended Network of exposures

# Quotes

- In recent years automatic trading has been increasing dramatically in different markets and financial markets are not the exception. What are the implications of such trading in financial markets? What is the effect of increasing intensive computing on the search for arbitrage opportunities? Is this sort of trading going to increase the volatility of the prices or to increase the likelihood of financial crashes?

- Financial markets are becoming an ever changing environment with automatic trading using powerful computer hardware and novel algorithms, better heuristics, and new statistical methods. Can we feel the presence of the Red Queen around? Are not financial markets the ultimate laboratory for competitive co-evolution?

# Systemic risk definitions

- Systemic risk is the risk of experiencing an event which threatens the well functioning of the system of interest (payments, financial, banking, etc.)

- "Systemic risk is defined as the risk of disruption to financial services that is caused by an impairment of all or parts of the financial system and has the potential to have negative consequences on the real economy" (IMF, 2010b)

- Systemic risk can be studied in two components Rochet (2009), Marquez & Martinez Jaramillo (2009):
  - An initial shock
  - A contagion process

# Measurement

- Measurement is essential in any scientific discipline
- Why is it important to measure systemic risk?
  - Because of social costs
  - To design proper regulation
- Why i s it difficult?
  - Low frequency high impact events.
  - There is still no consensus

# Systemic risk measurement

In July 2010, the U.S. Congress enacted the Dodd Frank Act. The Dodd Frank Act created the Financial Stability Oversight Council (FSOC). The FSOC has three broad mandates:

- to identify risks to financial stability arising from events or activities of large financial firms or elsewhere;

- to promote market discipline by eliminating participants expectations of possible government bailouts; and

- to respond to emerging threats to the stability of the financial system.

# Systemic risk Methodologies

In Bisias et al 2012, the authors identify 31 measures of systemic risk which can be classified under the following broad cathegories:

- Macroeconomic measures
- Granular foundations and network measures
- Forward looking risk measures
- Stress tests
- Cross-sectional measures
- Measures of illiquidity and insolvency

# Macroeconomic measures

- Asset prices bubbles
- Property prices, equity prices, credit-gap indicators
- Macroprudential regulation

# Granular foundations and network measures

- The default intensity model
- Network Analysis and financial linkages
- Simulating a credit scenario
- Simulating a credit and funding shock scenario
- Granger causality networks
- Bank funding risk
- Mark-to-market accounting and liquidity pricing

# Forward Looking risk measurement

- Contigent claims analysis

- Mahalanobis distance

- The option iPOD

- Multivariate density estimators

- Simulating the housing sector

- Consumer credit

# Stress tests

- "The banking systems reported financial indicators are above minimum regulatory requirements and stress tests suggest that the system is resilient" (IMF, Iceland: Financial Stability Assessment update, 19 August 2008, p 5)
- GDP stress tests
- SCAP
- Iceland/European stress tests

# Cross sectional measures

- CoVaR
- Distressed insurance premium
- Co-Risk
- Marginal and systemic expected shortfall

# Measures of illiquiduty and Insolvency

- Risk topography

- The leverage cycle

- Noise as information for illiquidity

- Crowded trades in currency funds

- Equity market illiquidity

- Serial correlation and Illiquidity in Hedge funds returns

- Broader hedge fund systemic risk measures

# Interconnectedness

- The GHOS, the oversight body of the BCBS, agreed on a consultative document setting out measures for G-SIBs.

- Measures include:
  - methodology for assessing systemic importance
  - additional required capital
  - arrangements by which they will be phased in

- Objectives:
  - strengthen the resilience of G-SIBs
  - create incentives to reduce systemic importance

# Interconnectedness

- Assessment methodology based on an indicator-based approach:
    - size
    - *interconnectedness*
    - *lack of substitutability*
    - global (cross-jurisdictional) activity
    - complexity
- Additional loss absorbency requirements are to be met with a progressive CET1 ranging from 1% to 2.5%.
- An additional 1% surcharge would be applied.

