Economic Networks

Theory and Empirics

Giorgio Fagiolo
Laboratory of Economics and Management (LEM)
Sant'Anna School of Advanced Studies, Pisa, Italy

http://www.lem.sssup.it/fagiolo/
giorgio.fagiolo@sssup.it

This Lecture

- What is a network? Examples of networks
- Why networks are important for economists?
- Networks and graphs
- Measures and metrics on networks
- Distributions of metrics and measures in large networks
- Models of network formation
- Null statistical network models
- Economic applications

Economic Applications

- Modeling the ITN: a gravity approach
- Product-space networks
- Diffusion of shocks in the ITN
- Financial Networks
    - Contagion
    - The IFN and country performance during the crisis
    - The network of corporate control
    - Financial markets and correlation-based networks

References (a partial list...)

- Duenas, M. and Fagiolo, G. (2011), "Modeling the International-Trade Network: A Gravity Approach", arXiv:1112.2867 [q-fin.GN]
- Fagiolo, G. (2010), "The International-Trade Network: Gravity Equations and Topological Properties", Journal of Economic Interaction and Coordination, 5:1-25.
- César A. Hidalgo and Ricardo Hausmann (2009), "The building blocks of economic complexity", PNAS 106 (26) 10570-10575
- C.A. Hidalgo, et al. (2007), "The Product Space Conditions the Development of Nations", Science 317, 482
- Tacchella et al. (2012), "A New Metrics for Countries' Fitness and Products' Complexity", Nature Scientific Reports, 2, 723.
- Lee et al. (2011), "Impact of the topology of global macroeconomic network on the spreading of economic crises", PLoS ONE 6(3): e18443.
- Chinazzi, M., Fagiolo, G., Reyes, J. and Schiavo, S. (2012), "Post-Mortem Examination of the International Financial Network", SSRN eLibrary

Modeling the International-Trade Network

A Gravity Approach

Marco Dueñas[1] Giorgio Fagiolo[1]
giorgio.fagiolo@sssup.it
http://www.lem.sssup.it/fagiolo/Welcome.html

[1]LEM, Sant'Anna School of Advanced Studies, Pisa (Italy)

Motivations

- **The International-Trade Network (ITN): Empirics vs. Models**
  - Empirical analyses: exploring statistical properties of the ITN and their evolution over time
  - Statistical analyses: discriminating between statistically-significant and noise-driven topological properties
  - Stochastic Models: beginning to build more structural models to investigate why the ITN is shaped as we observe it

- **But what about standard international-trade models?**
  - Is the gravity model (GM) able to replicate observed topological structure of the ITN?
  - We fit data on trade flows with a GM-specification using alternative fitting techniques
  - We employ GM estimates to build a weighted predicted ITN, whose topological properties are compared to observed ones

Motivations

- **The International-Trade Network (ITN): Empirics vs. Models**
  - Empirical analyses: exploring statistical properties of the ITN and their evolution over time
  - Statistical analyses: discriminating between statistically-significant and noise-driven topological properties
  - Stochastic Models: beginning to build more structural models to investigate why the ITN is shaped as we observe it
- **But what about standard international-trade models?**
  - Is the gravity model (GM) able to replicate observed topological structure of the ITN?
  - We fit data on trade flows with a GM-specification using alternative fitting techniques
  - We employ GM estimates to build a weighted predicted ITN, whose topological properties are compared to observed ones

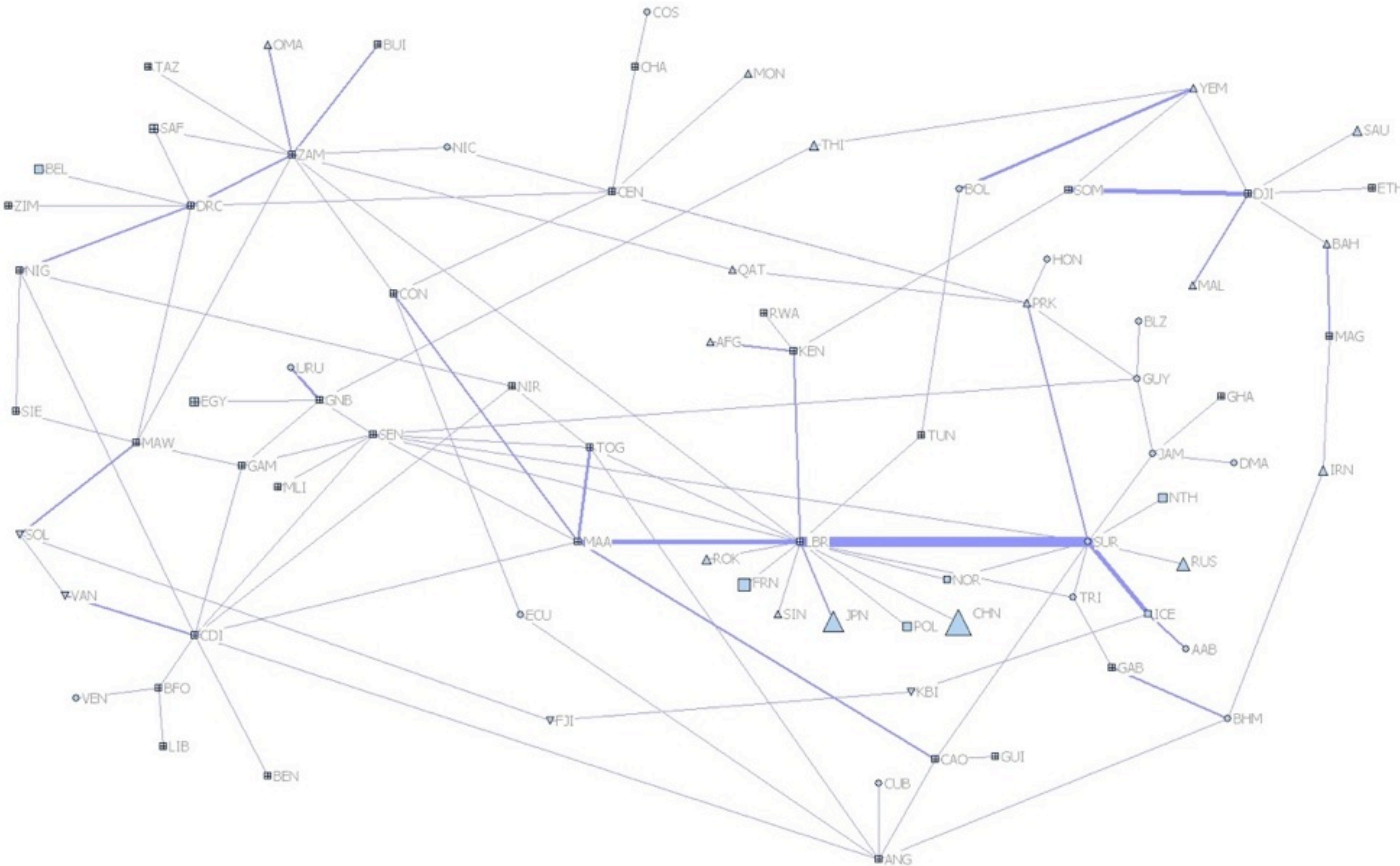
This (and Previous) Paper(s)

- **The Gravity Model and the ITN (Fagiolo, 2010, JEIC)**
  - Fits a GM to year 2000 data and asks whether the network built using the residuals from the GM estimation is not random
  - Shows that the residual network is more complex than the original one and displays a completely different network architecture
- **This Paper**
  - Back to a more fundamental question: can a (micro-founded) equilibrium explanation of trade flows like the GM recover most of ITN network topology?
  - Is the GM a good "null" economic model for the ITN architecture?
- **Results: A Sneak-in Preview**
  - The GM successfully replicates the weighted-network structure of the ITN, only if one fixes its binary architecture
  - The GM performs very badly when asked to predict the presence of a link, or the level of the trade flow, whenever the binary structure must be simultaneously estimated

Explaining WTW properties (IV)

- Fagiolo (2010): What is left in the residuals?
  - Residual network is more complex than original one
  - Some correlation structure is preserved, most is not
  - Residual WTW is organized around many relatively small-sized but trade-oriented countries that, independently of their geographical position, either play the role of local hubs or attract large and rich countries in complex trade-interaction patterns

Explaining WTW properties (IV)



This (and Previous) Paper(s)

- **The Gravity Model and the ITN (Fagiolo, 2010, JEIC)**
  - Fits a GM to year 2000 data and asks whether the network built using the residuals from the GM estimation is not random
  - Shows that the residual network is more complex than the original one and displays a completely different network architecture
- **This Paper**
  - Back to a more fundamental question: can a (micro-founded) equilibrium explanation of trade flows like the GM recover most of ITN network topology?
  - Is the GM a good "null" economic model for the ITN architecture?
- **Results: A Sneak-in Preview**
  - The GM successfully replicates the weighted-network structure of the ITN, only if one fixes its binary architecture
  - The GM performs very badly when asked to predict the presence of a link, or the level of the trade flow, whenever the binary structure must be simultaneously estimated

This (and Previous) Paper(s)

- **The Gravity Model and the ITN (Fagiolo, 2010, JEIC)**
  - Fits a GM to year 2000 data and asks whether the network built using the residuals from the GM estimation is not random
  - Shows that the residual network is more complex than the original one and displays a completely different network architecture

- **This Paper**
  - Back to a more fundamental question: can a (micro-founded) equilibrium explanation of trade flows like the GM recover most of ITN network topology?
  - Is the GM a good “null” economic model for the ITN architecture?

- **Results: A Sneak-in Preview**
  - The GM successfully replicates the weighted-network structure of the ITN, only if one fixes its binary architecture
  - The GM performs very badly when asked to predict the presence of a link, or the level of the trade flow, whenever the binary structure must be simultaneously estimated

The GM: Theory and Empirics

- **The Microfounded GM**
  - The GM aims at explaining international-trade bilateral flows using an equation obtained as the equilibrium prediction of a large (and quite heterogenous) family of micro-founded models of trade
  - The predicted relation between trade flows and explanatory variables is similar to Newton's formula: the magnitude of aggregated trade flows between a pair of countries is proportional to the product of country sizes and inversely proportional to their geographic distance
- **The Empirical GM**
  - The basic prediction of a microfounded GM can be extended to account for a number of additional explanatory factors
  - Country-specific: population, area, land-locking effects, etc.
  - Bilateral: geographical contiguity, common language and religion, colony relation, bilateral trade agreements, etc.

The GM: Theory and Empirics

- **The Microfounded GM**
  - The GM aims at explaining international-trade bilateral flows using an equation obtained as the equilibrium prediction of a large (and quite heterogenous) family of micro-founded models of trade
  - The predicted relation between trade flows and explanatory variables is similar to Newton's formula: the magnitude of aggregated trade flows between a pair of countries is proportional to the product of country sizes and inversely proportional to their geographic distance

- **The Empirical GM**
  - The basic prediction of a microfounded GM can be extended to account for a number of additional explanatory factors
  - Country-specific: population, area, land-locking effects, etc.
  - Bilateral: geographical contiguity, common language and religion, colony relation, bilateral trade agreements, etc.

Data

- **Bilateral-Trade Data**
  - We use international-trade data taken from Subramanian & Wei (2003)
  - We employ aggregate bilateral imports reported by the IMF Direction of Trade Statistics, measured in U.S. dollars and deflated by U.S. Consumer Price Index at 1982-83 prices
  - We focus on seven unbalanced cross-sections for the years 1970 to 2000, with a five-year lag
  - Let $w_{ij}(t)$ be exports from country i to country j in year t and let $N(t)$ the correspondent number of countries reporting at least a positive flow
- **Observed ITN**
  - The observed weighted ITN in year t is represented by a weighted-directed graph, where the nodes are the $N(t)$ countries and link weights are fully characterized by the $N(t) \times N(t)$ asymmetric matrix $W(t)$, with entries $w_{ij}(t)$
  - The observed binary ITN in year t is represented by a binary-directed graph, where the nodes are the $N(t)$ countries and binary links are fully characterized by the $N(t) \times N(t)$ asymmetric adjacency matrix $A(t)$, with entries $a_{ij}(t) = 1$ if and only if $w_{ij}(t) > 0$, i.e. exports from country i to country j are strictly positive

Data

- **Bilateral-Trade Data**
  - We use international-trade data taken from Subramanian & Wei (2003)
  - We employ aggregate bilateral imports reported by the IMF Direction of Trade Statistics, measured in U.S. dollars and deflated by U.S. Consumer Price Index at 1982-83 prices
  - We focus on seven unbalanced cross-sections for the years 1970 to 2000, with a five-year lag
  - Let $w_{ij}(t)$ be exports from country i to country j in year t and let $N(t)$ the correspondent number of countries reporting at least a positive flow
- **Observed ITN**
  - The observed weighted ITN in year t is represented by a weighted-directed graph, where the nodes are the $N(t)$ countries and link weights are fully characterized by the $N(t) \times N(t)$ asymmetric matrix $W(t)$, with entries $w_{ij}(t)$
  - The observed binary ITN in year t is represented by a binary-directed graph, where the nodes are the $N(t)$ countries and binary links are fully characterized by the $N(t) \times N(t)$ asymmetric adjacency matrix $A(t)$, with entries $a_{ij}(t) = 1$ if and only if $w_{ij}(t) > 0$, i.e. exports from country i to country j are strictly positive

Our Preferred GM Specification

$$w_{ij}(t) = \alpha_0 Y_i(t)^{\alpha_1} Y_j(t)^{\alpha_2} d_{ij}^{\alpha_3} \left[\prod_{k=1}^{K} X_{ik}(t)^{\beta_{1k}} X_{jk}(t)^{\beta_{2k}} \right] \times$$

$$\times \exp\left(\sum_{h=1}^{H} \theta_h D_{ijh}(t) + \sum_{l=1}^{L} (\delta_{1l} Z_{il} + \delta_{2l} Z_{jl}) \right) \eta_{ij}(t),$$

- t is the year ($t = 1950, 1955, \ldots, 2000$)
- $w_{ij}(t)$ are export flows from the observed weighted ITN
- $i, j = 1, ..., N(t)$, $i \neq j$; $Y_h(t)$ is year-t GDP of country $h = i, j$ (i=exporter; j=importer)
- d_{ij} is geographical distance;
- $X_h(t)$, $h = i, j$, are additional country-size effects (area and population);
- D_{ij} is a vector of bilateral-relationship variables (contiguity, common language, past and current colonial ties, common religion, common currency, a dummy to control if both countries share a generalized system of preferences, and a regional trade agreement flag);
- Z_i and Z_j are country-specific dummies (controlling for land-locking effects and continent membership);
- $\eta_{ij}(t)$ are the errors (whose mean conditional to explanatory variables obeys $E[\eta_{ij}(t)|\cdot] = 1$).

Issues in GM Estimation

- **Treatment of zero flows and other issues**
  - The GM assumes that all countries trade: log-linearization using OLS or non-linear estimation techniques (PPML, ZIP/ZINB, etc.)
  - Multilateral resistance in Anderson & Van Wincoop (2003) model with importer/exporter dummies
  - Cross-section vs. panel estimation
- **Estimation Strategy**
  - Begin with a series of standard cross-section fits using (log-linearized) OLS, PPML and ZIP
  - Check results against other issues: Our results surprisingly robust to alternatives
- **Re-Writing the GM Specification**

$$w_{ij} = \exp\{x_{ij} \cdot \gamma^M\}\eta_{ij},$$

where x_{ij} are logged country-specific and bilateral explanatory variables, γ^M is the vector of parameters and $\hat{\gamma}^M$ are parameter estimates using model $M \in \{OLS, PPML, ZIP\}$.

Issues in GM Estimation

- **Treatment of zero flows and other issues**
  - The GM assumes that all countries trade: log-linearization using OLS or non-linear estimation techniques (PPML, ZIP/ZINB, etc.)
  - Multilateral resistance in Anderson & Van Wincoop (2003) model with importer/exporter dummies
  - Cross-section vs. panel estimation
- **Estimation Strategy**
  - Begin with a series of standard cross-section fits using (log-linearized) OLS, PPML and ZIP
  - Check results against other issues: Our results surprisingly robust to alternatives
- **Re-Writing the GM Specification**

$$w_{ij} = \exp\{x_{ij} \cdot \gamma^M\}\eta_{ij},$$

where x_{ij} are logged country-specific and bilateral explanatory variables, γ^M is the vector of parameters and $\hat{\gamma}^M$ are parameter estimates using model $M \in \{OLS, PPML, ZIP\}$.

Issues in GM Estimation

- **Treatment of zero flows and other issues**
  - The GM assumes that all countries trade: log-linearization using OLS or non-linear estimation techniques (PPML, ZIP/ZINB, etc.)
  - Multilateral resistance in Anderson & Van Wincoop (2003) model with importer/exporter dummies
  - Cross-section vs. panel estimation
- **Estimation Strategy**
  - Begin with a series of standard cross-section fits using (log-linearized) OLS, PPML and ZIP
  - Check results against other issues: Our results surprisingly robust to alternatives
- **Re-Writing the GM Specification**

$$w_{ij} = \exp\{x_{ij} \cdot \gamma^M\}\eta_{ij},$$

where x_{ij} are logged country-specific and bilateral explanatory variables, γ^M is the vector of parameters and $\hat{\gamma}^M$ are parameter estimates using model $M \in \{OLS, PPML, ZIP\}$.

Fitting the GM to the Data

1. **OLS on log-linearized flows**
   - Assumes to keep fixed binary structure (i.e. predicted and observed binary ITN are the same)
   - Linear prediction: $\hat{\omega}_{ij}^{OLS} = \log[\hat{w}_{ij}^{OLS}] = x_{ij} \cdot \hat{\gamma}^{OLS}$
   - Prediction variance: $\hat{\sigma}^2_{OLS}$, i.e. the variance of the model
2. **PPML**
   - Fitting a Poisson model to the data (both zeroes and positive flows)
   - Predicted flows (in levels): $\hat{w}_{ij}^{PPML} = \exp\{x_{ij} \cdot \hat{\gamma}^{PPML}\}$
   - Prediction variance: equal to predicted values (equi-dispersion)
3. **ZIP**
   - Fitting a two-stage model: Zero flows (Logit) vs. all flows (Poisson)
   - Predicted flows (in levels): $\hat{w}_{ij}^{ZIP} = (1 - \hat{\psi}_{ij}) \exp\{x_{ij} \cdot \hat{\gamma}^{ZIP}\} = (1 - \hat{\psi}_{ij})\hat{\mu}_{ij}$
   - Prediction variance: $Var(\hat{w}_{ij}^{ZIP}|x_{ij}) = \hat{\psi}_{ij}(1 - \hat{\psi}_{ij})[1 + \hat{\psi}_{ij} \cdot \hat{\mu}_{ij}]$

Fitting the GM to the Data

1. **OLS on log-linearized flows**
   - Assumes to keep fixed binary structure (i.e. predicted and observed binary ITN are the same)
   - Linear prediction: $\hat{\omega}_{ij}^{OLS} = \log[\hat{w}_{ij}^{OLS}] = x_{ij} \cdot \hat{\gamma}^{OLS}$
   - Prediction variance: $\hat{\sigma}^2_{OLS}$, i.e. the variance of the model
2. **PPML**
   - Fitting a Poisson model to the data (both zeroes and positive flows)
   - Predicted flows (in levels): $\hat{w}_{ij}^{PPML} = \exp\{x_{ij} \cdot \hat{\gamma}^{PPML}\}$
   - Prediction variance: equal to predicted values (equi-dispersion)
3. **ZIP**
   - Fitting a two-stage model: Zero flows (Logit) vs. all flows (Poisson)
   - Predicted flows (in levels): $\hat{w}_{ij}^{ZIP} = (1 - \hat{\psi}_{ij}) \exp\{x_{ij} \cdot \hat{\gamma}^{ZIP}\} = (1 - \hat{\psi}_{ij})\hat{\mu}_{ij}$
   - Prediction variance: $Var(\hat{w}_{ij}^{ZIP}|x_{ij}) = \hat{\psi}_{ij}(1 - \hat{\psi}_{ij})[1 + \hat{\psi}_{ij} \cdot \hat{\mu}_{ij}]$

Fitting the GM to the Data

1. **OLS on log-linearized flows**
   - Assumes to keep fixed binary structure (i.e. predicted and observed binary ITN are the same)
   - Linear prediction: $\hat{\omega}_{ij}^{OLS} = \log[\hat{w}_{ij}^{OLS}] = x_{ij} \cdot \hat{\gamma}^{OLS}$
   - Prediction variance: $\hat{\sigma}^2_{OLS}$, i.e. the variance of the model
2. **PPML**
   - Fitting a Poisson model to the data (both zeroes and positive flows)
   - Predicted flows (in levels): $\hat{w}_{ij}^{PPML} = \exp\{x_{ij} \cdot \hat{\gamma}^{PPML}\}$
   - Prediction variance: equal to predicted values (equi-dispersion)
3. **ZIP**
   - Fitting a two-stage model: Zero flows (Logit) vs. all flows (Poisson)
   - Predicted flows (in levels): $\hat{w}_{ij}^{ZIP} = (1 - \hat{\psi}_{ij}) \exp\{x_{ij} \cdot \hat{\gamma}^{ZIP}\} = (1 - \hat{\psi}_{ij})\hat{\mu}_{ij}$
   - Prediction variance: $Var(\hat{w}_{ij}^{ZIP} | x_{ij}) = \hat{\psi}_{ij}(1 - \hat{\psi}_{ij})[1 + \hat{\psi}_{ij} \cdot \hat{\mu}_{ij}]$

Predicted Weighted ITN

Definition

The predicted weighted International Trade Network, for each given cross-section t, is represented by a weighted-directed graph, where the nodes are countries and link weights are fully characterized by the asymmetric matrix $\hat{W}^M$, with entries $\hat{w}_{ij}^M$ and $M \in \{OLS, PPML, ZIP\}$.