# Network models and payment systems.

- Studies describing payment systems around the world:
  - Soramki et al. (2006)
  - Bech & Atalay (2008)
  - Becher et al. (2008)
  - Rordam & Bech (2008)
  - Propper et al. (2008)
  - Wetherilt et al. (2010)

# Network models and financial contagion.

- Direct contagion through the interbank market widely studied by central banks in several countries, Upper(2007).
  - maximum entropy assumption
  - individual idiosyncratic failures

- Contagion has been studied by simulating networks in Nier et al. (2007) and Gai & Kapadia (2010). They use randomly generated networks.
  - random models use scale free properties which interbank exposures networks exhibit

# Network models and systemic risk.

- More recently contagion and systemic risk have been studied:
  - Muller (2006)
  - Nier et al (2006)
  - Babus (2007)
  - Mistrulli (2007)
  - Markose et al (2009)
- Others include contagion within a wider simulation framework:
  - Boss et al. (2006)
  - Aikman et al. (2009)
  - Alessandri et al. (2009)
  - Marquez-Diez-Canedo et al. (2009)
  - Martinez-Jaramillo et al. (2010b & 2010b)
  - Gauthier et al. (2010a & 2010b)

# Other Related Works.

- Empirical analysis of the Italian interbank market, Iori et al. (2008)
- Simulation to model interbank lending and study contagion, Iori et al. (2006)
- Coupled stochastic processes, Battiston et al. (2012)
- Cascade processes on networks, Lorenz et al. (2009)

# Interbank's data

- daily data from January 2004 onwards
- a time window contemplating data from the 3rd of January 2005 to 31st December 2010
- comprises deposits and loans, securities, and foreign exchange

Three type of networks:

- Interbank
- Interbank - CLS
- Interbank - FX

# SPEI's data

- daily data from January 2004 onwards
- a time window contemplating data from the 3rd of January 2005 to 31st December 2010

Three types of networks:

- Low value
- Large value
- Total value

Network built accumulating the daily payments between each pair of banks in both directions.

# Topological measures

- Topological measures
  - Degree
  - Clustering coefficient
  - Reciprocity
  - Affinity
  - Completeness Index
- Other measures
  - Strength
  - Flow
  - Herfindahl-Hirschman Index (HHI)
  - Preference Index

# Centrality measures

- Concept commonly used in social networks
- Several important interpretations
  - power
  - influence
  - independence
  - control
- Characteristics of a relevant financial institution (Henggeler-Muller (2006)):
  - possesses many linkages to other members (degree)
  - Amount of assets, liabilities or flow is very large (strength)
  - its failure could transmit contagion rapidly (closeness)
  - its counterparties are also relevant (eec & pagerank)
  - there are many paths which passes through it (betweenness)

# Centrality measures

- Strength centrality
  - The sum of its interbank assets and liabilities.
- Degree centrality
  - A vertex is more important if it is connected to many other vertices.
- Betweenness centrality
  - A vertex with high betweenness centrality can stop or distort the information that passes through it.
- Closeness centrality
  - A node with high centrality would depend less on others.

# Centrality measures

- Entropic Eigenvector Centrality (Bonacich (1972))
  - Based on Perron's eigenvector ($e^{PF}$)
  - Considers the relevance of its neighbors.
- PageRank centrality (Page et al. (1999))
  - Based on the Google's algorithm
  - Considers the centrality of its neighbors.
- A principal components unified measure of centrality
  - different measures equally important
  - preserve most informatino provided by such measures
  - from the policy making perspective, it is important to have only one measure of importance enabling to rank vertices

# Scale-free Networks

|  | Interbank | | Interbank - CLS | | Interbank - FX | |
|---|---|---|---|---|---|---|
| p-value | $< .05$ | $< .1$ | $< .05$ | $< .1$ | $< .05$ | $< .1$ |
| Degree | 77% | 60% | 81% | 65% | 54% | 41% |
| In Degree | 81% | 66% | 83% | 67% | 84% | 76% |
| Out Degree | 80% | 60% | 80% | 64% | 56% | 45% |
| Exposures | 57% | 50% | 63% | 54% | 83% | 76% |

Table : Percentage of days in which the exposures network exhibited power law distributions.

# SPEI Network
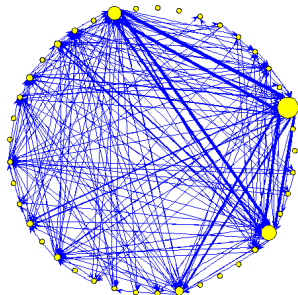


Figure : January the 3rd 2005
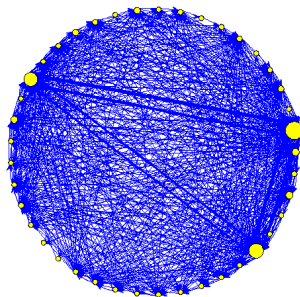


Figure : July the 27th 2010

# Interbank exposures network
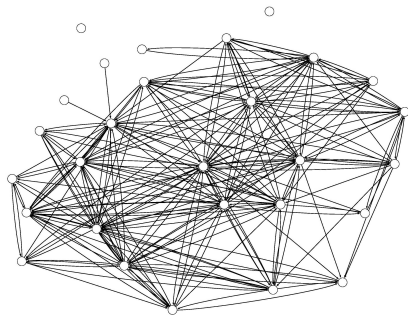


Figure : January the 3rd 2005
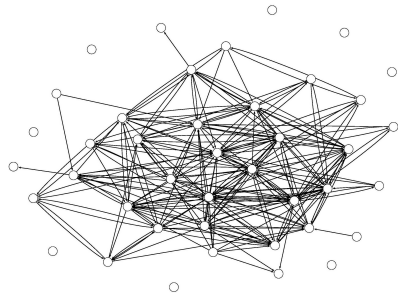
Figure : December the 31st 2010

# SPEI



Number of arcs

Average degree

# SPEI
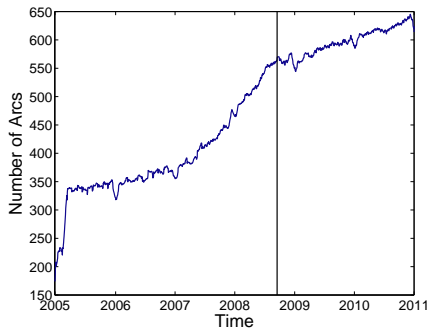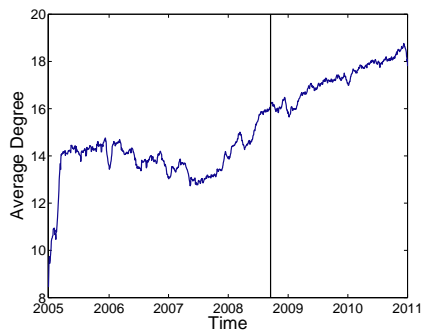
## Completeness index
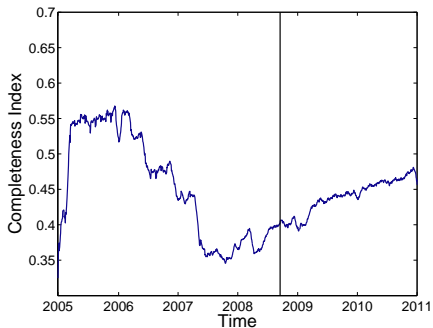


| | Large Value | Low Value | Total |
|---|---|---|---|
| Core Size | 30.8 | 33.0 | 34.2 |
| Completeness Index | 0.3 | 0.4 | 0.4 |
| Average Degree | 10.1 | 13.3 | 15.2 |
| Reciprocity | 0.4 | 0.4 | 0.4 |
| Average Distance | 1.7 | 1.6 | 1.5 |
| Total Arcs | 290.2 | 405.9 | 470.9 |
| Average Strength* | 24.0 | 1.24 | 25.2 |
| Total Volume* | 415.8 | 22.41 | 438.7 |

# SPEI



Affinity vs. degree
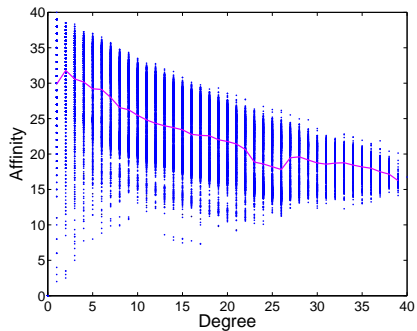
Reciprocity
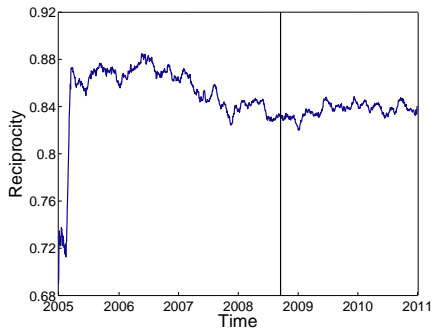
# SPEI



Borrowing HHI for bank 12
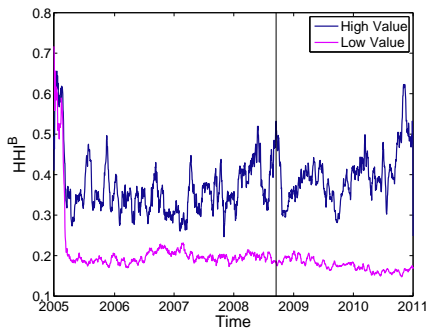
Lending HHI for bank 3