- In OLS case, the predicted binary ITN coincides with observed binary ITN
- In PPML/ZIP cases, the predicted binary ITN is a full network

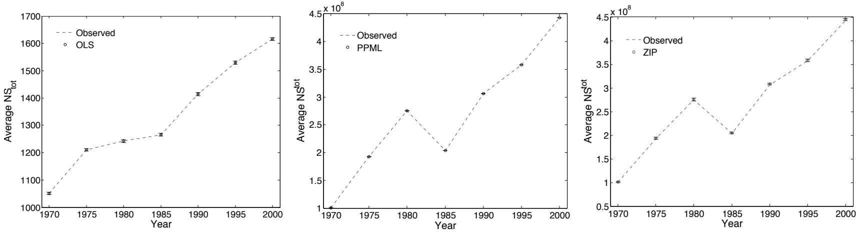
Network Statistics and Confidence Intervals

- **Standard Family of Weighted-Network Measures**
  - In/Out/Total Strength
  - Average Nearest-Neighbor Strength (in all their possible declinations for directed networks)
  - Weighted Node Clustering Coefficients
  - Population averages and correlation structure
- **Observed vs. Predicted Network Statistics**
  - Observed: Computed over observed ITN
  - Predicted: Computed over predicted ITN
  - Variance of predicted network statistics: analytically derived (when possible) vs. simulations (10000 replications)

Network Statistics and Confidence Intervals

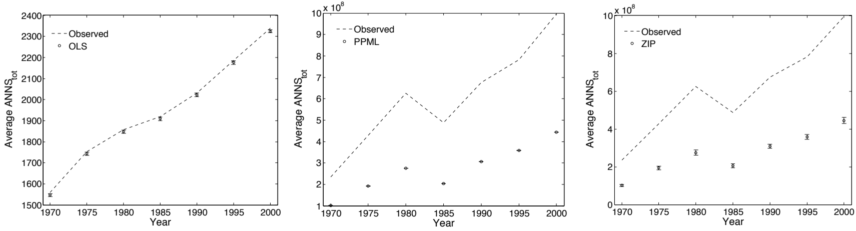
- **Standard Family of Weighted-Network Measures**
  - In/Out/Total Strength
  - Average Nearest-Neighbor Strength (in all their possible declinations for directed networks)
  - Weighted Node Clustering Coefficients
  - Population averages and correlation structure
- **Observed vs. Predicted Network Statistics**
  - Observed: Computed over observed ITN
  - Predicted: Computed over predicted ITN
  - Variance of predicted network statistics: analytically derived (when possible) vs. simulations (10000 replications)

Total Strength



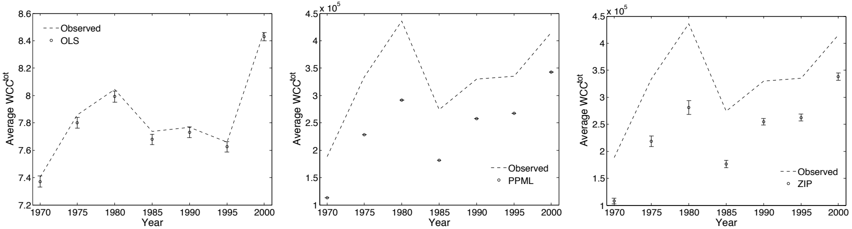
- All three methods perfectly match average total strength
- Average total strength equals total world trade divided by $N(t)$
- Not surprising: GM should perform well in matching any linear transformation of total world trade

Total Average Nearest-Neighbor Strength (ANNS)



- OLS (almost) perfectly predicts total average ANNS (slight overestimation)
- PPML/ZIP capture trend but fail to get levels
- Very narrow confidence bands

Total Weighted Clustering Coefficient (WCC)



- OLS still ok, with a more marked underestimation
- PPML/ZIP still very bad

A First Assessment

- **The binary structure counts!**
  - ZIP takes binary structure as given, PPML/ZIP completely destroy the topology
  - PPML/ZIP predicts a strictly-positive (albeit possibly very small) trade flow for every country pair (full predicted binary graph)
  - To compute ANNS/WCC one must well reproduce binary structure
  - Total average strength does not need binary structure, thus possible overestimation of trade flow on absent links is not dramatic

- **Comparing observed and predicted node-statistic distributions**
  - Performing two-sample KS tests to check that observed vs. predicted node statistics come from the same distributions
  - Node strength: OK for all methods
  - ANNS/WCC: only OLS can generate statistically-similar distributions

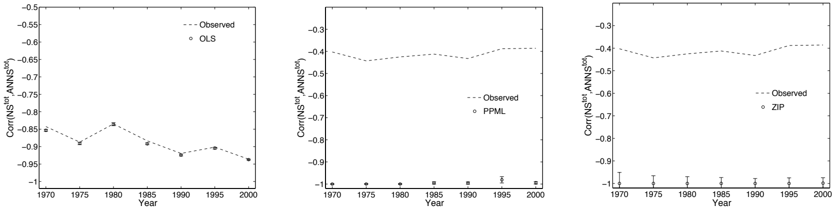
A First Assessment

- **The binary structure counts!**
  - ZIP takes binary structure as given, PPML/ZIP completely destroy the topology
  - PPML/ZIP predicts a strictly-positive (albeit possibly very small) trade flow for every country pair (full predicted binary graph)
  - To compute ANNS/WCC one must well reproduce binary structure
  - Total average strength does not need binary structure, thus possible overestimation of trade flow on absent links is not dramatic

- **Comparing observed and predicted node-statistic distributions**
  - Performing two-sample KS tests to check that observed vs. predicted node statistics come from the same distributions
  - Node strength: OK for all methods
  - ANNS/WCC: only OLS can generate statistically-similar distributions

Weighted Correlation Structure

Disassortativity: Correlation between ANNS and NS



- OLS can correctly replicate observed disassortativity
- PPML/ZIP always predict extreme disassortativity (as in null-model exercises, see Fagiolo, Squartini, Garlaschelli, 2011; this workshop)
- Similar pattern arising for clustering/strength correlation
- Results robust to directed-network statistics

GM Predictions of the Binary ITN

- **Is the GM able to correctly predict the binary structure of the ITN?**
  - Any GM model aiming at endogenously estimating binary links must try to obtain a more accurate estimation of the exact location of the zeros in trade matrices
  - Can one employ the independent variables traditionally used in GM equations to predict whether a trade link exists or not?

- **A Logit Specification**

$$Prob\{a_{ij} = 1 | x_{ij}\} = \frac{\exp\{x_{ij} \cdot \theta\}}{1 + \exp\{x_{ij} \cdot \theta\}} = \Lambda(x_{ij}; \theta)$$

  - x_{ij} are GM covariates
  - Note: Estimated probabilities are the same as those in ZIP first stage
  - They are always strictly positive! How can one use them to meaningfully predict a binary network?

GM Predictions of the Binary ITN

- **Is the GM able to correctly predict the binary structure of the ITN?**
  - Any GM model aiming at endogenously estimating binary links must try to obtain a more accurate estimation of the exact location of the zeros in trade matrices
  - Can one employ the independent variables traditionally used in GM equations to predict whether a trade link exists or not?

- **A Logit Specification**

$$Prob\{a_{ij} = 1 | x_{ij}\} = \frac{\exp\{x_{ij} \cdot \theta\}}{1 + \exp\{x_{ij} \cdot \theta\}} = \Lambda(x_{ij}; \theta)$$

  - x_{ij} are GM covariates
  - Note: Estimated probabilities are the same as those in ZIP first stage
  - They are always strictly positive! How can one use them to meaningfully predict a binary network?

The Predicted Binary ITN

- **Density-Induced Predicted Binary ITN**
  - Take the matrix of logit predicted probabilities $\hat{\xi}_{ij}$
  - Delete all the links associated to predicted probabilities smaller than observed ITN density
  - This generates a unique instance of a predicted binary ITN with a density approximately similar to the observed one
- **Bernoulli-Induced Predicted Binary ITN**
  - We generate a sample of M independent adjacency matrices $\hat{A}^m = \{\hat{a}_{ij}^m\}$, for $m = 1, \ldots, M$
  - In each sample $\hat{a}_{ij}^m$ is drawn from a Bernoulli distribution with parameter $\hat{\xi}_{ij}$ independently across all pairs ij
- **Comparing Observed and Predicted Binary ITN**
  - We compare binary network statistics and their correlation in observed vs. predicted binary ITN
  - We focus on node degree (ND), average nearest-neighbor degree (ANND) and binary clustering coefficient (BCC)

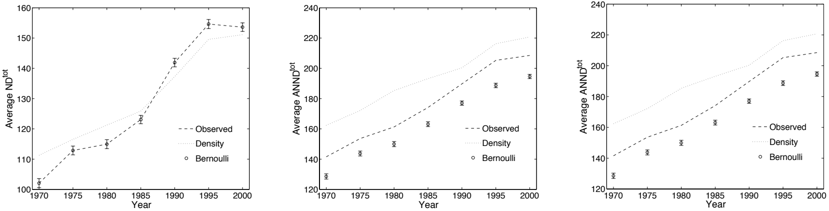
The Predicted Binary ITN

- **Density-Induced Predicted Binary ITN**
  - Take the matrix of logit predicted probabilities $\hat{\xi}_{ij}$
  - Delete all the links associated to predicted probabilities smaller than observed ITN density
  - This generates a unique instance of a predicted binary ITN with a density approximately similar to the observed one
- **Bernoulli-Induced Predicted Binary ITN**
  - We generate a sample of M independent adjacency matrices $\hat{A}^m = \{\hat{a}_{ij}^m\}$, for $m = 1, \ldots, M$
  - In each sample $\hat{a}_{ij}^m$ is drawn from a Bernoulli distribution with parameter $\hat{\xi}_{ij}$ independently across all pairs ij
- **Comparing Observed and Predicted Binary ITN**
  - We compare binary network statistics and their correlation in observed vs. predicted binary ITN
  - We focus on node degree (ND), average nearest-neighbor degree (ANND) and binary clustering coefficient (BCC)

The Predicted Binary ITN

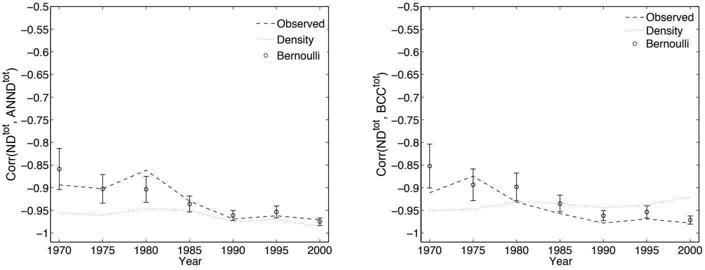
- **Density-Induced Predicted Binary ITN**
  - Take the matrix of logit predicted probabilities $\hat{\xi}_{ij}$
  - Delete all the links associated to predicted probabilities smaller than observed ITN density
  - This generates a unique instance of a predicted binary ITN with a density approximately similar to the observed one
- **Bernoulli-Induced Predicted Binary ITN**
  - We generate a sample of M independent adjacency matrices $\hat{A}^m = \{\hat{a}_{ij}^m\}$, for $m = 1, \dots, M$
  - In each sample $\hat{a}_{ij}^m$ is drawn from a Bernoulli distribution with parameter $\hat{\xi}_{ij}$ independently across all pairs ij
- **Comparing Observed and Predicted Binary ITN**
  - We compare binary network statistics and their correlation in observed vs. predicted binary ITN
  - We focus on node degree (ND), average nearest-neighbor degree (ANND) and binary clustering coefficient (BCC)

The Binary ITN: Average Statistics



- Logit does a very well job in estimating average ND (i.e. density)
- Logit fails in reproducing ANND and BCC
- This explains why ZIP reproduces NS and not ANNS or WCC: NS does not require to know where links are actually placed but only density; ANNS/WCC require instead a fine knowledge of where links are placed
- The GM is unable to well predict the presence a link

The Binary ITN: Correlations



- Logit performance seems to improve in reproducing binary correlations
- Density-induced predictions are able to well capture binary disassortativity in the last part of the sample, but they only partially get right clustering-degree correlation
- Conversely, Bernoulli-based predictions seem to perform quite satisfactorily in both cases

Concluding Remarks

- **The GM and the ITN**
  - The GM turns out to be a good model for estimating trade flows, but not to explain why a link in the ITN gets formed and persists over time
  - Knowing country-specific variables (country GDP, etc.) and country bilateral interactions (bordering conditions, belonging to the same RTA, etc.) is not enough to predict the presence of a link
  - However, conditional on the information that a link exists, such variables can well predict how much trade that link actually carries

- **Future Research**
  - Augmenting GM specification with network-related variables (and solving endogeneity problems)
  - Extending GM microfoundations to account for a richer link-formation process

Concluding Remarks

- **The GM and the ITN**
  - The GM turns out to be a good model for estimating trade flows, but not to explain why a link in the ITN gets formed and persists over time
  - Knowing country-specific variables (country GDP, etc.) and country bilateral interactions (bordering conditions, belonging to the same RTA, etc.) is not enough to predict the presence of a link
  - However, conditional on the information that a link exists, such variables can well predict how much trade that link actually carries
- **Future Research**
  - Augmenting GM specification with network-related variables (and solving endogeneity problems)
  - Extending GM microfoundations to account for a richer link-formation process

Papers

- Fagiolo, G. (2010), “The International-Trade Network: Gravity Equations and Topological Properties”, *Journal of Economic Interaction and Coordination*, 5:1-25.
- Duenas, M. and Fagiolo, G. (2011), “Modeling the International-Trade Network: A Gravity Approach”, arXiv:1112.2867 [q-fin.GN]. Also in: LEM Working Paper, 2011/25.

Product-Space Networks

- Based on: Hidalgo et al, Science, 2007; Hidalgo and Hausmann, PNAS, 2009; Tacchella et al., 2012, Nature Sci Reps
- Main question:
  - Does the type of product that a country exports matter for subsequent economic performance?
- Metaphor:
  - Product as a tree and set of all products as a forest, firms as monkeys living on and exploiting different trees
  - Growth implies moving from a poorer part of the forest, where trees have little fruit, to better parts of the forest
  - Traditional growth theory assumes there is always a tree within reach; hence, the structure of this forest is unimportant
  - What if structure of the forest is not dense and homogeneous? The structure of this space becomes of great importance to the development of countries

Product Similarity

- Agnostic (outcome-based) approach: Two goods are similar if they can be produced in tandem; the ability of a country to produce a product depends on its ability to produce other products

- Ability to produce = ability to export (crucial assumption!)

- Proximity between two products i and j:

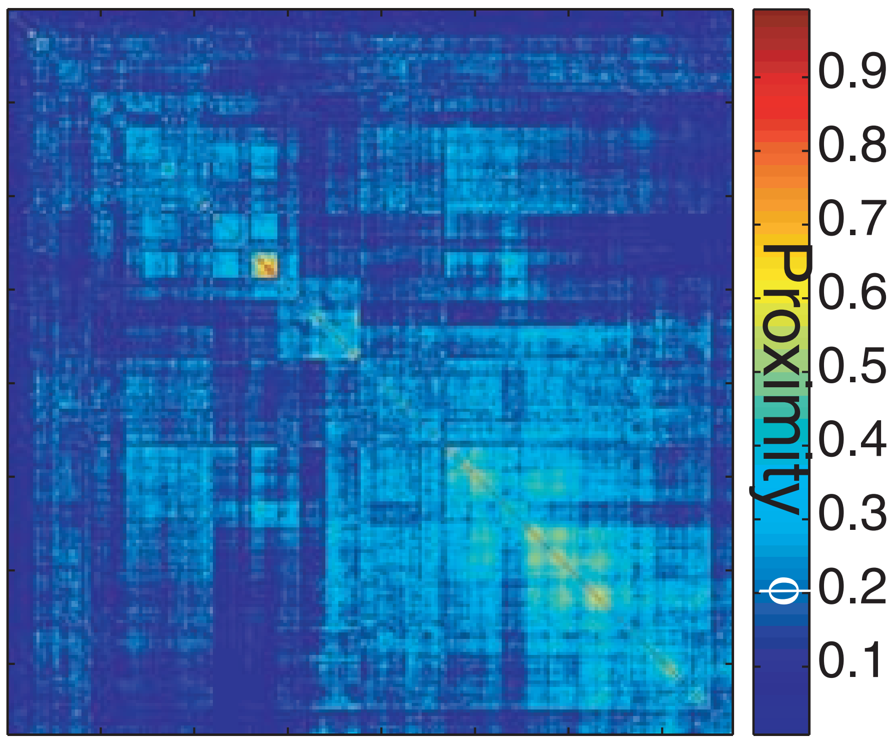
$$\phi_{i,j} = \min\{P(RCAx_i|RCAx_j), P(RCAx_j|RCAx_i)\}$$

- RCA: revealed comparative advantage for country c and product i

$$RCA_{c,i} = \frac{x(c,i)}{\sum_i x(c,i)} \Bigg/ \frac{\sum_c x(c,i)}{\sum_{c,i} x(c,i)}$$

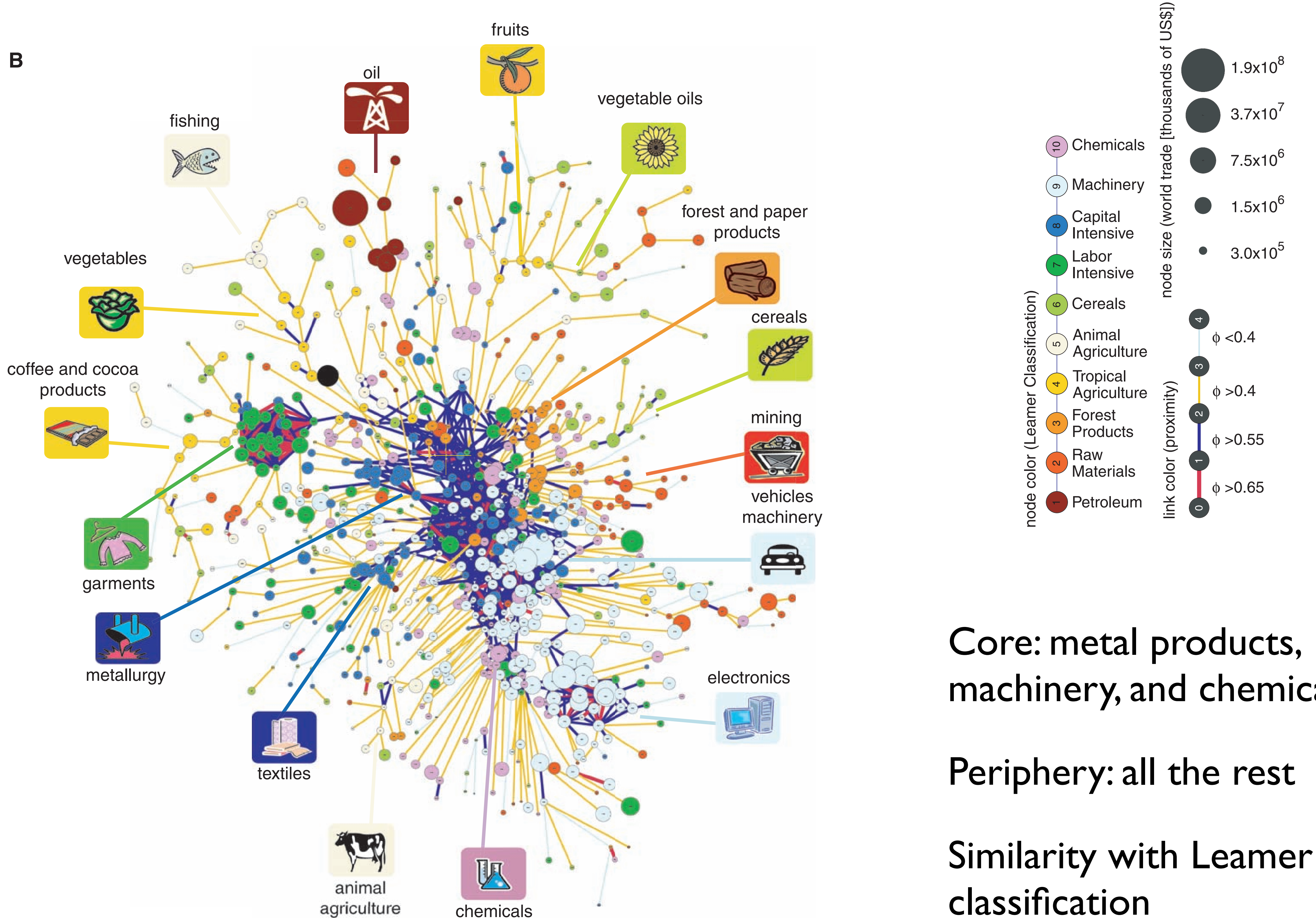
Empirics

- Data: international trade (Feenstra)
- Data disaggregated according to four-digit level (SITC-4), providing for each country the value exported to all other countries for 775 product classes.
- Building a 775-by-775 matrix of revealed proximities between every pair of products by using RCA-based proximity (PSN)



- Modular structure
- Heterogeneous patterns
- Product space is not homogeneous

Core-Periphery in the PSN (MST)

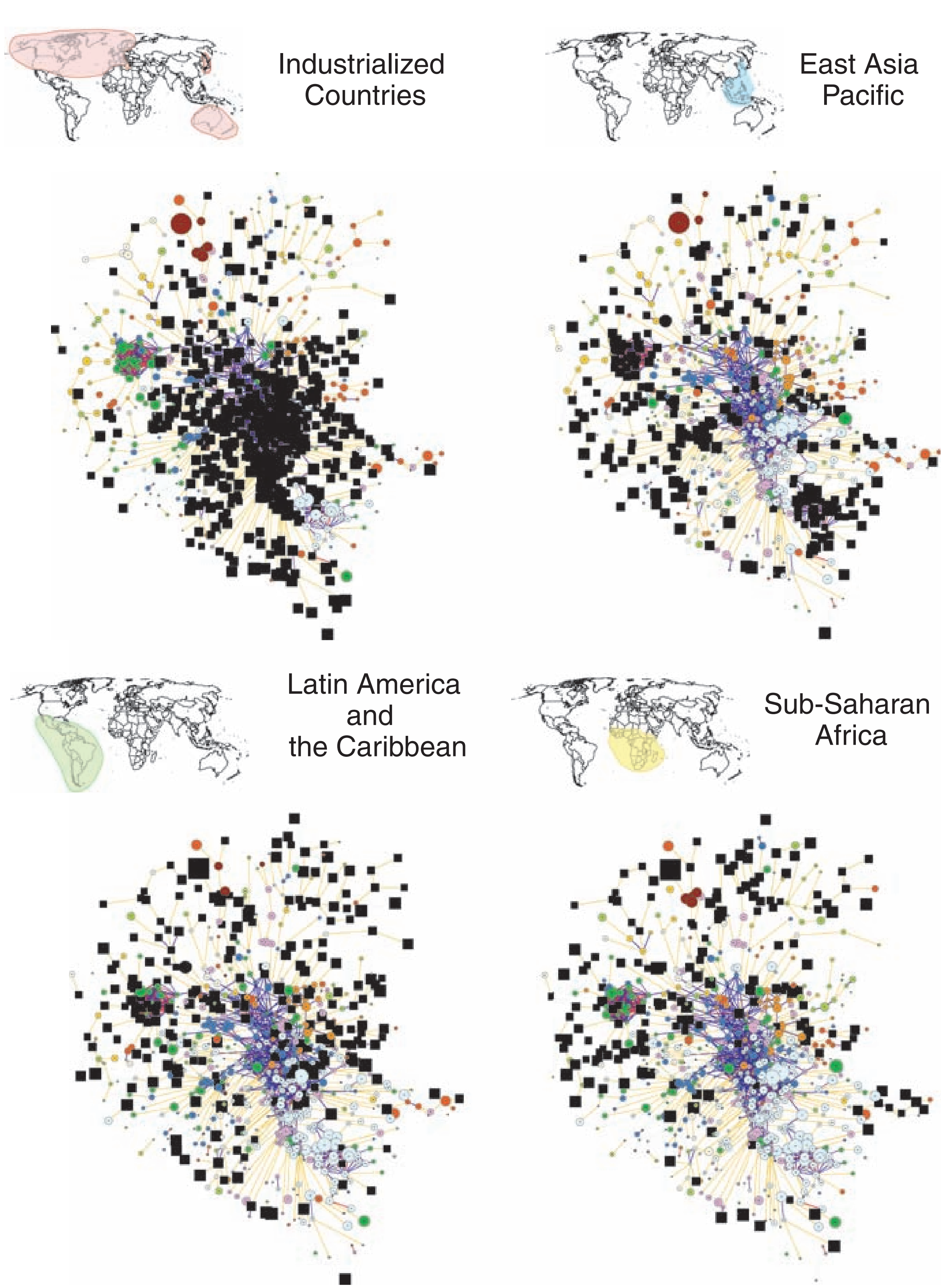


Core: metal products, machinery, and chemicals,

Periphery: all the rest

Similarity with Leamer classification

Locating countries in the PSN



Holding PS fixed

Studying where countries are located in the PS

Products for which a countries has a RCA>1 are shown as black dots

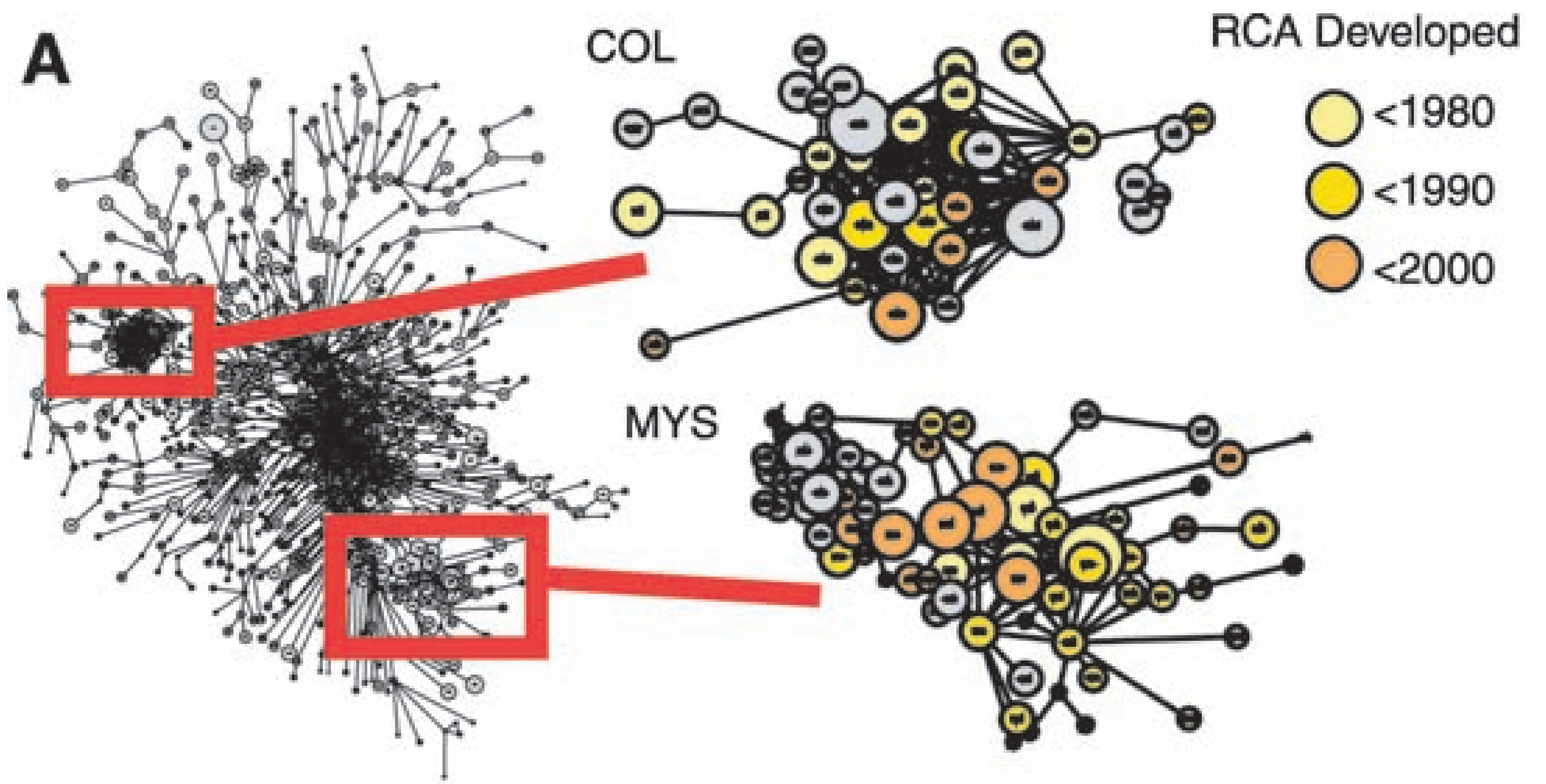
Industrialized countries: occupy the core, (machinery, metal products, and chemicals), and more peripheral products (textiles, forest products, and animal agriculture).

East Asian countries: garments, electronics, and textile clusters

Latin America and the Caribbean are in the periphery (mining, agriculture, and garments).

Lastly, sub-Saharan Africa export a few peripheral products

Evolution of country productive structures



Malaysia vs Colombia: follow a cumulative diffusion process in which comparative advantage move preferentially toward products close to existing goods: garments in Colombia and electronics in Malaysia

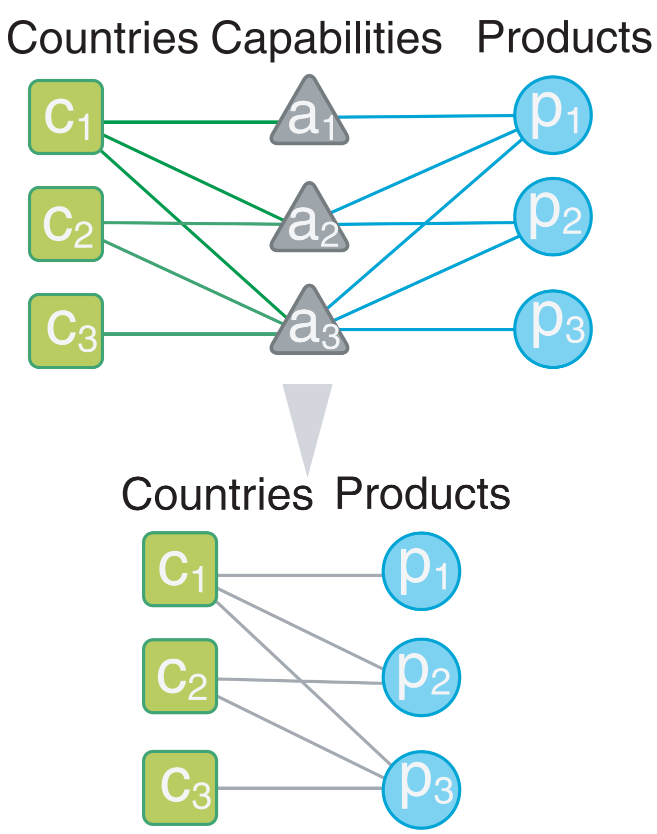
Does this mean that countries move in a sticky way through the MSN? Do some countries move easier and others not?

A First Assessment

- Building network of proximity between products
- Exporting vs producing?
- Playing with diffusion processes over the PSN: allowing countries to move to nearby products with proximities greater than a given threshold
- Not all countries face the same opportunities when it comes to development
- Poorer countries tend to be located in the periphery, where moving toward new products is harder to achieve
- Even similar countries (in terms of development, export sophistication, etc.) are constrained by the PSN and exhibit a ignificant variation in the option set implied by their current productive structure

The Method of Reflections

- Building a bipartite country-product network
- Rectangular adjacency matrix M(c,p)=1 if country c exports product p
- Idea: modeling the unobservable tri-partite network between countries, capabilities and products

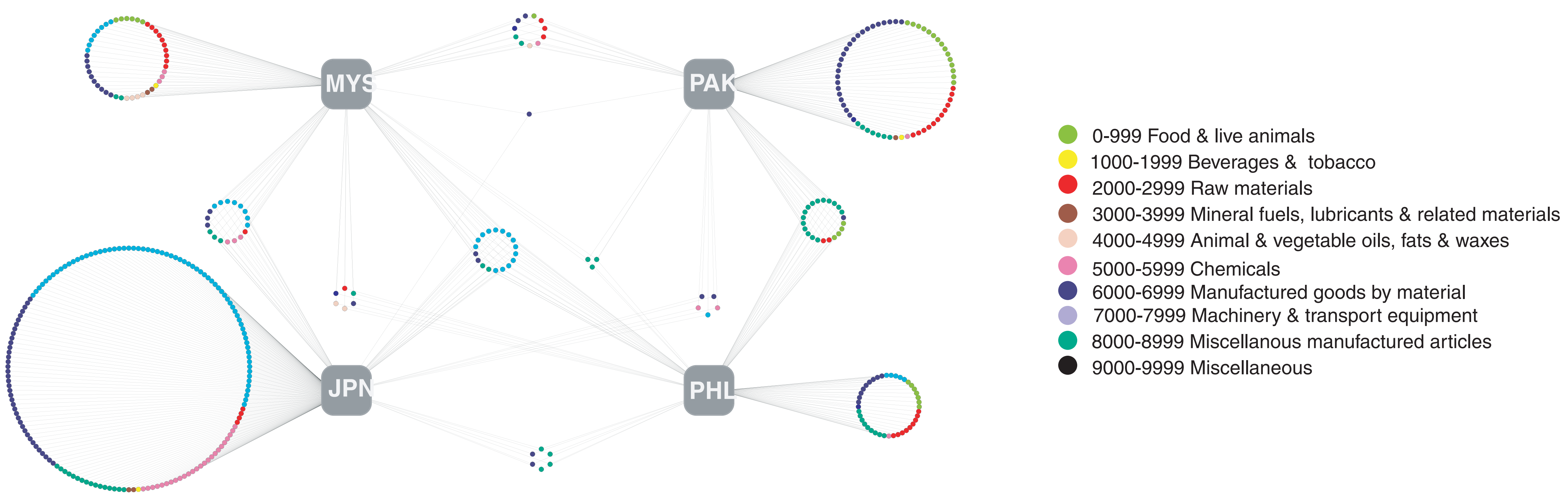


Countries have capabilities to produce

Products require capabilities to be produced

The Method of Reflections

- Building a bipartite country-product network
- Rectangular adjacency matrix M(c,p)=1 if country c is a significant exporter of product p, i.e. if RCA(c,p)>1
- Characterizing profile of any country and product...



The Method of Reflections

- Step zero: Start from country and product degrees

$$k_{c,0} = \sum_p M_{cp},$$

$$k_{p,0} = \sum_c M_{cp}.$$

  - Country: level of export/production diversification
  - Product: ubiquity of a product (no. of countries exporting it)
- Step one: average nearest-neighbor degrees
  - Country: average ubiquity of products a country exports
  - Product: average diversification of countries exporting that product

The Method of Reflections

- More generally, for N=0,1,2,...

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} k_{p,N-1},$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} k_{c,N-1},$$

- Attaching to each country and produc a vector of N entries

$$\vec{k}_c = (k_{c,0}, k_{c,1}, k_{c,2} \ldots k_{c,N})$$

$$\vec{k}_p = (k_{p,0}, k_{p,1}, k_{p,2}, \ldots, k_{p,N})$$

The Method of Reflections

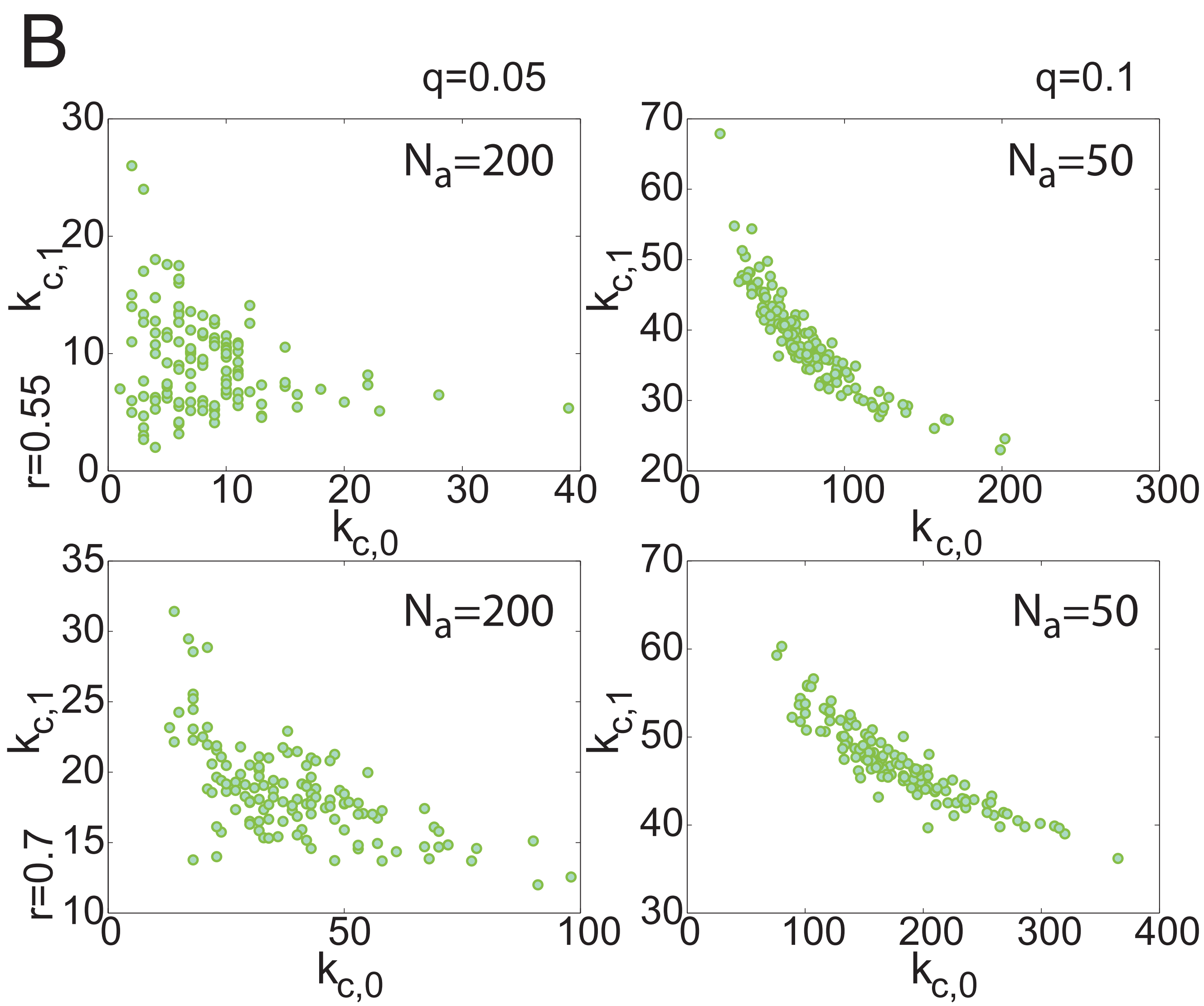
- Interpretation: increasing N means going farther and farther away from the (country or product) node