# Interbank

# Interbank

# Interbank



Figure : Lending HHI bank B
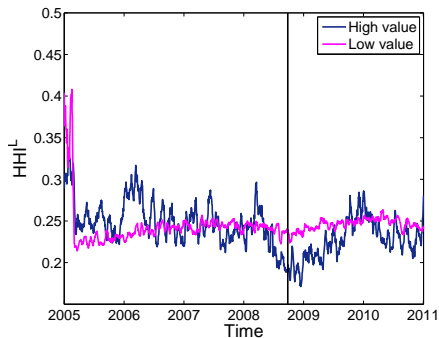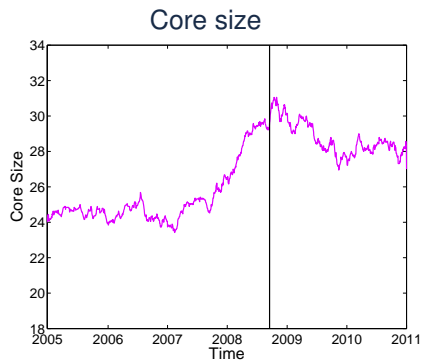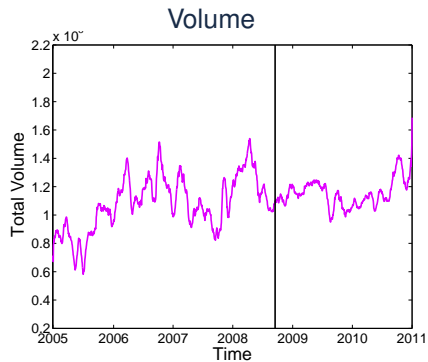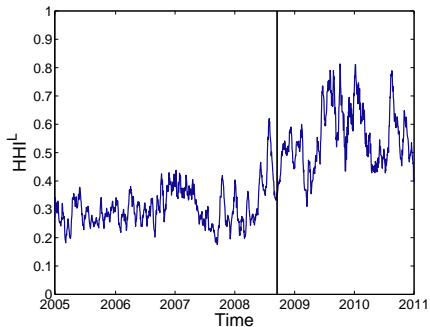
| Mean | Interbank | Interbank - CLS |
|---|---|---|
| Core Size | 26.7 | 26.7 |
| Completeness Index | 0.3 | 0.3 |
| Average Degree | 9.0 | 8.7 |
| Reciprocity | 0.4 | 0.4 |
| Average Distance | 1.7 | 1.8 |
| Total Arcs | 279.7 | 262.2 |
| Average Strength* | 7.1 | 6.4 |
| Total Volume* | 125.5 | 110.8 |

# Interbank's centrality
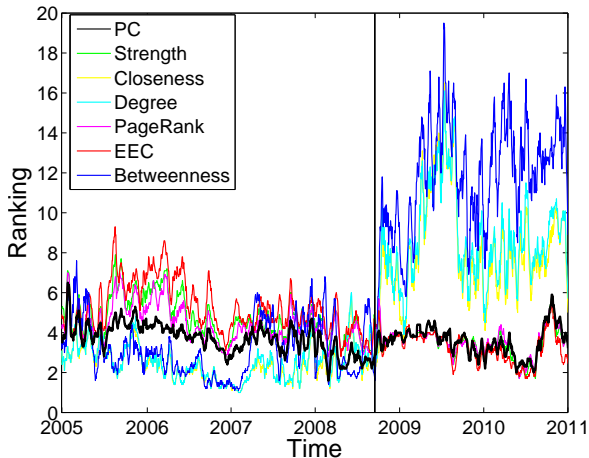


Figure : Principal components centrality

# Pairwise correlations
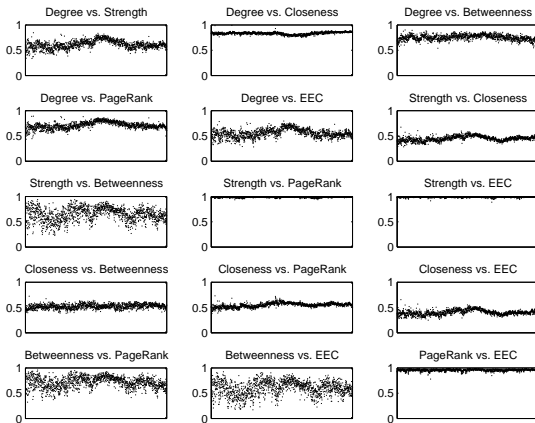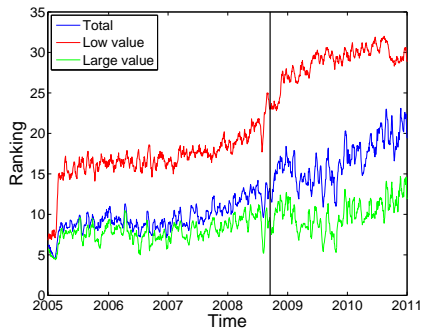
# SPEI's centrality



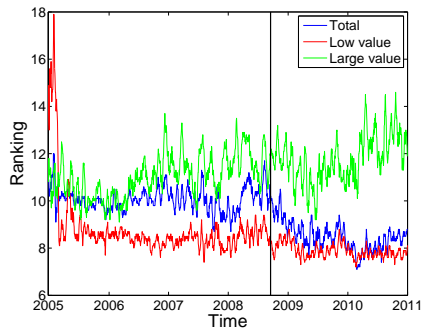Figure : Low vs large centrality bank C



Figure : Low vs large centrality bank D
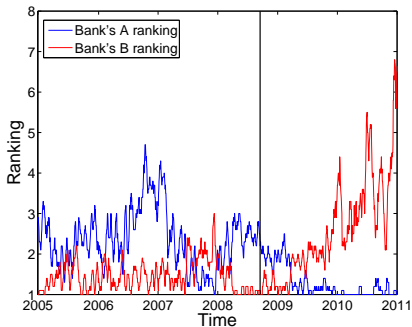
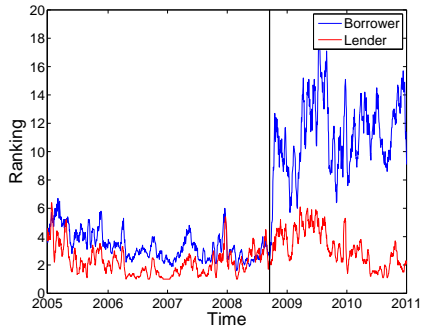# Interbank's centrality
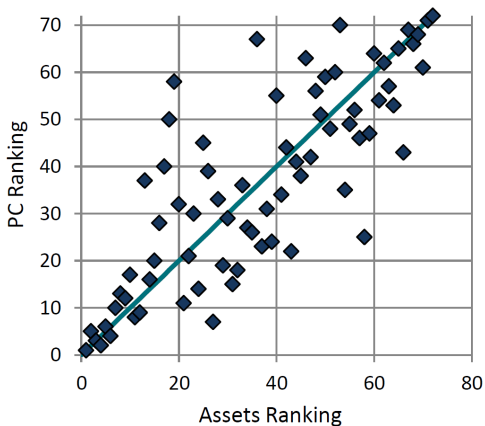


Figure : Changes in ranking for banks A & B



Figure : Changes in behavior bank C

# PC centrality ranking vs. Asset size ranking

# Congruence: Low value vs. Large value network

| Number of banks | Top 1 | Top 3 | Top 10 | Average Overlaping |
|---|---|---|---|---|
| 27 | 0.53 | 0.97 | 0.97 | 0.70 |
| 28 | 0.60 | 1.00 | 1.00 | 0.69 |
| 29 | 0.48 | 1.00 | 1.00 | 0.68 |
| 30 | 0.58 | 1.00 | 1.00 | 0.64 |
| 31 | 0.57 | 1.00 | 1.00 | 0.58 |
| 32 | 0.52 | 1.00 | 1.00 | 0.61 |
| 33 | 0.33 | 1.00 | 1.00 | 0.67 |
| 35 | 0.62 | 1.00 | 1.00 | 0.63 |
| 36 | 0.62 | 1.00 | 1.00 | 0.68 |
| 37 | 0.60 | 0.98 | 0.98 | 0.62 |
| 38 | 0.26 | 1.00 | 1.00 | 0.64 |
| 39 | 0.43 | 0.94 | 0.94 | 0.62 |
| 40 | 0.51 | 1.00 | 1.00 | 0.60 |
| 41 | 0.52 | 0.98 | 0.98 | 0.58 |