- Countries:
  - Even entries: generalized measures of diversification
  - Odd entries: generalized measures of ubiquity of the products they export

- Product:
  - Even entries: generalized measures of ubiquity
  - Odd entries: generalized measures of diversification of the countries that export the product

Results

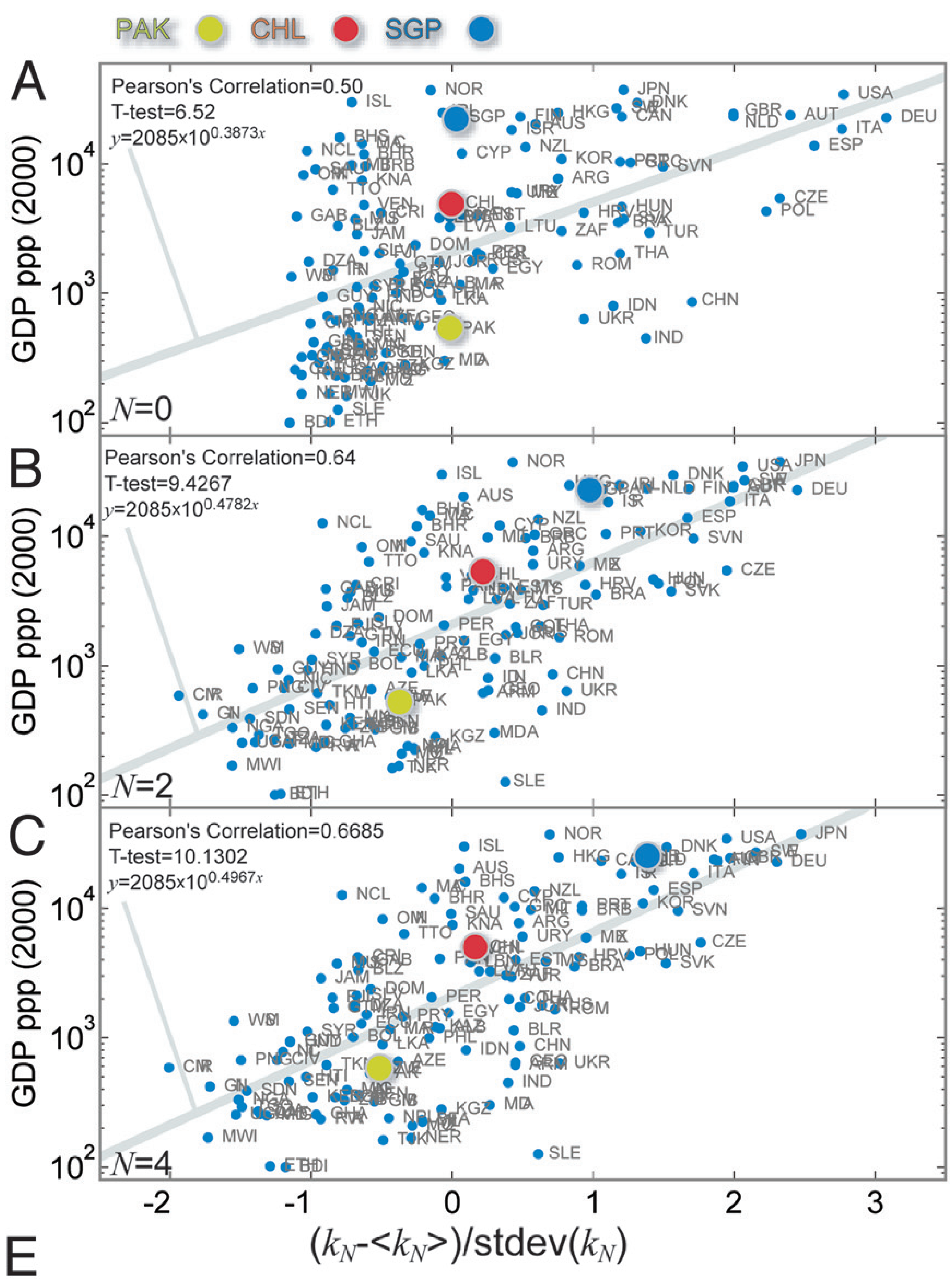
- Correlating diversification and ubiquity: disassortativity!
- Diversified countries tend to export less ubiquitous products



Results

- Deviations are informative!
- Malaysia (MYS) and Pakistan (PAK) export the same number of products: K(MYS,0)=K(PAK,0)=104
- Products exported by MYS are exported by fewer countries than those exported by PAK: K(MYS,1)=18 < 27.5=K(PAK,0)
- Products exported by MYS are exported by more diversified countries than those of PAK: K(MYS,2)=163 > 142=K(PAK,2)
- This suggests that the productive structure of Malaysia is more complex than that of Pakistan, due to a larger number of capabilities available in Malaysia than in Pakistan

Production, Income and Growth



As N increases the ranking among countries changes

Ranking becomes more correlated with GDP

Recursive measures of diversification of a country extract information about relative position of countries

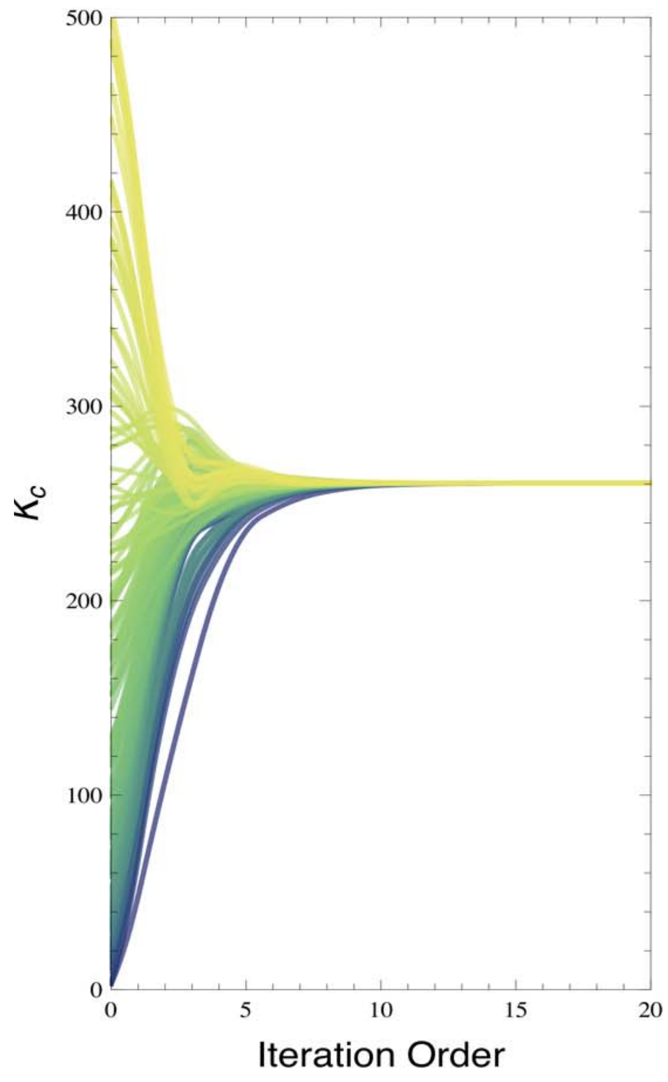
Example: PAK, CHL, SGP get separated even though they exported similar # of products while having different GDP

Singapore is connected to diversified countries mainly through nonubiquitous products, signaling the availability in Singapore of capabilities that are required to produce goods in diversified countries

Pakistan is connected to poorly diversified countries, and mostly through ubiquitous products: it has capabilities that are available in most countries and its relatively high level of diversification is probably due to size

Method of Reflections: Some Issues

- What does it really measure? Convergence to GDP?
- What if one iterates the method for N growing very large?



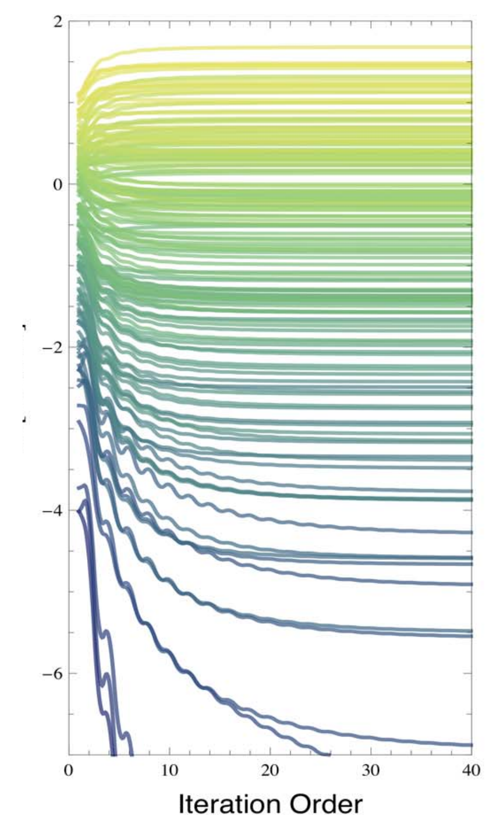
The linear "method of reflections" tends to minimize the differences between countries as the number of iterations grows large

An Alternative Approach (Tacchella et al, 2012)

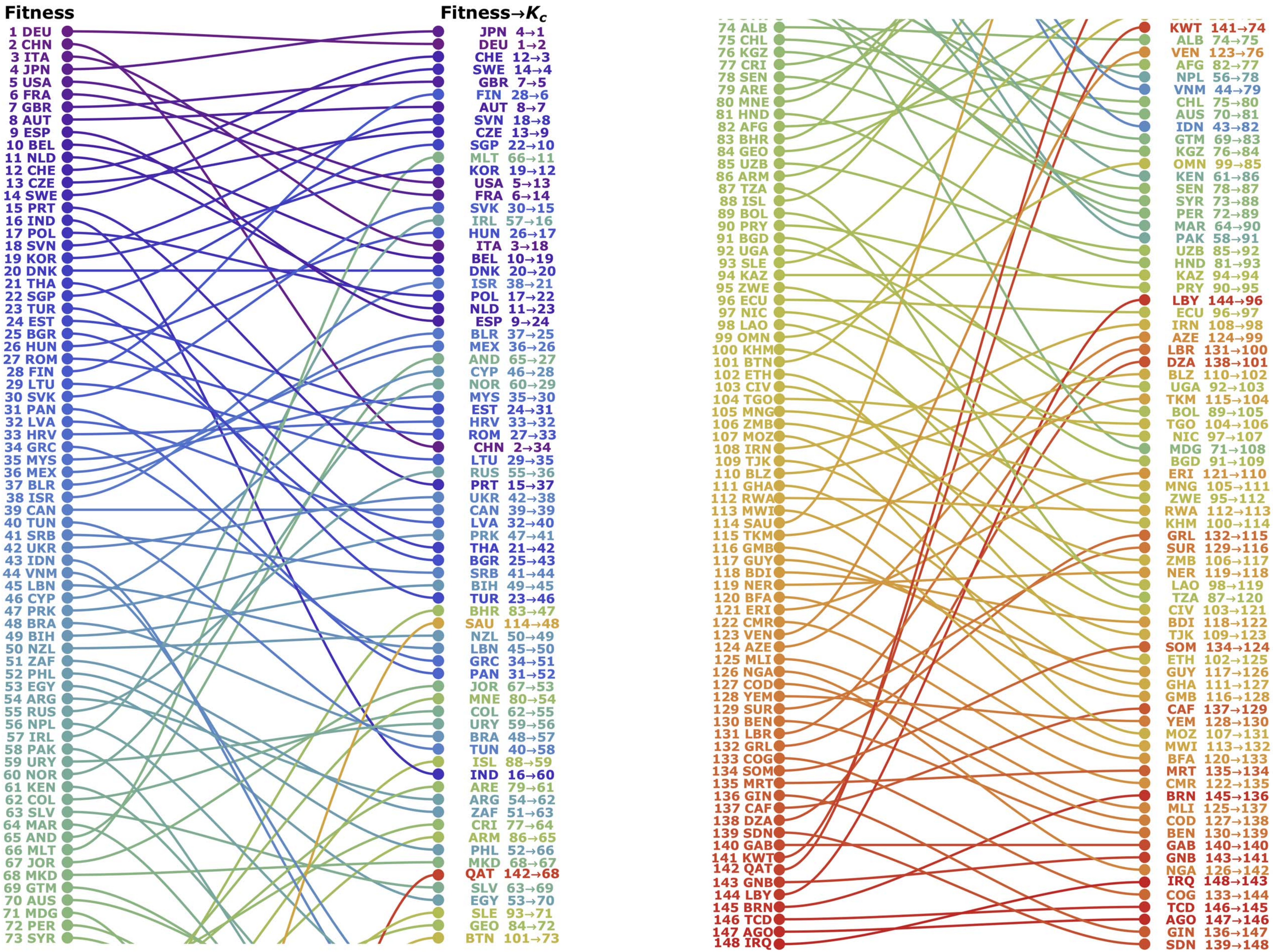
- Measuring complexity Q of product c and fitness F of a country c that produces it

- Main idea: introducing non-linearities in the coupling...
  - Fitness: proportional to the sum of the products exported weighted by their complexity Q
  - Complexity: proportional to the number of countries which export it but the larger the fitness of a country, the smaller its contribution to product complexity

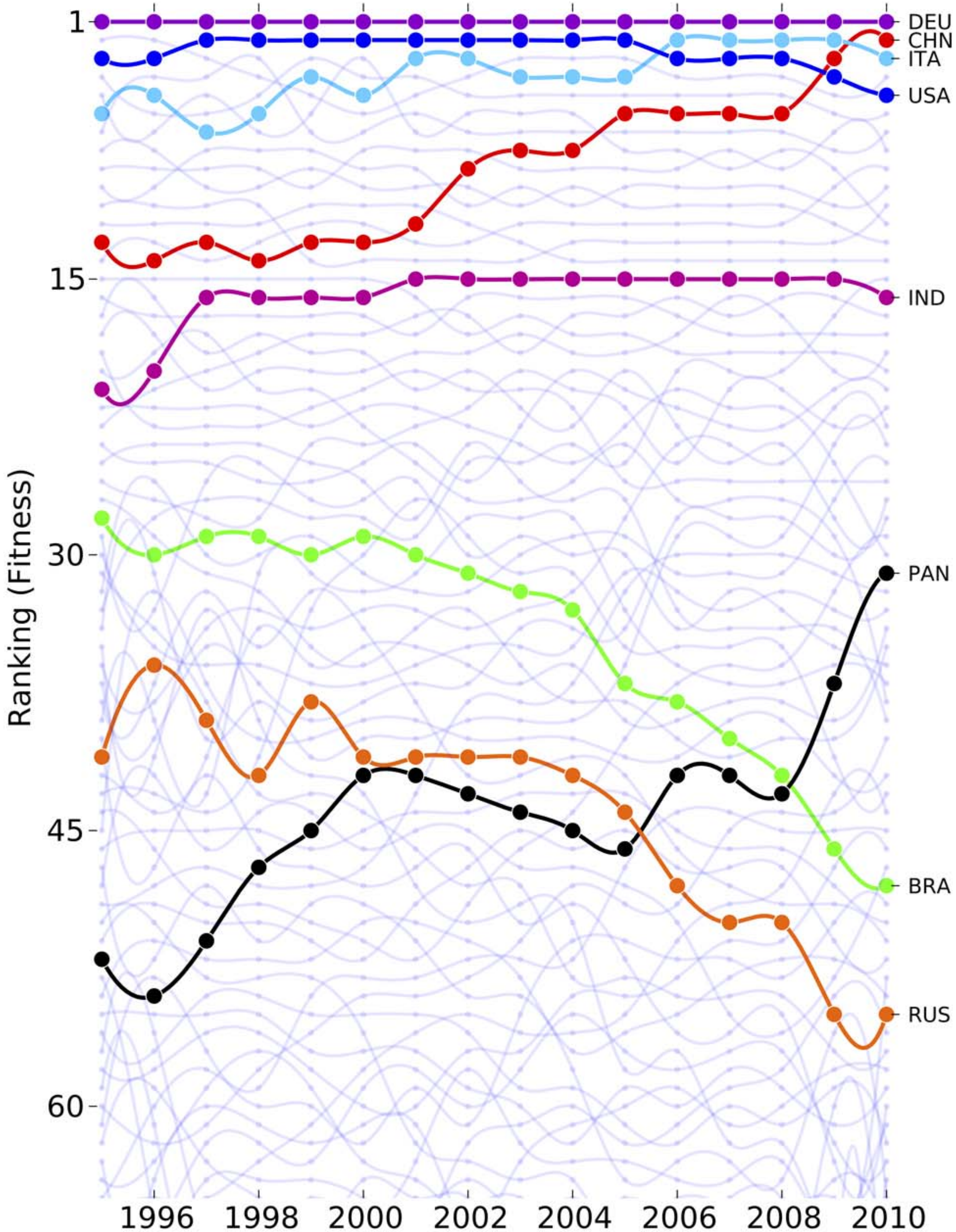
$$\begin{cases} \tilde{F}_c^{(n)} = \sum_p M_{cp} Q_p^{(n-1)} \\ \tilde{Q}_p^{(n)} = \dfrac{1}{\sum_c M_{cp} \dfrac{1}{F_c^{(n-1)}}} \end{cases}$$



Old vs New Metric



The Case of BRICS



Brazil and even more Russia display a decreasing fitness: GDP growth is essentially fuelled by the increasing prices of raw materials?

"They are not using their surplus of richness deriving from raw materials to develop their capabilities in order to give firm basis to their industrial economic system".

GDP growth of China and India reflects a genuine development of the capabilities and a real increase of the competitiveness of these two countries

Spectacular growth in fitness by China: moved from the 13th position to the 2nd, just below Germany.

The HH method ranks China in the 29th position in 2010, just above Panama.

Discussion

- "Non-monetary" metrics for the competitiveness of the countries and the complexity of the products in order to assess quantitatively the advantage of diversification
- Is it really a measure of competitiveness?
- Again: trade data to infer structure of production
- Robustness to other functional forms in the complexity definition: why this and not other ones? Economic model?
- Statistical properties of the metrics? Null models?

Diffusion of Shocks in the ITN

- Based on: Lee et al, PlosOne, 2011
- Main ideas:
  - Using the ITN to understand the impact of shocks in the macroeconomic network
  - Relative roles of country size, geography and country position in the network
- Using the ITN as a proxy for interaction channels between countries
- One needs an underlying model of shock input-output at the level of nodes (and across in/outgoing links)

The Model (I)

- Using data on country GDP and trade from 2002-2006
- Build the ITN with node size = country GDP (capacity)
- Weighted directed links
- Spread of economic crisis modeled as cascading failure or avalanche process

The Model (2)

- Suppose country i is hit by a (homogeneous) shock (collapses in the extreme case)
- All outgoing and incoming links are decreased by a fraction f
- Consider any country j connected to country i
- If total decrement of link weights exceeds a fraction t of country capacity, then country j is also hit by the shock (collapses)
- The process continues until there is no other country hit by the shock (avalanche of collapses stops)

Key Quantities

- Avalanche size (A) of a country: Number of subsequently collapsed countries starting from a given country's collapse

- Distribution P(A) of avalanche size

- Model can be studied in terms of the ratio f/t

Results (I): Avalanche size distribution

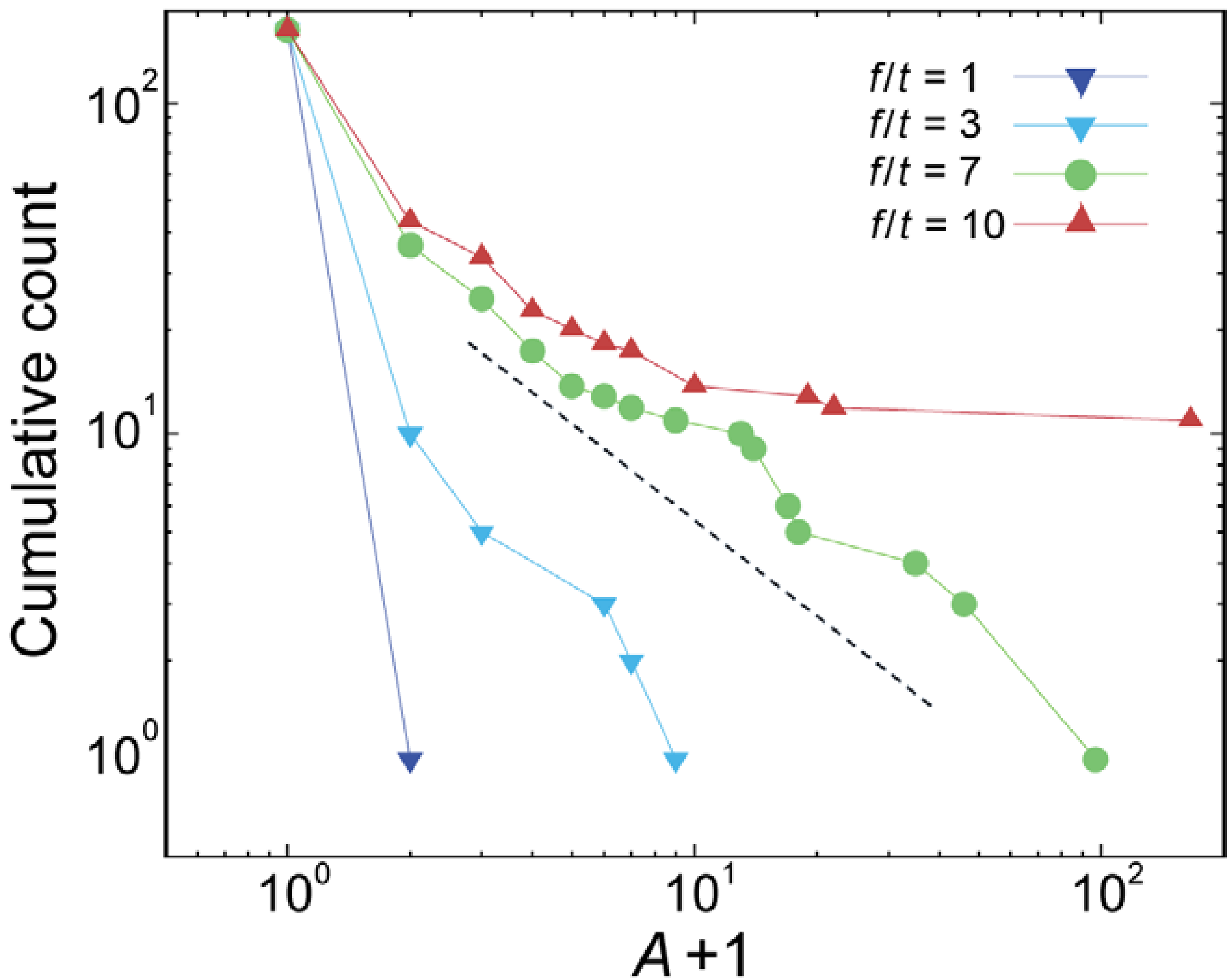


Figure 2. Avalanche size distributions. The cumulative counts of countries with avalanche sizes equal to or greater than A, which behaves in the same way as the cumulative distribution of $P(A)$, is plotted. At the critical parameter $f/t=7$, the plot becomes straight with a slope of -1 (dashed line) on a logarithmic scale, indicating the power-law relation $P(A)\sim A^{-2}$. The horizontal axis has been offset by one, to plot the countries with $A=0$ on a logarithmic scale.

Avalance size distribution as a function of f/t

When f/t is too small, there is no large avalanche, so P(A) decays rapidly with A.

When f/t is too large, there is an excess of global avalanches giving rise to a finite peak around the network-spanning avalanche sizes.

In between, there exists a critical point, at which P(A) becomes power-law-like and the system exhibits the broadest spectrum of avalanche outcomes

Power-law crises? Evidence?

Results (2): Avalanche size and GDP

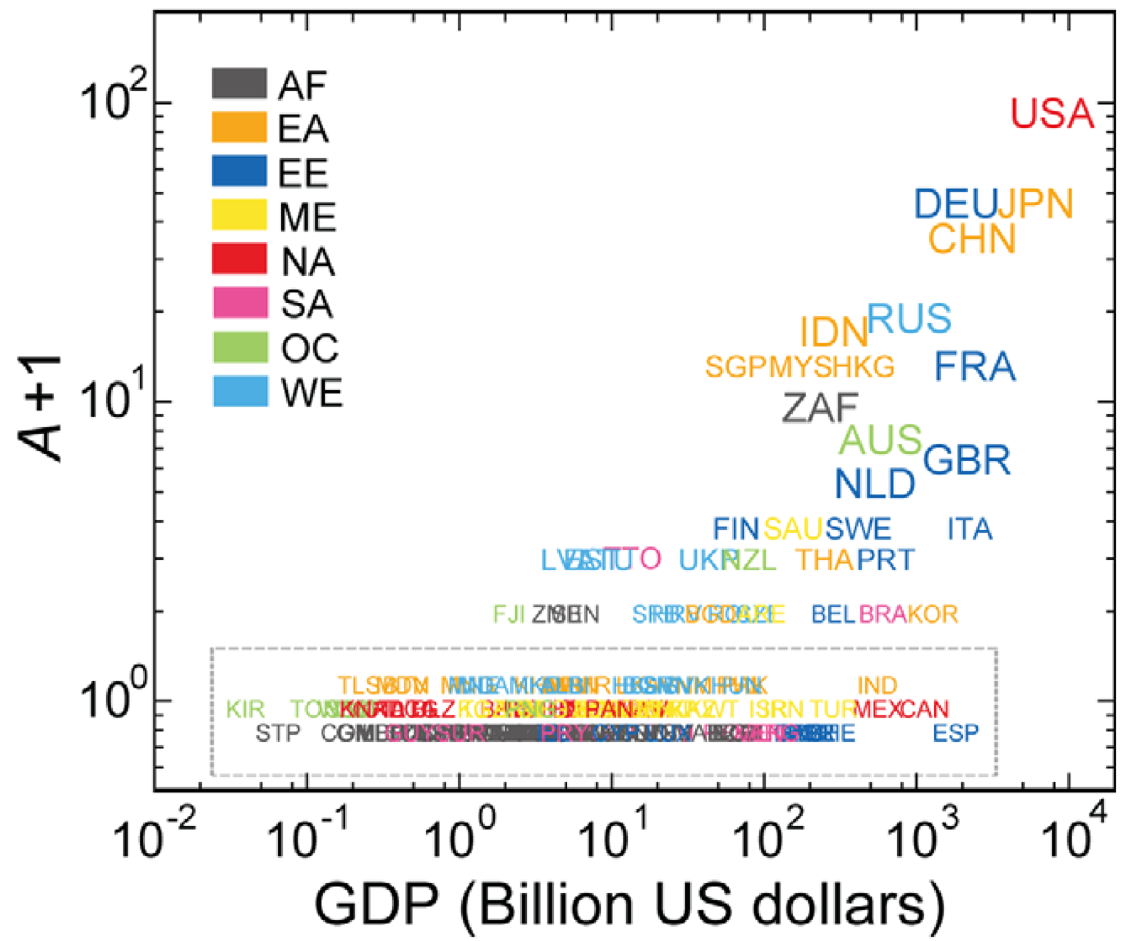


Figure 3. Avalanche size vs. GDP. Scatter plot of the avalanche size of each country offset by one (*A*+1) as a function of its GDP is displayed with the color code by continental association (AF: Africa, EA: East Asia, EE: East Europe, ME: Middle-East, NA: North America, SA: South America, OC: Oceania, and WE: West Europe). The overall increasing trend with some deviations indicates that the avalanche size of a country is partly accounted for by the GDP, but not entirely. The dashed box indicates a group of countries with $A=0$ (split to minimize overlaps to enhance visual comprehensibility). Country name codes follow the ISO 3166-1 alpha-3 code throughout the paper.

The avalanche size roughly scales with GDP, especially for large GDP countries.

However, the GDP cannot fully explain avalanche size.

Avalanche size also depends on indirect effects through the relationship between country GDP and the portfolio of import-export flows (as compared to partner's GDP)

Results (3): Weak vs strong links

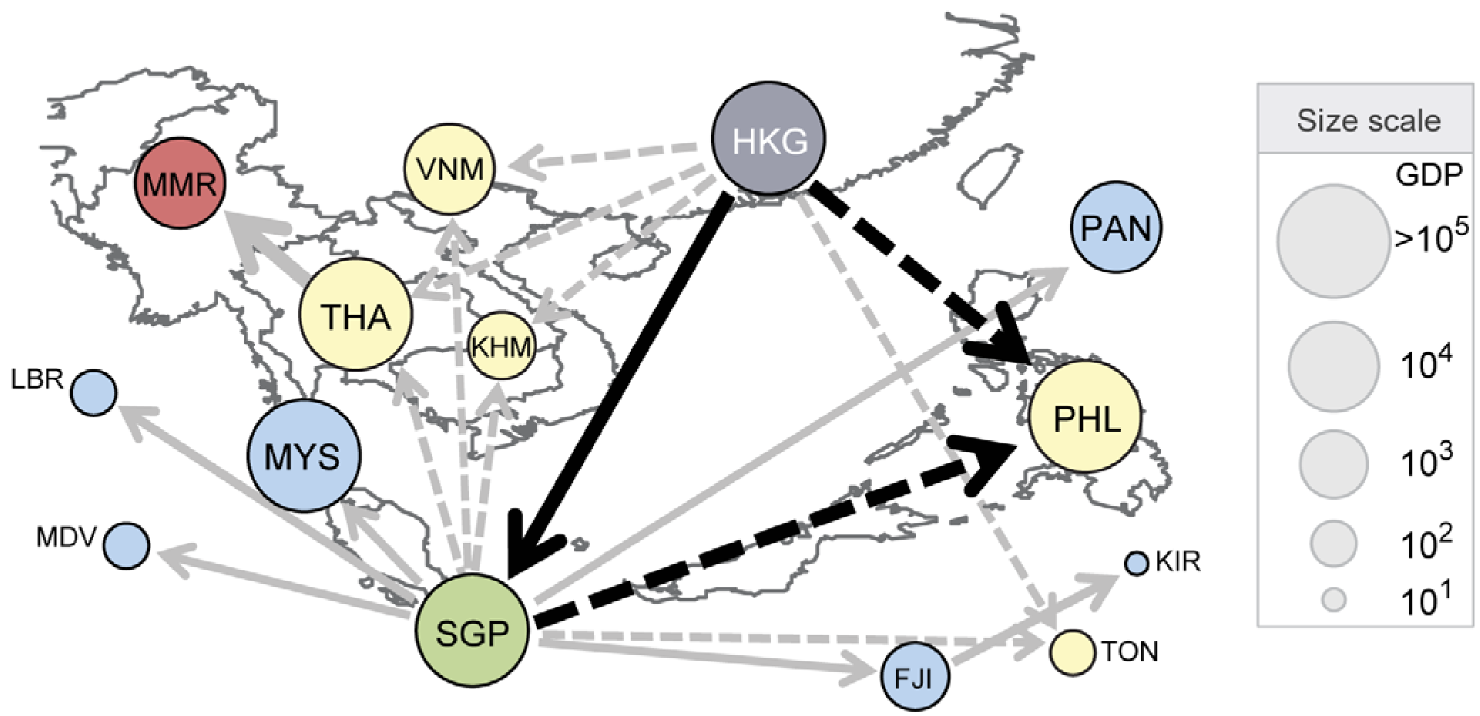


Figure 5. Full sequence of avalanche process starting from Hong Kong. Direct channels (solid arrows) and indirect channels (dashed arrows) are distinguished because they contribute to the avalanche process by different mechanisms. Countries are colored according to the sub-process they belong to, and their size is given by the GDP (in million US dollars). The starting country, Hong Kong, is colored in gray.

Cascades can proceed directly by following successive direct trade channels (solid arrows) or indirectly following detours (dashed arrows)

An indirect cascade propagates through weak links, the weight of which is insufficient to transmit the cascade directly.

However, when the impact through weak channels combines with impacts through detours, the aggregate impact can be strong enough to transmit the cascade.

Results (4): The importance of indirect links

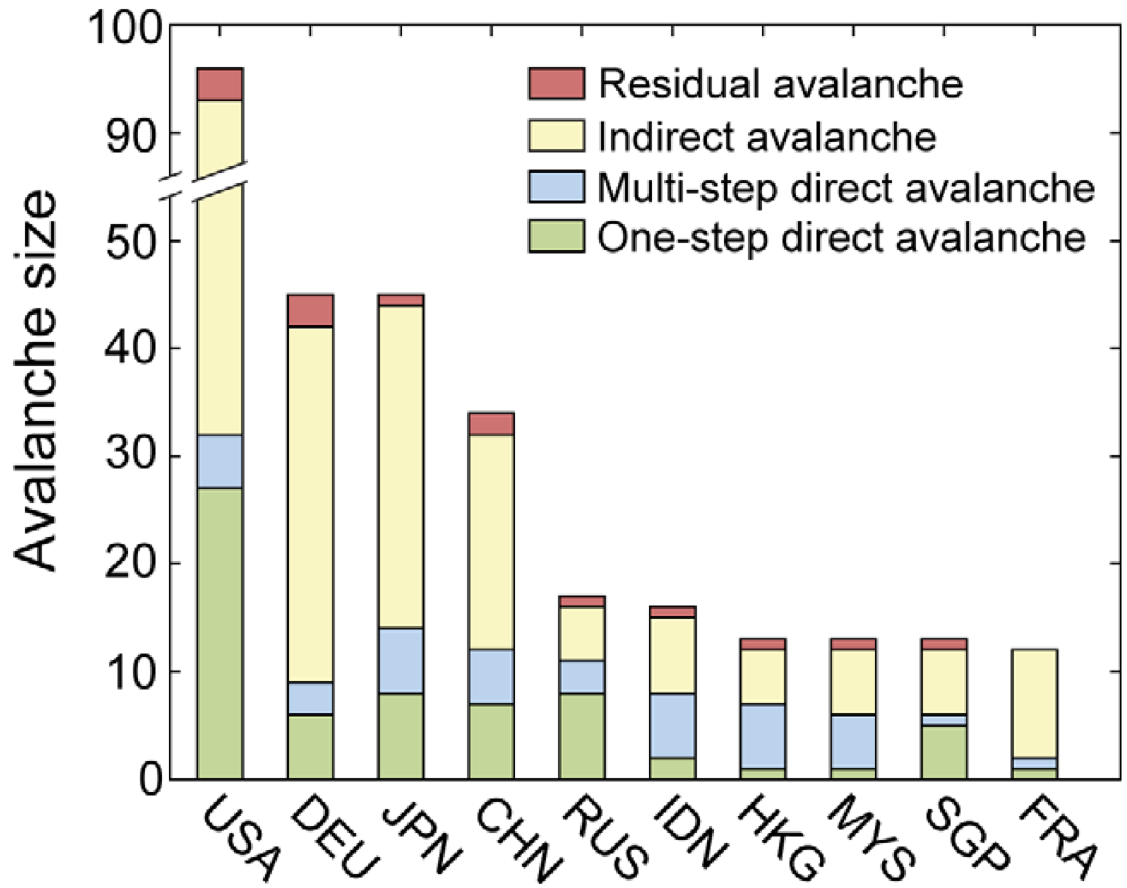


Figure 6. Avalanche profiles. Bar plot showing the avalanche profile of countries with the ten largest avalanche sizes is displayed. The total avalanche process is divided into four sub-processes and the colored bar denotes their distribution. For most countries shown in the figure, the indirect avalanche (yellow) constitutes the largest fraction of the total avalanche process.

Most of avalanche profiles are accounted for indirect avalanche sub processes, i.e. indirect avalanche comprised of countries that collapse through indirect cascades

Results (5): Comparison with alt networks

- Consider two alternative (null-model) networks
  - GSN: global shuffled network
  - GDN: global distributed network
- GSN: preserves degree and (roughly) trading profiles; destroys geographical (local) structure
  - Overall degree of crisis spreading increases; due to the untangling of continental clustering, the failure of major countries could spread farther and more broadly than in the GMN; avalanches polarize...
- GDN: preserves node strength only; destroys even more the binary structure
  - The avalanche size distribution becomes even more polarized (only US, Germany, and China have dominant avalanche sizes). Yet, the average avalanche size of these three countries spans as much as 75% of the globe

Conclusions

- "Results suggest that there can be a potential hidden cost in the ongoing globalization movement towards establishing less-constrained, trans-regional economic links between countries, by increasing vulnerability of the global economic system to extreme crises"
- A promising framework to quantify indirect effects
- Issues
    - Too simplified model of crisis spreading
    - Trade is not enough to characterize linkages between countries
    - A lot of work to do in this direction....

Financial Networks

Institute of Economics, Sant'Anna School of Advanced Studies, Pisa (Italy)

Agenda

- The International Financial Network (IFN) and the crisis
- Contagion in financial networks
- Networks of corporate control
- Correlation-based networks
- Macro-financial networks

Financial Networks

- Consider the financial system as a complex adaptive systems (CAS) [6].
- Economic agents (individual investors, banks, hedge-funds, etc. . .) interact, adapt and learn from each other creating a complex set of financial interconnections.
- The overall behavior of the system can be understood only by explicitly taking into account the effects of such relationships by looking at the properties of the entire network.
- This can help us understand the structural vulnerabilities of the system which contributed to cause the current financial crisis.

Genesis of the financial crisis

According to Andy Haldane (Executive Director, Financial Stability - Bank of England), the genesis of the current financial crisis has been cause by:

- the *over-extension of credit*
- the *over-inflation of asset prices* (e.g. real estate)
- the *exuberance of participants*

Also, the *robust-yet-fragile* property of the financial system can be explained by:

- homogeneity of strategies (mainly caused by *follow-the-leader* dynamics)
- complexity of interactions (mainly caused by securitization)

Homogeneity:

- risk became a commodity (structured credit, securitization of debt, derivatives, etc. . .)
- diversification of business lines caused a *follow-the-leader* phenomenon

⇒ from an individual point of view, diversification was seen as an effective strategies for purging risk

⇒ from a systemic point of view, diversification strategies by individual firms generated a lack of diversity across the system as a whole

Complexity:

- securitization increased the dimensionality and hence the complexity of the IFN
- uncertainty regarding the location of underlying claims became anyone's guess

Complexity + Homogeneity = Fragility!

Why fragility?

Five mechanism influence the stability of the network:

- Connectivity
- Feedback
- Uncertainty
- Innovation
- Diversity

Connectivity and Stability

Three key robustness results:

- *robust-yet-fragile* property i.e. interconnected networks exhibit a knife-edge or tipping point property

$\Rightarrow$ within a certain range risk-sharing/diversification prevails, but with big shocks interconnections serve as shock-amplifiers (more on this later)

- *long-tailed distribution* of connected networks, i.e. the *degree distribution* is not symmetric and bell-shaped, instead we have a *larger-than-expected* number of nodes with high degree (i.e. hubs)

$\Rightarrow$ the network is more robust to random disturbances but more susceptible to targeted attacks (e.g. Lehman Brothers)

- *small world* property, i.e. certain nodes can introduce short-cuts connecting detached local communities (low average path length)

$\Rightarrow$ this increases the likelihood of local disturbances having global effects

Feedback and Stability

- In epidemiology, the impact of a disease depends on the *mortality rate* (fixed and biological) and on the *transmission rate* across agents (variable and sociological).
- The behavioral responses to an infection typically are: *hide* or *flight*.
- Hide responses tend to contain the infection locally, thus protecting the global system.
- Flight responses tend to propagate the infection globally.
- During the financial crisis, hide = hoarding of liquidity, flight = sales of (toxic) assets.
- Both responses contributed to de-stabilize the financial system:
  - hoarding worsened the funding position of all agents in the inter-bank network
  - financial firms funding problems increased the number of sales, lowering the prices of assets
  - new price levels diffused the infection to initially healthy agents

Uncertainty and Stability

- Uncertainties are amplified by the complex chains of claims generated by the financial network
- Example - pricing in the credit default swap (CDS) market:

- three agents: Ms. Wise, Mr. Greedy and Mr. Faulty.
- Wise buys a CDS from Greedy to hedge herself against the default of Faulty.
- So far, no uncertainty: Wise faces only counterparty risk on Greedy.
- What happens if also Greedy had *bought* credit default swaps to protect himself against the defaults of other agents?
- What happens if also Greedy had *sold* other credit default swaps?
- The number of possible counterparties explodes and to determine Greedy's counterparty risk you have to follow the entire chain of claims.
- Therefore, judging the default prospects of Mr. Greedy becomes a lottery where you do not know the odds.