# Congruence: Exposures vs. payments network

| Number of banks | Top 1 | Top 3 | Top 10 | Average Overlaping |
|---|---|---|---|---|
| 27 | 0.16 | 1.00 | 1.00 | 0.73 |
| 28 | 0.12 | 0.98 | 0.98 | 0.76 |
| 29 | 0.12 | 1.00 | 1.00 | 0.74 |
| 30 | 0.36 | 1.00 | 1.00 | 0.70 |
| 31 | 0.27 | 0.97 | 0.97 | 0.60 |
| 32 | 0.23 | 0.98 | 0.98 | 0.64 |
| 33 | - | 1.00 | 1.00 | 0.77 |
| 35 | - | 1.00 | 1.00 | 0.71 |
| 36 | 0.15 | 1.00 | 1.00 | 0.71 |
| 37 | 0.12 | 0.97 | 0.97 | 0.69 |
| 38 | 0.05 | 1.00 | 1.00 | 0.72 |
| 39 | 0.15 | 0.92 | 0.92 | 0.64 |
| 40 | 0.27 | 0.98 | 0.98 | 0.68 |
| 41 | 0.03 | 0.98 | 0.98 | 0.65 |

# Average correlations[1] on rankings

|           | Exposures vs. Payments | Low vs. Large |
|-----------|:----------------------:|:-------------:|
| Maximum   | 0.77                   | 0.65          |
| Minimum   | -0.29                  | -0.38         |
| Average   | 0.25                   | 0.06          |

[1]Correlations were computed for the largest time-window when the number of banks was constant at 40.
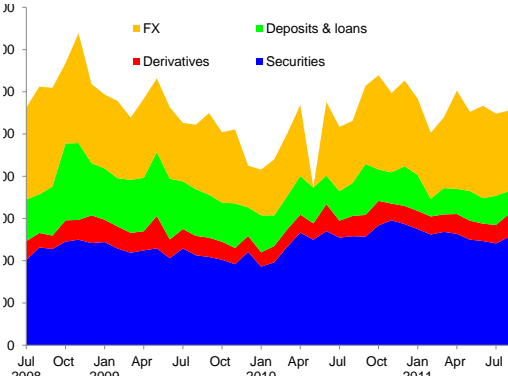
# Extended network

Figure: dependency between the Mexican financial system and its foreign counterparts
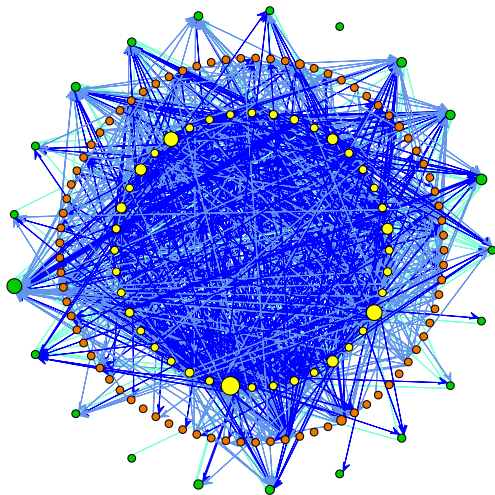
# Exposures



Figure : Exposures by type of exposure
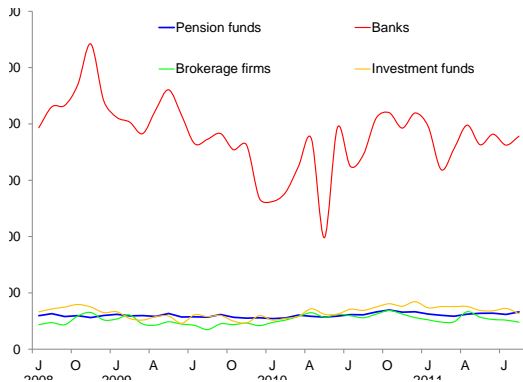
# Exposures II



Figure : Exposures by type of intermediarie
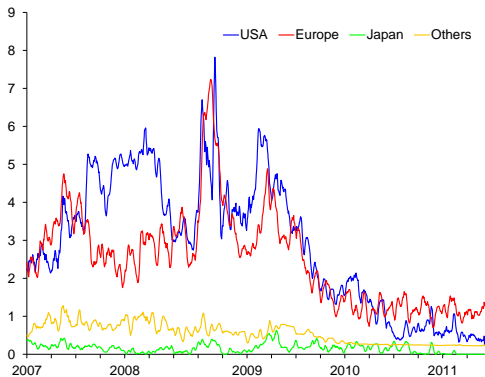
# Exposures III