$\Rightarrow$ asset prices are no longer determined!

$\Rightarrow$ also, it becomes almost impossible to spot the weakest link/node in the network!

Innovation and Stability

- New financial products: e.g. asset-backed securities (ABS), collateralized debt obligations (CDOs), etc. . .
- Structured finance amplified even further the network fragility of the financial system by increasing its complexity.
- For instance, the number of pages an investor should read before buying a CDO^2 are: 1 125 000 300! [6]
- For an interesting review see: "*The nature of financial innovation*" by Paul Nightingale and Taylor Spears [link].

Diversity and Stability

- In nature, diversity of the gene pool improve durability (e.g. coastal eco-systems, resilience of crops to pathogen outbreaks, etc. . .).
- In the financial system, the lack of diversity seems to be a common denominator.
- Financial imitation turned into near-cloning: correlations of returns across sectors averaged in excess of 0.9 in the period 2004–2007.
- Risk management amplified homogeneity: Basell II accord provided a prescriptive rule-book ensuring a level playing field (e.g. Value-at-Risk models).

⇒ the financial system became less disease-resistant!

Literature on Financial Networks

- Financial contagion, 3 examples: Allen and Gale (2000), Gai and Kapadia (2010)

⇒ how the topology of the network influences the possibility of contagion?

- International Financial Network: Chinazzi, Fagiolo, Reyes, Schiavo (2012)

⇒ has the 2008 financial crisis resulted in a significant change in the topological properties of the IFN?

⇒ is international connectedness a relevant predictor of crisis intensity once one explicitly accounts for the position of each country within the IFN?

- Networks of Global Corporate Control: Vitali, Glattfelder, Battiston (2011)

⇒ what is the worlwide structure of corporate control?

- Correlation-based networks

⇒ how is characterized the network of (correlated) financial assets?

Financial Contagion - Allen and Gale (2000) [1]

- Financial contagion is modeled as an equilibrium phenomenon
- Banks hold interregional claims on other banks to provide insurance against liquidity preference shocks
- First-best allocation of risk sharing can be achieved with no aggregate uncertainty
- But the system is fragile: a small liquidity preference shock in one region can spread by contagion throughout the economy
- The structure of the network is key in determining the possibility of contagion
- Complete networks are found to be more robust than incomplete structures

Framework

- Hypothesis: small shocks affecting few institutions or a particular region may spread by contagion and infect the larger economy
- Channel of contagion : overlapping claims that different regions or sectors of the banking system have on one another
- Transmission mechanism:
  - when one region suffers a bank crisis, the other regions suffer a loss because their claims on the troubled region fall in value
  - if this spillover effect is strong enough, it can cause a crisis in the adjacent regions
  - in extreme cases, the crisis passes from region to region and becomes a contagion

Assumptions I

- Agents have complete information about the environment

⇒ no self-fulfilling expectation of a crisis

- There is only one currency

⇒ exclude the effect of international currency markets in the propagation of financial crises

- There are three dates: $t = 0, 1, 2$ and N identical consumers each endowed with one unit of a homogeneous consumption good
- Consumers learn at $t = 1$ whether they are *early consumers*, who consumes in $t = 1$, or *late consumers*, who consumes in $t = 2$
- Preference uncertainty creates a demand for liquidity

Assumptions II

- Banks provide liquidity by investing consumers' deposits in two (storage technology) assets: a *short-term asset* that pays a return $r = 1$ in $t = 1$ and a *long-term asset* that pays $r' < 1$ in $t = 1$ or $r'' > 1$ after two periods
- The banking sector is perfectly competitive
- The economy consists of four ex-ante identical regions: A, B, C and D
- The number of early and late consumers in each region fluctuates but the aggregate demand for liquidity is constant
- Through an interbank market in deposits, regions with liquidity surpluses provide liquidity for regions with liquidity shortages

Example

- If region A has a higher than average number of early consumers at date 1, then banks in region A can meet their obligations by liquidating some of their deposits in the banks of region B.
- Region B is happy to oblige because it has an excess supply of liquidity in the form of the short asset.
- At the final date the process is reversed, as banks in region B liquidate the deposits they hold in region A to meet the above-average demand from late consumers in region B.

⇒ No problems if there is enough liquidity in the system
⇒ If that is not the case, banks have to start liquidating the *long-term assets*
⇒ If the interbank market is *complete* (each region is connected to all the other regions) the initial impact of the crisis is attenuated
⇒ If we have an *incomplete* market, contagion will spread across regions!

Mathematical framework

Consumer preferences:

$$U(c_1, c_2) = \begin{cases} u(c_1) & \text{with probability } p_i \\ u(c_2) & \text{with probability } 1 - p_i \end{cases} \quad (1)$$

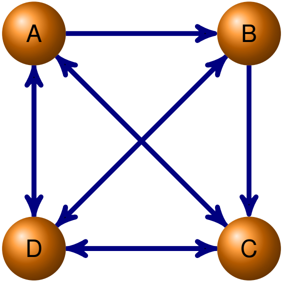
- $u(.)$ is twice continuously differentiable, increasing, and strictly concave.
- p_i is the probability of being an *early-consumer* in region i.
- There are two possible values for *pi*: $0 < p_L < p_H < 1$.
- Such values depends on the state of nature that is drawn at random (the two states are equally probable): S_1 or S_2:

	A	B	C	D
S_1	ω_H	ω_L	ω_H	ω_L
S_2	ω_L	ω_H	ω_L	ω_H

Scenario 1: no interbank market

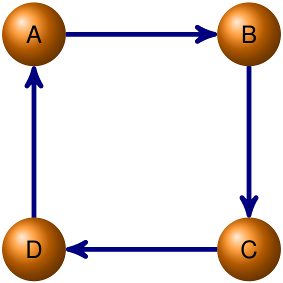
- Let γ be the average fraction of early consumer
- By construction we have that $\gamma < p_H$
- Let y and x be, respectively, the amount of *short-term* and *long-term* held by the bank
- Imagine that we are in region A and the state of nature is S_1
- Then, we have a liquidity shortage with banks in A forced to sell the *long-term* assets
- However, this would mean that they won't be able to fulfill the demand from *late-consumers*
- Since *late consumer* can foresee this, they will withdrawn their deposits causing a bank run

Scenario 2: the interbank market exists and it is complete



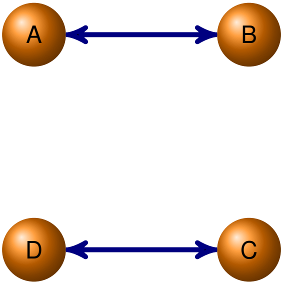
- In this case, the budget constraints for high and low liquidity regions is satisfied at every t
- High liquidity shocks regions will borrow from low liquidity regions in $t = 1$, while low liquidity shocks regions will do the same in $t = 2$

Scenario 3: the interbank market exists but it is incomplete



- Banks can have deposits only in one adjacent neighbor
- Banks in regions with high liquidity shocks have claims on deposits held in low liquidity shocks regions and viceversa
- Also in this case, the budget constraints are satisfied

Scenario 4: the interbank market is incomplete and disconnected



- Banks can have deposits only in one adjacent neighbor
- Banks in regions with high liquidity shocks have claims on deposits held in low liquidity shocks regions and viceversa
- Also in this case it is possible to satisfy the budget constraints of the banks

Financial Fragility

- Assume now that there exists a state of nature $\bar{S}$ where the aggregate demand for liquidity is greater than the system's ability to supply liquidity

	A	B	C	D
S_1	ω_H	ω_L	ω_H	ω_L
S_2	ω_L	ω_H	ω_L	ω_H
$\bar{S}$	$\gamma + \epsilon$	γ	γ	γ

- Define a bank as being *solvent* if it can meet the demands of every depositor who wants to withdraw (including banks in other regions) by using only its liquid assets, that is, the short asset and the deposits in other regions
- Define a bank as being *insolvent* if it can meet the demands of its deposits but only by liquidating some of the long asset
- Define a bank as being *bankrupt* if it cannot meet the demands of its depositors by liquidating all its assets

- Allen and Gale show that if we allow for a state of nature $\overline{S}$ in Scenario 3, we can have financial contagion for values of ε above a certain threshold
- The incompleteness of markets in Scenario 3 is essential to the contagion result, i.e. there exist parameter values for which any equilibrium with incomplete markets involves runs in state $\overline{S}$
- However, for the same parameter values, we can always find an equilibrium with complete markets that does not involve runs in state $\overline{S}$

⇒ Comparing the three market structures in Scenarios 1–3 we can see that there is a non-monotonic relationship between completeness and incompleteness of markets, while the actual topology of the network determines whether or not contagion occurs

Financial Contagion - Gai and Kapadia (2010) [5]

Two channel of contagion in financial systems are examined:

- *Direct contagion*: how losses may potentially spread via the complex network of direct counterparty exposures
- *Indirect contagion*: how changes in asset prices can transmit the crisis by forcing agents to write down the value of their assets in the balance sheet

Results:

- financial systems exhibit a *robust-yet-fragile* tendency, i.e. the probability of contagion may be low but the effects can be extremely widespread when problems occur
- seemingly indistinguishable shocks can have very different consequences depending on whether or not the shock hits at a particular pressure point in the network structure

Intuition

- In a highly connected system, the counterparty losses of a failing institution can be more widely dispersed to, and absorbed by, other entities; so increased connectivity and risk sharing may lower the probability of contagious default
- Conditional on the failure of one institution triggering contagious defaults, a high number of financial linkages also increases the potential for contagion to spread more widely
- High connectivity increases the chances that institutions which survive the effects of the initial default will be exposed to more than one defaulting counterparty after the first round of contagion, thus making them vulnerable to a second-round default
- The effects of any crises that do occur can, therefore, be extremely widespread

Methodology

- A financial network in which n financial intermediaries (i.e. banks)
- Banks are randomly linked together by their claims on each other
- Incoming links to a bank reflect the interbank assets/exposures of that bank, i.e. money owed to the bank by a counterparty
- Outgoing links from a bank correspond to its interbank liabilities
- The total assets of each bank consist of interbank assets (A_i^{IB}) and illiquid external assets (A_i^M)
- The total interbank asset position of every bank is evenly distributed over each of its incoming links and is independent of the number of links the bank has
- Every interbank asset is another bank's liability (L_i^{IB})
- Also, there are exogenously given customer deposits (D_i)
- Let ϕ be the faction of defaulted neighbors and q the resale price of illiquid assets
- A bank i is solvent iff: $(1-\phi)A_i^{IB} + qA_i^M - L_i^{IB} - D_i > 0$

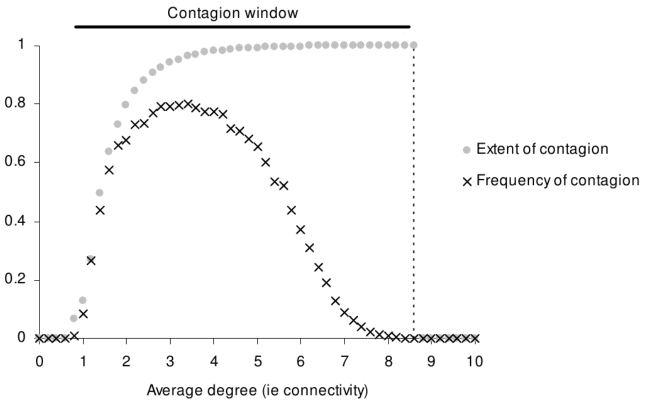
Contagion

- All banks in the network are initially solvent but the network is perturbed at time $t = 1$ by the initial default of a single bank
- The solvency condition is: $\phi < \frac{K_i - (1-q)A_i^M}{A_i^{IB}}$, where $A_i^{IB} \neq 0$
- $K_i = A_i^{IB} + A_i^M - L_i^{IB} - D_i$ is the bank's capital buffer, i.e. the difference between the book value of its assets and liabilities
- Default can spread if there is a neighbouring bank for which: $\frac{K_i - (1-q)A_i^M}{A_i^{IB}} < \frac{1}{j_i}$, where j_i is the in-degree of i
- Banks for which this condition holds are said to be *vulnerable* with probability: $v_j = P\left[\frac{K_i - (1-q)A_i^M}{A_i^{IB}} < \frac{1}{j_i}\right], \forall j \geq 1$
- Other banks are considered as *safe*
- The probability of a bank having in-degree j, out-degree k and being *vulnerable* is $v_j p_{jk}$, where p_{jk} is the joint probability distribution of in and out-degree

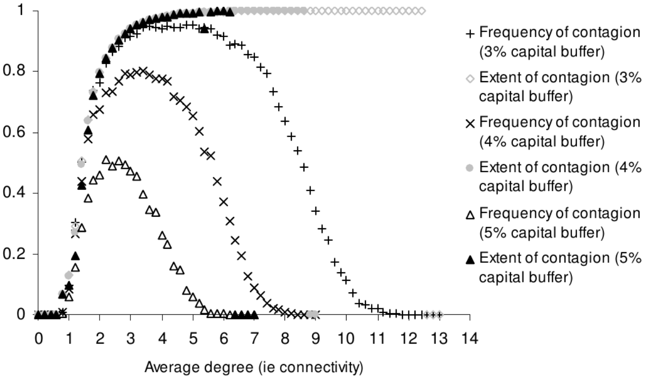
Numerical Simulations

- In the baseline model, the number of banks is set to 1 000
- A uniform random graph is assumed (i.e. each link is present with independent probability p)
- Average degree (i.e. connectedness of the graph) is allowed to vary in each simulation
- Banks are identical in terms of asset endowment : 80% external (non-bank) assets, 20% interbank assets
- Capital buffers are set to 4% of total assets
- A random *fraud shock* is drawn at each simulation: i.e. one bank is selected and all of its external assets are wiped out
- Neighboring banks can default if their capital buffer is insufficient to cover their loss on interbank assets

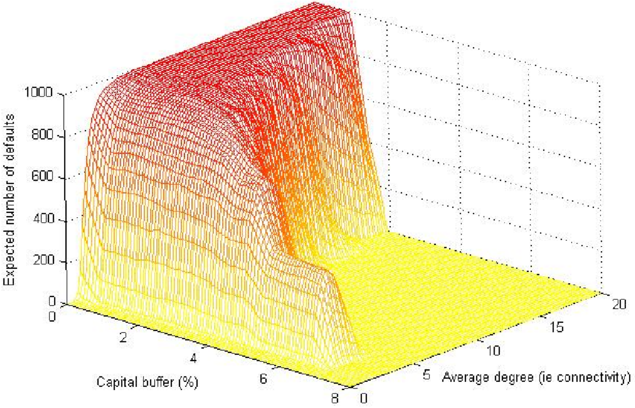
Benchmark case



Varying the capital buffer



Connectivity, capital buffers, and the expected number of defaults



Adding liquidity risk

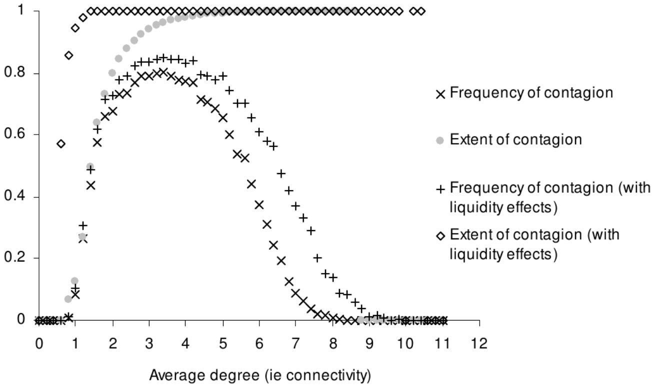
- Financial markets have a limited capacity to absorb the illiquid external assets which are sold

$\Rightarrow$ A_i^M asset prices are depressed in case of fire selling caused by defaulting banks

$\Rightarrow$ $q = e^{-\alpha x}$, where $x > 0$ is the fraction of system (illiquid) assets which have been sold onto the market

$\Rightarrow$ If $\Downarrow q \Rightarrow K_i \Downarrow$

$\Rightarrow$ Both the extend of contagion and the contagion window widen!


1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6 7 8 9 10 11 12
Average degree (ie connectivity)
Frequency of contagion
Extent of contagion
Frequency of contagion (with liquidity effects)
Extent of contagion (with liquidity effects)

Conclusions

- The probability of contagion is non-monotonic in the average-degree
- *A priori* indistinguishable shocks can have vastly different consequences for contagion
- Erosion of capital buffers both widens the contagion window and increase the probability of contagion for fixed values of connectivity
- Liquidity risk magnifies the extent of contagion when it breaks out and also widens the contagion window
- *Robust-yet-fragile* property of the financial system is confirmed!

Post-Mortem Examination of the International Financial Network

Matteo Chinazzi[1] Giorgio Fagiolo[1]
Javier A. Reyes[2] Stefano Schiavo[3]

giorgio.fagiolo@sssup.it
http://www.lem.sssup.it/fagiolo/Welcome.html

[1]Sant'Anna School of Advanced Studies (Italy)

[2]University of Arkansas (USA)

[3]University of Trento (Italy)

Global Systems as Networks of Networks
May 2012, Florence

Motivations

- **The Crisis and Financial-Market Interconnectdness**
  - Banks too connected to be allowed to fail?
  - Financial integration and potential worldwide spreading of local shocks

Motivations

- **The Crisis and Financial-Market Interconnectdness**
  - Banks too connected to be allowed to fail?
  - Financial integration and potential worldwide spreading of local shocks
- **The Role of Network Theory**
  - We need a better understanding of the structure and evolution of financial networks, defined as systems where economic players (countries, banks, financial institutions) do not act in isolation but rather are linked via a complex set of interactions (Schweitzer et al., 2009, Science)

Related Literature

- **Theory: Contagion effects in the inter-bank lending network**
  - Allen & Gale (2000): Shocks are more easily dissipated within full networks, sparser networks less robust; cf also Freixas et al. (2000), Leitner (2005)
  - Gai & Kapadia (2010): higher connectivity reduces likelihood of widespread default, but implies also more fragility (when contagion occurs, effects can be tougher)
  - Role of node heterogeneity: positive effects of higher density on diversification is counterbalanced by fragility implied by network stars (Iori et al, 2006; Caccioli et al 2006).

Related Literature

- **Theory: Contagion effects in the inter-bank lending network**
  - Allen & Gale (2000): Shocks are more easily dissipated within full networks, sparser networks less robust; cf also Freixas et al. (2000), Leitner (2005)
  - Gai & Kapadia (2010): higher connectivity reduces likelihood of widespread default, but implies also more fragility (when contagion occurs, effects can be tougher)
  - Role of node heterogeneity: positive effects of higher density on diversification is counterbalanced by fragility implied by network stars (Iori et al, 2006; Caccioli et al 2006).

- **Empirics: Exploring topological properties of inter-bank networks**
  - Domestic and cross-border interbank networks (Cocco et al., 2009; Von Peter, 2007; Rordan & Bech, 2009; Li et al, 2010; Iori et al, 2011; Cajueiro & Tabak, 2007; Imakubo & Soejima, 2010; Propper et al, 2008; Georg, 2010; Soramaki et al, 2006; De Masi et al, 2006; Boss et al, 2003; Sokolov et al, 2012; Bech et al, 2008; Iazzetta et al, 2010; Haldane & May, 2009; Garratt et al, 2009)
  - Global banking network (Hale, 2011)

This Paper

- **Country-level International Financial Network (IFN)**
  - Weighted-directed multigraph where nodes are world countries and links represent debtor-creditor relationships in equities and short/long-run debt
  - Schiavo, Reyes & Fagiolo, 2010; Minoiu & Reyes, 2011

This Paper

- **Country-level International Financial Network (IFN)**
  - Weighted-directed multigraph where nodes are world countries and links represent debtor-creditor relationships in equities and short/long-run debt
  - Schiavo, Reyes & Fagiolo, 2010; Minoiu & Reyes, 2011

- **Research Questions**
  - Has the 2008 financial crisis resulted in a significant change in the topological properties of the IFN?
  - Is country "position" in the IFN a good predictor of its performance during the crisis?

This Paper

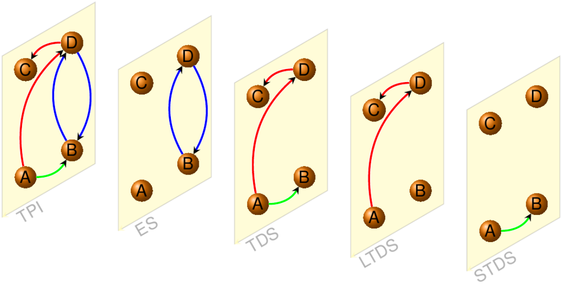
- **Country-level International Financial Network (IFN)**
  - Weighted-directed multigraph where nodes are world countries and links represent debtor-creditor relationships in equities and short/long-run debt
  - Schiavo, Reyes & Fagiolo, 2010; Minoiu & Reyes, 2011
- **Research Questions**
  - Has the 2008 financial crisis resulted in a significant change in the topological properties of the IFN?
  - Is country "position" in the IFN a good predictor of its performance during the crisis?
- **What do we do?**
  - Explore the topological properties of the IFN as the crisis unfolds
  - Perform econometric analyses to examine the ability of country network statistics to explain cross-country differences in crisis intensity (cf. Rose and Spiegel, 2010, 2011; Frankel and Saravelos, 2011; Lane and Milesi-Ferretti, 2011; Giannone et al., 2011)

Data

- Main source of data: Coordinated Portfolio Investment Survey (CPIS), collected by the International Monetary Found (IMF)
- Data include cross-border portfolio investment holdings of equity securities, long-term debt securities and short-term debt securities listed by country of residence of issuer
- We have complete bilateral data for roughly 70 countries for the period 2001–2010
- Additional data include: World Development Indicators (WDI), collected by the World Bank

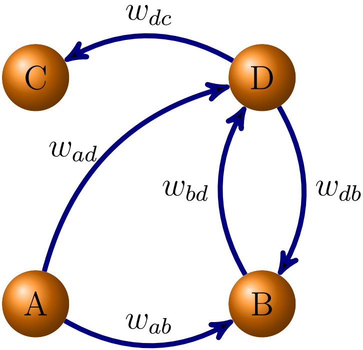
The IFN

- We build a 5-layer weighted-directed multigraph, where each directed link is weighted by the value of security – in millions of current dollars – issued by the origin node and held by the target



TPI = Total Portfolio Investments, i.e. the graph is built considering of all the financial exposures between countries. ES = Equity Securities, i.e. consider only equity securities. TDS = Total Debt Securities, i.e. consider only debt securities. LTDS = Long-term Debt Securities, i.e consider only long-term debt securities. STDS = Short-term Debt Securities, i.e. consider only short-term debt securities.

The IFN



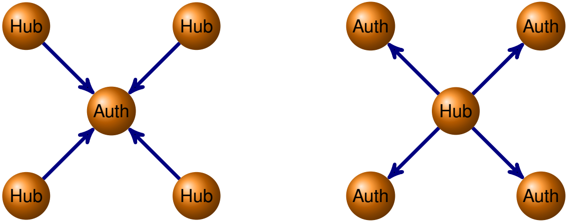
Links connect issuing country to security holder. For example, A issues securities held by B and D (i.e. A is a debtor of B and D) where w_{ab} and w_{ad} are the values of such securities in (millions of) current dollars.

Network Statistics

- In/Out Degree and Strength
- Average Nearest-Neighbor Degree (ANND) and Strength (ANNS)
- Binary (BCC) and Weighted (WCC) Clustering Coefficient

Network Statistics

- In/Out Degree and Strength
- Average Nearest-Neighbor Degree (ANND) and Strength (ANNS)
- Binary (BCC) and Weighted (WCC) Clustering Coefficient
- Hubs and Authority Centrality



- Financial authorities are primary sources of investments, i.e. countries that hold securities issued by many hubs
- Financial hubs are primary borrowers, i.e. countries that issue securities held by many authorities

Evolution of IFN Structure: Pre vs Post Crisis (1)

- **Density**
  - IFN density increased until 2007, dropped in 2008, and then increased again
  - The crisis caused some countries to revise their relationships, reducing their financial linkages (Hale, 2011)

Evolution of IFN Structure: Pre vs Post Crisis (1)

- **Density**
  - IFN density increased until 2007, dropped in 2008, and then increased again
  - The crisis caused some countries to revise their relationships, reducing their financial linkages (Hale, 2011)
- **Node Degree/Strength Distributions**
  - From bimodal (pre) to unimodal (post) distributions, especially in the ES layer
  - Very connected nodes seem to have reduced their exposures. This is especially true for nodes that had many creditors as compared to the average behavior of all other countries.

Evolution of IFN Structure: Pre vs Post Crisis (1)

- **Density**
  - IFN density increased until 2007, dropped in 2008, and then increased again
  - The crisis caused some countries to revise their relationships, reducing their financial linkages (Hale, 2011)
- **Node Degree/Strength Distributions**
  - From bimodal (pre) to unimodal (post) distributions, especially in the ES layer
  - Very connected nodes seem to have reduced their exposures. This is especially true for nodes that had many creditors as compared to the average behavior of all other countries.

The financial crisis not only changed the topology of the network by decreasing the overall number of connections among the countries, but also by altering the distributions of such statistics

Evolution of IFN Structure: Pre vs Post Crisis (2)

- **ANND/ANNS**
  - ANND/ANNS distributions shift to the right and become less dispersed: countries tend to connect over time to more/better connected countries
  - Negative shocks can be better absorbed since their impact is shared by many countries, but can diffuse more easily throughout the network (Gai and Kapadia, 2010)

Evolution of IFN Structure: Pre vs Post Crisis (2)

- **ANND/ANNS**
  - ANND/ANNS distributions shift to the right and become less dispersed: countries tend to connect over time to more/better connected countries
  - Negative shocks can be better absorbed since their impact is shared by many countries, but can diffuse more easily throughout the network (Gai and Kapadia, 2010)
- **Node Clustering**
  - Clustering distributions in equity vs debt layers go in opposite directions
  - Equity: shift to the left in 2008, but then moves to the right again
  - Debt: steady shift to the left after 2008
  - Equity securities recovered more quickly from the 2008 shock, whereas investment behavior in debt securities have been strongly impacted by the crisis

Evolution of IFN Structure: Pre vs Post Crisis (2)

- **ANND/ANNS**
  - ANND/ANNS distributions shift to the right and become less dispersed: countries tend to connect over time to more/better connected countries
  - Negative shocks can be better absorbed since their impact is shared by many countries, but can diffuse more easily throughout the network (Gai and Kapadia, 2010)
- **Node Clustering**
  - Clustering distributions in equity vs debt layers go in opposite directions
  - Equity: shift to the left in 2008, but then moves to the right again
  - Debt: steady shift to the left after 2008
  - Equity securities recovered more quickly from the 2008 shock, whereas investment behavior in debt securities have been strongly impacted by the crisis

This is observed in many other stats: debt layers require more time to invert the trend after the crisis

Evolution of IFN Structure: Pre vs Post Crisis (3)

- **Correlation Structure among Node Network Statistics**
  - Countries with a large number of creditors/debtors tend also to hold/issue more dollars of securities
  - Over time: Countries who have more debtors increase securities they hold; countries that have more creditors tend to diminish their exposures
  - IFN is disassortative: neighbors of well connected and highly influential countries have fewer creditors/debtors and hold/issue less securities
  - No structural changes in correlation structure before and after the crisis: robustness of IFN (see also WTW)

Evolution of IFN Structure: Pre vs Post Crisis (3)

- **Correlation Structure among Node Network Statistics**
  - Countries with a large number of creditors/debtors tend also to hold/issue more dollars of securities
  - Over time: Countries who have more debtors increase securities they hold; countries that have more creditors tend to diminish their exposures
  - IFN is disassortative: neighbors of well connected and highly influential countries have fewer creditors/debtors and hold/issue less securities
  - No structural changes in correlation structure before and after the crisis: robustness of IFN (see also WTW)

- **Rich-Club in the IFN?**
  - Binary IFN: Creditors/debtors of many countries interact with countries that are not debtors or creditors of each other (hub-and-spoke structure)
  - Weighted IFN: NS-WCC correlation is positive and high, hinting to a rich-club structure
  - Opsahl et al. (2008) coefficient suggests a rich-club core composed of top 25/30 countries (in terms of NS) linked to the periphery

Evolution of IFN Structure: Pre vs Post Crisis (4)

- **Hub-Authority Centrality**
  - Top hub-authority centrality ranks feature developed economies and well-known financial centers (Luxembourg, Switzerland, tax heavens)
  - In the weighted case there is a higher likelihood that countries display both high hub and authority centrality than in the binary case
  - Presence of many tax heavens among the top binary financial authorities

Evolution of IFN Structure: Pre vs Post Crisis (4)

- **Hub-Authority Centrality**
  - Top hub-authority centrality ranks feature developed economies and well-known financial centers (Luxembourg, Switzerland, tax heavens)
  - In the weighted case there is a higher likelihood that countries display both high hub and authority centrality than in the binary case
  - Presence of many tax heavens among the top binary financial authorities
- **Tax Heavens in the IFN**
  - Opposite roles that Cayman Islands and Luxembourg play in the IFN
  - Cayman Islands are more important as a financial hub than as a financial authority
  - Luxembourg appears to be a financial authority but not a financial hub
  - Cayman Islands are more important as a country where depositing money, while Luxembourg is more useful to incorporate companies that then can be employed as holdings for companies operating elsewhere

Evolution of IFN Structure: Summing Up

- The crisis forced countries to revise their relationships, implying an overall reduction of financial linkages and a distributional shift

Evolution of IFN Structure: Summing Up

- The crisis forced countries to revise their relationships, implying an overall reduction of financial linkages and a distributional shift
- Very connected nodes reduced their exposures and preferentially selected more/better connected countries, adopting a more careful selection strategy

Evolution of IFN Structure: Summing Up

- The crisis forced countries to revise their relationships, implying an overall reduction of financial linkages and a distributional shift
- Very connected nodes reduced their exposures and preferentially selected more/better connected countries, adopting a more careful selection strategy
- Debt layers required more time to invert the trend after the crisis, equity security layer quicker

Evolution of IFN Structure: Summing Up

- The crisis forced countries to revise their relationships, implying an overall reduction of financial linkages and a distributional shift
- Very connected nodes reduced their exposures and preferentially selected more/better connected countries, adopting a more careful selection strategy
- Debt layers required more time to invert the trend after the crisis, equity security layer quicker
- Correlation structure very robust to the crisis

Evolution of IFN Structure: Summing Up

- The crisis forced countries to revise their relationships, implying an overall reduction of financial linkages and a distributional shift
- Very connected nodes reduced their exposures and preferentially selected more/better connected countries, adopting a more careful selection strategy
- Debt layers required more time to invert the trend after the crisis, equity security layer quicker
- Correlation structure very robust to the crisis
- Disassortative network, rich-club emergence in weighted IFN

Evolution of IFN Structure: Summing Up

- The crisis forced countries to revise their relationships, implying an overall reduction of financial linkages and a distributional shift
- Very connected nodes reduced their exposures and preferentially selected more/better connected countries, adopting a more careful selection strategy
- Debt layers required more time to invert the trend after the crisis, equity security layer quicker
- Correlation structure very robust to the crisis
- Disassortative network, rich-club emergence in weighted IFN
- Centrality analysis hints to important role of tax heavens

Impact of Network Structure on Crisis Intensity

- **Literature on Early-Warning Systems (EWS)**
  - Explaining cross-sectional difference in crisis intensity and finding predictors of systemic-risk building up
  - See Berkmen et al, 2009; Blanchard et al, 2010; Claessens et al, 2010; Rose & Spiegel, 2010, 2011; Frankel & Saravelos, 2011; Lane & Milesi-Ferretti, 2011; Giannone et al, 2011
  - Weakness: they do not properly consider international linkages

Impact of Network Structure on Crisis Intensity

- **Literature on Early-Warning Systems (EWS)**
  - Explaining cross-sectional difference in crisis intensity and finding predictors of systemic-risk building up
  - See Berkmen et al, 2009; Blanchard et al, 2010; Claessens et al, 2010; Rose & Spiegel, 2010, 2011; Frankel & Saravelos, 2011; Lane & Milesi-Ferretti, 2011; Giannone et al, 2011
  - Weakness: they do not properly consider international linkages
- **Our Empirical Strategy**
  - Define a measure of crisis intensity
  - Select a vector of macro-economic controls
  - Add country network indicators
  - Run cross-sectional or panel GMM estimation to see if network indicators can explain crisis intensity (given macroeconomic controls)

Cross-Sectional Estimation: Setup

- **Benchmark Econometric Specification**

$$y_{i,2008} = \gamma x'_{i,2006} + \theta g_{i,2006} + v_{i,2008}$$

where y_i is any crisis measure, x_{it} is a vector of macro-economic controls, g_{it} is a vector of network measures, $v_{i,t}$ is the error component and $i = \{1 \dots 74\}$.

Cross-Sectional Estimation: Setup

- **Benchmark Econometric Specification**

$$y_{i,2008} = \gamma x'_{i,2006} + \theta g_{i,2006} + v_{i,2008}$$

where y_i is any crisis measure, x_{it} is a vector of macro-economic controls, g_{it} is a vector of network measures, $v_{i,t}$ is the error component and $i = \{1 \dots 74\}$.

- **Crisis Intensity, Controls and Network Measures**
  - Real: 2009-2008 Change in rGDP; Financial: Volatility-adjusted stock-market returns (Sep 15, 2008 – Mar 31, 2009)
  - Credit market regulation, rGDP pc, bank credit to private sector over GDP, current account over GDP, etc.)
  - ND in and out; directed ANNDs; BCC; BAC (endogeneity issues)

Cross-Sectional Estimation: Results

- **Real Measures of Crisis Intensity**
  - Controls: GDP suffered more in countries with higher income, less regulated capital markets, smaller current-account surpluses, and those experiencing credit crunches
  - Network Effects: The higher the number of debtors (ND-in) the smaller crisis intensity (risk diversifiction?)
  - Nonlinear effect of connectivity: the marginal effect of an increase in ND-in vanishes for very connected countries (those in the core)
  - Network variables allow for a substantial improvement of GoF

Cross-Sectional Estimation: Results

- **Real Measures of Crisis Intensity**
  - Controls: GDP suffered more in countries with higher income, less regulated capital markets, smaller current-account surpluses, and those experiencing credit crunches
  - Network Effects: The higher the number of debtors (ND-in) the smaller crisis intensity (risk diversifiction?)
  - Nonlinear effect of connectivity: the marginal effect of an increase in ND-in vanishes for very connected countries (those in the core)
  - Network variables allow for a substantial improvement of GoF
- **Financial Measures of Crisis Intensity**
  - Controls: Stronger negative effect of income (subprime crisis)
  - Network variables: Stock market performance increases (non-linearly) with both ND-in and ND-out, and with the number of creditors of a country creditors (out-out ANND)
  - Adding network variables improves even more GoF

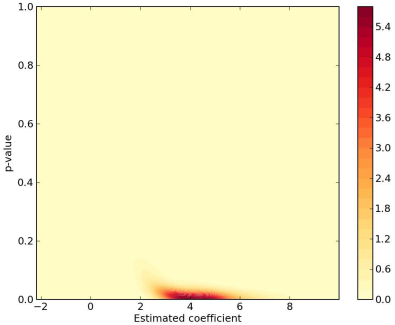
Panel GMM: Motivations and Setup

- **Problems with Cross-Section Estimation**
  - Small sample size forces to use small set of controls and network effects
  - Endogeneity (dependent variables and network effects)
  - Omitted variable bias

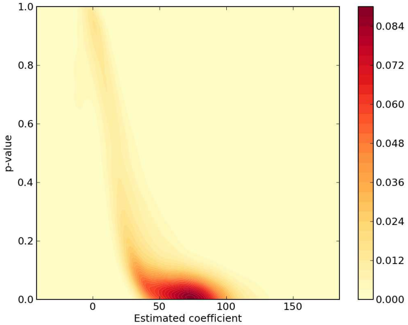
Panel GMM: Motivations and Setup

- **Problems with Cross-Section Estimation**
  - Small sample size forces to use small set of controls and network effects
  - Endogeneity (dependent variables and network effects)
  - Omitted variable bias
- **A (partial) solution**
  - We fit a panel GMM using Arellano & Bond (1991) estimator and we employ Windmeijer (2005) correction for finite samples, including crisis dummy variables as interaction terms for network indicators
  - Robustness analysis: we overcome small sample-bias problems by running ALL possible regression specifications (around 1.3 million) stemming from the choice of all controls plus 4 network indicators (out of 26 available)
  - This allows us to see how stable are network-effect results for all possible specifications
  - Significance and sign of the impact of a network variable is evaluated looking at (p-val,estimated coeff) surface plots obtained gathering data from all regressions where that network variable enters the specification

Panel GMM: Example of *Significant* Regressors

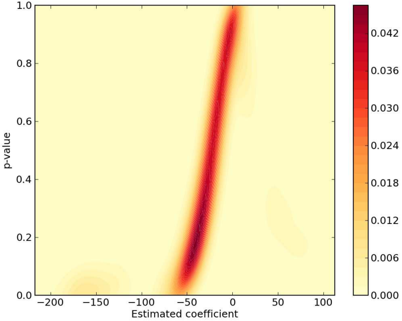


(a) NDin - TPI

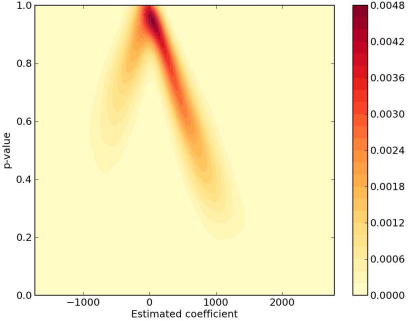


(b) log(WCC) - TPI

Panel GMM: Example of *Unsignificant* Regressors



(a) log(BAC) - ES



(b) WAC - TPI

Panel GMM: Main Results

- **Risk diversication vs vulnerability**
  - Significant first- and second-order network regressors have a positive effect on stock-market performance, supporting the risk-diversification hypothesis
  - Significant higher-order binary network regressors (e.g. clustering and centrality) tend to enter negatively, hinting to higher vulnerability due to country embeddedness within the IFN
  - High WCC values shield instead a country from contagion, as that typically means being part of the IFN rich-club

Panel GMM: Main Results

- **Risk diversication vs vulnerability**
  - Significant first- and second-order network regressors have a positive effect on stock-market performance, supporting the risk-diversification hypothesis
  - Significant higher-order binary network regressors (e.g. clustering and centrality) tend to enter negatively, hinting to higher vulnerability due to country embeddedness within the IFN
  - High WCC values shield instead a country from contagion, as that typically means being part of the IFN rich-club
- **Role of Network Variables**
  - Unsignificant interaction effects between crisis dummies and network indicators
  - The role of network indicators remains the same before and after the crisis
  - Network indicators can be used to predict country vulnerability to shocks, no matter whether we are in a period of distress or not

Take-Home Messages

- The structure of the IFN has been severely hit by the financial crisis
- Detectable impact not only at the aggregate level (density) but also on node-specific network statistic distributions (degree, ANND, etc.)
- Different layers (debt vs security) of the IFN responded in a different way to the crisis

Take-Home Messages

- The structure of the IFN has been severely hit by the financial crisis
- Detectable impact not only at the aggregate level (density) but also on node-specific network statistic distributions (degree, ANND, etc.)
- Different layers (debt vs security) of the IFN responded in a different way to the crisis
- Country network indicators exert a significant and stable role in explaining both real and financial impact of the crisis on a country
- Their effects are typically non-linear (Iori et al, 2006; Caccioli et al, 2011)

Take-Home Messages

- The structure of the IFN has been severely hit by the financial crisis
- Detectable impact not only at the aggregate level (density) but also on node-specific network statistic distributions (degree, ANND, etc.)
- Different layers (debt vs security) of the IFN responded in a different way to the crisis

- Country network indicators exert a significant and stable role in explaining both real and financial impact of the crisis on a country
- Their effects are typically non-linear (Iori et al, 2006; Caccioli et al, 2011)

- Higher local connectivity shields country from severe impact via risk diversification
- Higher (binary) global embeddedness in the IFN exposes a country to a higher vulnerability, especially if the country is not within the rich-club of the IFN

Extensions

- Targeted shocks and network-resilience tests
- Exploring alternative (synthetic?) crisis indicators
- Expanding the analysis using a macroeconomic multi-network (financial linkages, trade, FDIs, human mobility, etc.)
- Replicating our exercises on the global banking network (Fagiolo, Minoiu, Reyes, fc)