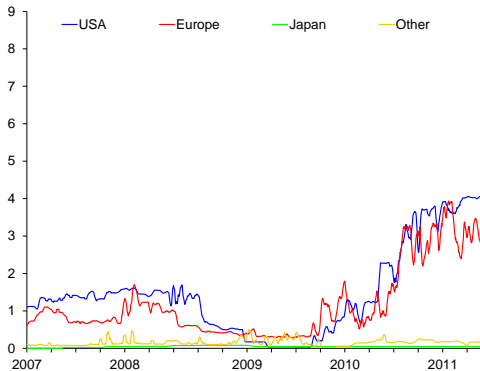Figure : Exposures by region of the counterpart

# Loans



Figure : Loans by region of the counterpart
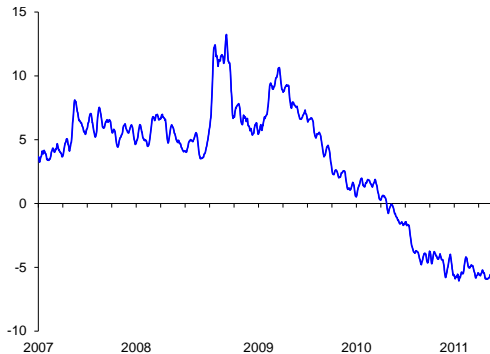
# Net exposures



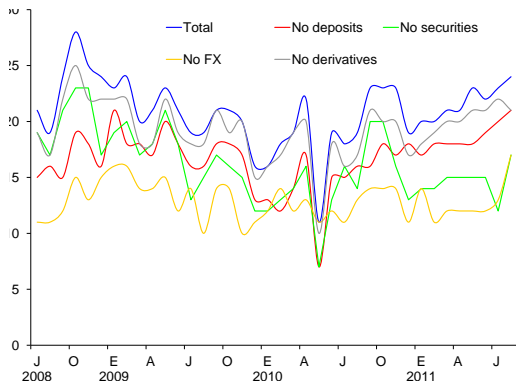Figure : Net Exposures

# Over-Exposure for Banks



Figure : Number of banks which are overexposed
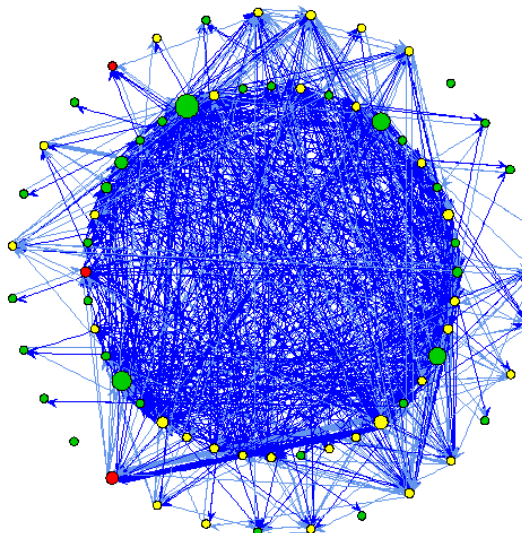
# Over-Exposure for Brokerage houses



Figure : Number of brokerage houses which are overexposed

# Over-exposure and contagion I



Figure : Original Network.

# Over-exposure and contagion II



Figure : Network after the initial shock.
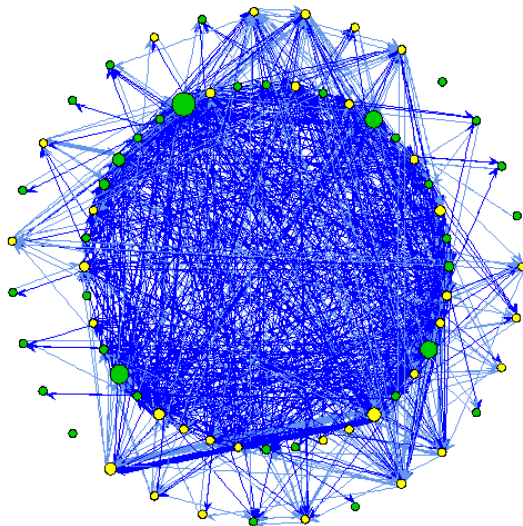
# Over-exposure and contagion III
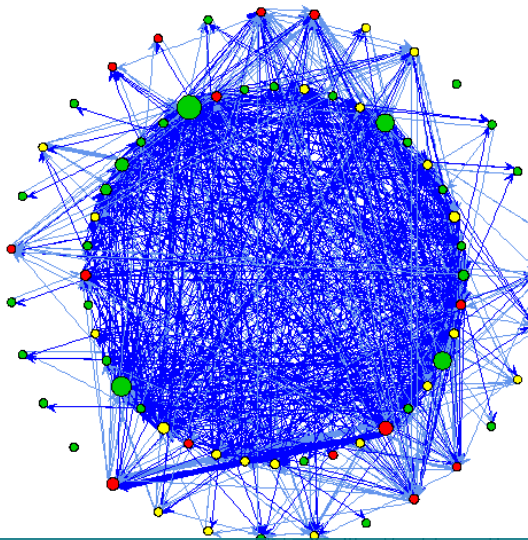


Figure : Network after contagion.

# Over-exposure and contagion IV



Figure : Over-exposure
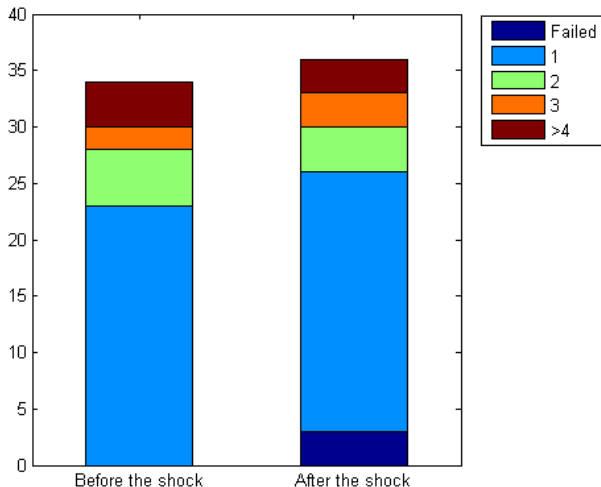
# Stress testing conceptual framework



$$\boxed{\text{Scenario generator}} \Rightarrow \begin{pmatrix} esc_1 \\ esc_2 \\ \vdots \\ esc_n \end{pmatrix} \Rightarrow \boxed{\text{RiskWatch}} \Rightarrow \begin{pmatrix} \ell^0_{1,esc_k} \\ \ell^0_{2,esc_k} \\ \vdots \\ \ell^0_{r,esc_k} \end{pmatrix} \Rightarrow$$



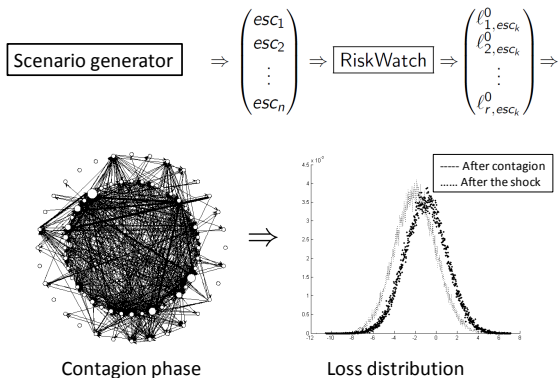Contagion phase

Loss distribution

Figure : Banco de Mexico stress testing framework.

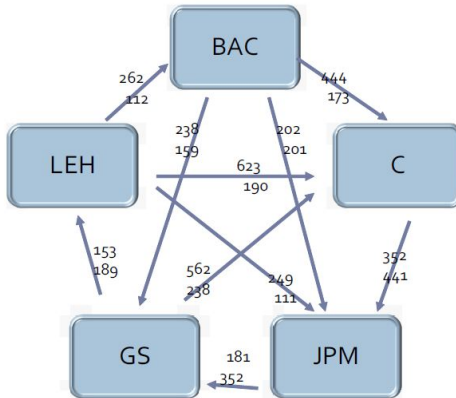# What to do when there is no supervisory data



Figure : Adrian and Brunnermeier CoVaR network.

# Summary

- The payments system network is more connected than the interbank exposures network.
- Importance in the payments network is different than in the exposures network.
- The unified centrality measure can be employed on the methodology proposed by the BCBS to determine G-SIBs.
- Bank's importance changes depending on the type of payment and depending if they are acting as lenders of borrowers.
- Bank's behavior can change over time.
- Determining systemic importance based only on asset's size could be misleading.
- Most centrality measures are robust.
- Topology of the network is not enough to characterize systemic importance.

# Future work:

- Network formation models
- Studying other financial networks, like the securities settlement network
- Bank's behavior in distress
- Bank's funding strategies
- Link to economic variables

# Thanks

**Thank you!**