Extensions

- Targeted shocks and network-resilience tests
- Exploring alternative (synthetic?) crisis indicators
- Expanding the analysis using a macroeconomic multi-network (financial linkages, trade, FDIs, human mobility, etc.)
- Replicating our exercises on the global banking network (Fagiolo, Minoiu, Reyes, fc)

Paper:

Chinazzi, M., Fagiolo, G., Reyes, J. and Schiavo, S. (2012), "Post-Mortem Examination of the International Financial Network", SSRN eLibrary, available at `http://papers.ssrn.com`

The Network of Global Corporate Control [9]

- Starting point: firms may exert control over other firms via a web of direct and indirect ownership relations which extends over many countries
- Aim of the paper: uncover the worldwide structure of corporate control
- Policy implications:
  - linkages among financial institutions have ambiguous effects on their financial fragility
  - mutual ownership relations can jeopardize market competition
- Results:
  - bow-tie relationships at the core of the network
  - existence of an economic “super-entity”

Transnational corporations (TNCs) definition by OECD:

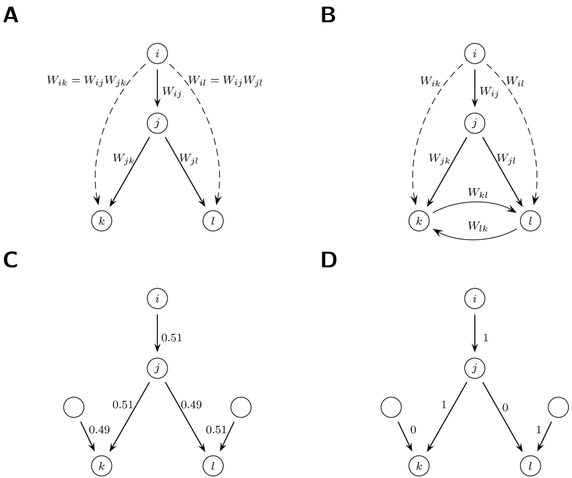
> *[. . .] comprise companies and other entities established in more than one country and so linked that they may coordinate their operations in various ways, while one or more of these entities may be able to exercise a significant influence over the activities of others, their degree of autonomy within the enterprise may vary widely from one multinational enterprise to another. Ownership may be private, state or mixed.*

Data:

- Orbis 2007 marketing database
- 37 million economic actors (firms and physical persons) located in 194 countries
- 13 million directed and weighted ownership links (equity relationships)
- other info: industrial classification, geographical position and operating revenue
- the percentage of ownership refers to shares associated with voting rights (whenever possible)
- selected companies hold at least 10% of shares in companies located in more than one country

Methodology:

- Ownership matrix W where $W_{ij} \in [0,1]$ is the percentage of ownership that the owner i holds in firm j
- Indirect ownership is detected, e.g. indirect ownership of l by i through j is measured as $W_{ij} W_{jl}$
- Control C_{ij} computed from ownership W_{ij} with a simple threshold rule: the majority shareholder has full control
- Network control c_i^{net} sums up the value controlled by i, i.e. network control has the meaning of the total amount of economic value over which i has an influence
- $c_i^{net} = \sum_j C_{ij} v_j + \sum_j C_{ij} c_j^{net}$, where v_j is the economic value of firm j



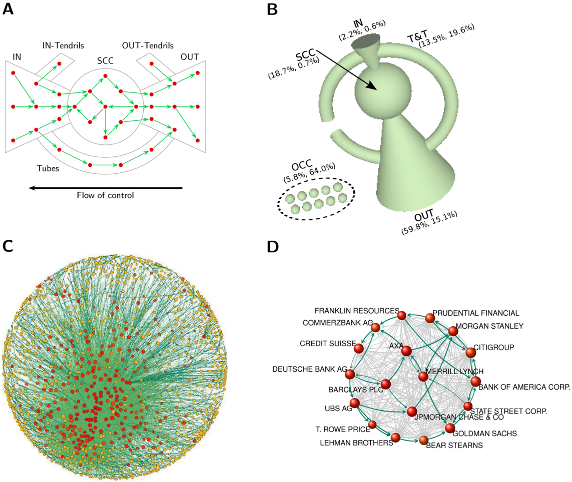
Ownership and Control (A&B) Direct and indirect ownership. (A) Firm i has W_{ij} percent of direct ownership in firm *j*. Through *j*, it has also an indirect ownership in *k* and *l*. (B) With cycles one has to take into account the recursive paths. (C&D) Threshold model. (C) Percentages of ownership are indicated along the links. (D) If a shareholder has ownership exceeding a threshold (e.g. 50%), it has full control (100%) and the others have none (0%). Source [9]

Results - Network Topology:

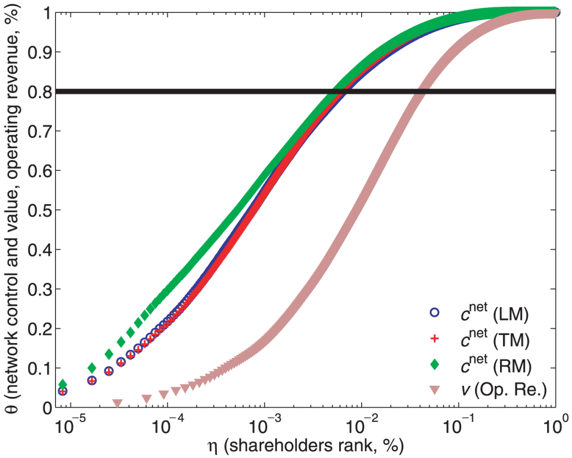
- the network consists of many small connected components
- the largest one (3/4 of all nodes) contains all the top TNCs by economic value
- abundance of cycles of length two (mutual cross-shareholdings) or greater (competition is weakened)
- the largest connected component contains only one dominant strongly connected component (*core*)
- *bow-tie* structure of the core: i.e. one can pass from any node of IN through SCC to any node of OUT. Hanging off IN and OUT are *tendrils* containing nodes that are reachable from portions of IN, or that can reach portions of OUT, without passage through SCC. It is possible for a tendril hanging off from IN to be hooked into a tendrils leading into OUT, forming a *tube* (a passage from a portion of IN to a portion of OUT without touching SCC)
- 3/4 of the ownership of firms in the core remains in the hands of firms of the core itself

Results - Concentration of Control:

- network control is much more unequally distributed than wealth
- the top ranked actors hold a control ten times bigger than what could be expected based on their wealth



Network topology (A) A bow-tie consists of in-section (IN), out-section (OUT), strongly connected component or core (SCC), and tubes and tendrils (T&T). (B) Bow-tie structure of the largest connected component (LCC) and other connected components (OCC). Each section volume scales logarithmically with the share of its TNCs operating revenue. In parenthesis, percentage of operating revenue and number of TNCs. (C) SCC layout of the SCC (1318 nodes and 12191 links). Node size scales logarithmically with operation revenue, node color with network control (from yellow to red). Link color scales with weight. (D) Zoom on some major TNCs in the financial sector. Some cycles are highlighted. Source [9]



Concentration of network control and operating revenue Economic actors (TNCs and shareholders) are sorted by descending importance, as given by c_{net}. A data point located at (η,θ) corresponds to a fraction θ of top economic actors cumulatively holding the fraction θ of network control, value or operating revenue. The different curves refer to network control computed with three models (LM, TM, RM) and operating revenue. The horizontal line denotes a value of h equal to 80%. The level of concentration is determined by the η value of the intersection between each curve and the horizontal line. The scale is semi-log. Source [9]

Rank	Economic actor name	Country	NACE code	Network position	Cumul. network control (TM, %)
1	BARCLAYS PLC	GB	6512	SCC	4.05
2	CAPITAL GROUP COMPANIES INC, THE	US	6713	IN	6.66
3	FMR CORP	US	6713	IN	8.94
4	AXA	FR	6712	SCC	11.21
5	STATE STREET CORPORATION	US	6713	SCC	13.02
6	JPMORGAN CHASE & CO.	US	6512	SCC	14.55
7	LEGAL & GENERAL GROUP PLC	GB	6603	SCC	16.02
8	VANGUARD GROUP, INC., THE	US	7415	IN	17.25
9	UBS AG	CH	6512	SCC	18.46
10	MERRILL LYNCH & CO., INC.	US	6712	SCC	19.45
11	WELLINGTON MANAGEMENT CO. L.L.P.	US	6713	IN	20.33
12	DEUTSCHE BANK AG	DE	6512	SCC	21.17
13	FRANKLIN RESOURCES, INC.	US	6512	SCC	21.99
14	CREDIT SUISSE GROUP	CH	6512	SCC	22.81
15	WALTON ENTERPRISES LLC	US	2923	T&T	23.56
16	BANK OF NEW YORK MELLON CORP.	US	6512	IN	24.28
17	NATIXIS	FR	6512	SCC	24.98
18	GOLDMAN SACHS GROUP, INC., THE	US	6712	SCC	25.64
19	T. ROWE PRICE GROUP, INC.	US	6713	SCC	26.29
20	LEGG MASON, INC.	US	6712	SCC	26.92
21	MORGAN STANLEY	US	6712	SCC	27.56
22	MITSUBISHI UFJ FINANCIAL GROUP, INC.	JP	6512	SCC	28.16
23	NORTHERN TRUST CORPORATION	US	6512	SCC	28.72
24	SOCIÉTÉ GÉNÉRALE	FR	6512	SCC	29.26
25	BANK OF AMERICA CORPORATION	US	6512	SCC	29.79
26	LLOYDS TSB GROUP PLC	GB	6512	SCC	30.30
27	INVESCO PLC	GB	6523	SCC	30.82
28	ALLIANZ SE	DE	7415	SCC	31.32
29	TIAA	US	6601	IN	32.24
30	OLD MUTUAL PUBLIC LIMITED COMPANY	GB	6601	SCC	32.69
31	AVIVA PLC	GB	6601	SCC	33.14
32	SCHRODERS PLC	GB	6712	SCC	33.57
33	DODGE & COX	US	7415	IN	34.00
34	LEHMAN BROTHERS HOLDINGS, INC.	US	6712	SCC	34.43
35	SUN LIFE FINANCIAL, INC.	CA	6601	SCC	34.82
36	STANDARD LIFE PLC	GB	6601	SCC	35.2
37	CNCE	FR	6512	SCC	35.57
38	NOMURA HOLDINGS, INC.	JP	6512	SCC	35.92
39	THE DEPOSITORY TRUST COMPANY	US	6512	IN	36.28
40	MASSACHUSETTS MUTUAL LIFE INSUR.	US	6601	IN	36.63
41	ING GROEP N.V.	NL	6603	SCC	36.96
42	BRANDES INVESTMENT PARTNERS, L.P.	US	6713	IN	37.29
43	UNICREDITO ITALIANO SPA	IT	6512	SCC	37.61
44	DEPOSIT INSURANCE CORPORATION OF JP	JP	6511	IN	37.93
45	VERENIGING AEGON	NL	6512	IN	38.25
46	BNP PARIBAS	FR	6512	SCC	38.56
47	AFFILIATED MANAGERS GROUP, INC.	US	6713	SCC	38.88
48	RESONA HOLDINGS, INC.	JP	6512	SCC	39.18
49	CAPITAL GROUP INTERNATIONAL, INC.	US	7414	IN	39.48
50	CHINA PETROCHEMICAL GROUP CO.	CN	6511	T&T	39.78

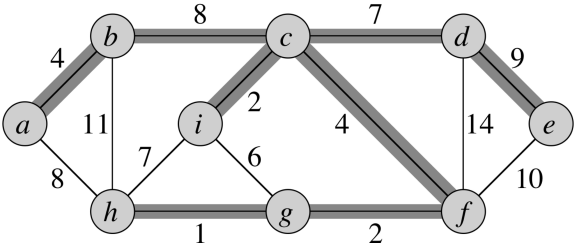
Minimum Spanning Tree (MST)

Definition

A *tree* is a connected, undirected network that contains no closed loops. By connected we mean that every vertex in the network is reachable from every other via some path through the network [8].

Definition

Let G be an undirected graph (V, E), where V is the set of nodes and E is the set of edges/links. For each edge $(u, v) \in E$, we have a weight $w(u, v)$. Then, a *minimum spanning tree (MST)* of G is a tree T such that $w(T) = \sum_{(u,v)\in T} w(u, v)$ is minimized.



A minimum spanning tree for a connected graph The weights on edges are shown, and the edges in a minimum spanning tree are shaded. The total weight of the tree shown is 37. This minimum spanning tree is not unique: removing the edge (b, c) and replacing it with the edge (a, h) yields another spanning tree with weight 37. Source [4]

Correlation-based minimal spanning trees [2]

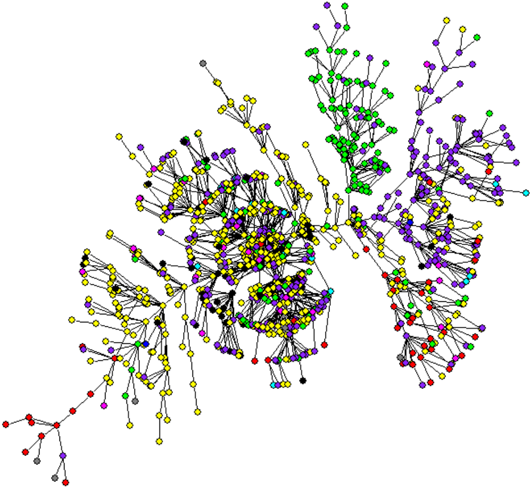
- Starting point:
- Aim of the paper: study the topological properties of the minimum spanning tree (MST) obtained from the return cross correlation matrix of a portfolio of financial assets
- Results:
  - the topology of the MST for the real and for the considered artificial markets is different for nodes with both high and low degrees
  - the real market has a hierarchical distribution of importance of the nodes whereas the considered models are not able to catch such a hierarchical complexity
  - in the random model the fluctuations select randomly few nodes and assign them small values of degree, thus the MST of the random model is essentially non hierarchical
  - the MST of the one factor model shows a simple one-center hierarchy creating a star like structure

Data:

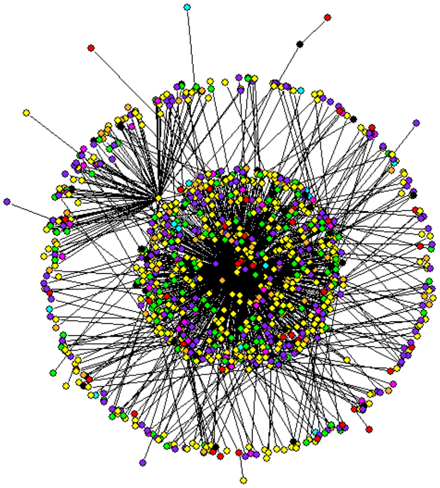
- Daily closure prices for 1071 stocks traded at the NYSE and continuously present in the 12-year period 1987-1998

Methodology:

- Given a portfolio composed of N assets traded simultaneously in a time period of T trading days, extract the $N \times N$ correlation matrix
- Correlations are computed on daily closure prices for 1071 stocks traded at the NYSE and continuously present in the 12-year period 1987-1998 (3030 trading days)
- To each correlation ρ_{ij} can be associated a metric distance $D_{ij} = \sqrt{2(1 - \rho_{ij})}$
- The MST is obtained from the distance matrix D as the nearest neighbor single linkage cluster algorithm



Correlation based minimal spanning tree - real data The node color is based on Standard Industrial Classification system. The correspondence is: red for mining - cyan for construction - yellow for manufacturing - green for transportation, communications, electric, gas and sanitary services - magenta for wholesale trade - black for retail trade - purple for finance, insurance and real estate - orange for service industries - light blue for public administration. Source [2]



Correlation based minimal spanning tree - one factor model The correlations have been obtained from the estimates of the one factor model $r_i(t) = \alpha_i + \beta_i r_M(t) + \varepsilon_i(t)$, where $r_i(t)$ are the returns of asset *i* at time *t*, $r_M(t)$ are the returns of the market factor Standard & PoorâĂŹs 500 index at time *t*, $\varepsilon_i(t)$ is a zero mean noise term. The color code is the same as before. Source [2]

References I

F. Allen and D. Gale.
Financial contagion.
Journal of political economy, 108(1):1–33, 2000.

G. Bonanno, G. Caldarelli, F. Lillo, and R.N. Mantegna.
Topology of correlation-based minimal spanning trees in real and model markets.
Physical Review E, 68(4):046130, 2003.

Matteo Chinazzi, Giorgio Fagiolo, Javier A. Reyes, and Stefano Schiavo.
Post-Mortem Examination of the International Financial Network.
SSRN eLibrary, 2012.

T.H. Cormen.
Introduction to algorithms.
The MIT press, 2001.

P. Gai and S. Kapadia.
Contagion in financial networks.
Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science, 466(2120):2401, 2010.

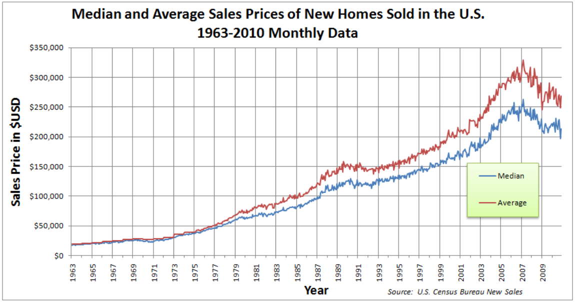
References II

A.G. Haldane.
Rethinking the financial network.
Speech delivered at the Financial Student Association, Amsterdam, April, 2009.

S. Kalemli-Ozcan, B. Sorensen, and S. Yesiltas.
Leverage across firms, banks, and countries.
Technical report, National Bureau of Economic Research, 2011.

M.E.J. Newman.
Networks: an introduction.
Oxford Univ Pr, 2010.

S. Vitali, J.B. Glattfelder, and S. Battiston.
The network of global corporate control.
PloS one, 6(10):e25995, 2011.



Source: US Census Median and Average Sales Price of New Houses Sold Data

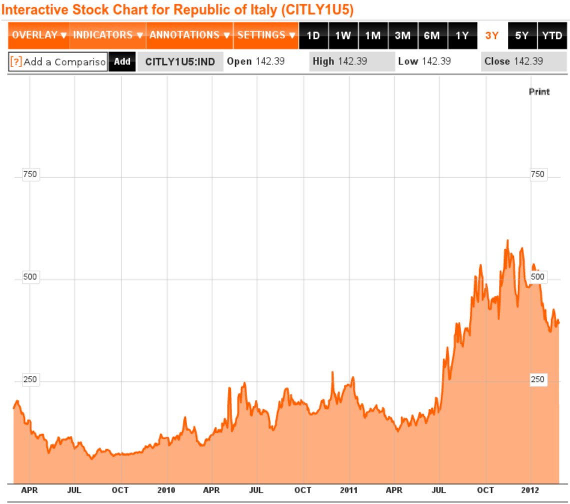
	(2007)			(2008)		
	Assets	Equity	Leverage	Assets	Equity	Leverage
Bank of America	1616	138.3	11.7	1648.9	160.6	10.3
Bearn Stearns	372.4	11.1	33.5	N.A.	N.A.	N.A.
Citigroup	2060.5	112	18.4	1758.2	130.6	13.5
Goldman Sachs	1054.7	47.2	22.4	802.3	59.9	13.4
JP Morgan	1471.4	116.9	12.6	1972.8	152.4	12.9
Lehman Brothers	650.9	21.2	30.7	N.A.	N.A.	N.A.
Merrill Lynch	960.8	30.1	31.9	605.5	18.1	33.4
Morgan Stanley	984.7	29.5	33.4	597.6	46.1	13
Wells Fargo	542	45.1	12	1187.9	92.8	12.8
BNP Paribas	71.4	4.8	14.9	N.A.	N.A.	N.A.
Barclays	2073.8	54.1	38.3	3335.7	77	43.3
Deutsche Bank	2315.9	47.3	49	N.A.	N.A.	N.A.
Fortis Bank	331.3	27.3	12.1	N.A.	N.A.	N.A.
RBS	3211.1	154.5	20.8	3051.3	76.8	39.7
UBS	1.5	0.2	6.4	N.A.	N.A.	N.A.

The leverage ratio is defined as the ratio of total assets to equity. Total Assets are composed of tangible and intangible assets. Equity is measured as shareholder funds (i.e. the balance sheet value of the shareholders' interest in a company). All non-ratio items are in real billion dollars. Source: [7]

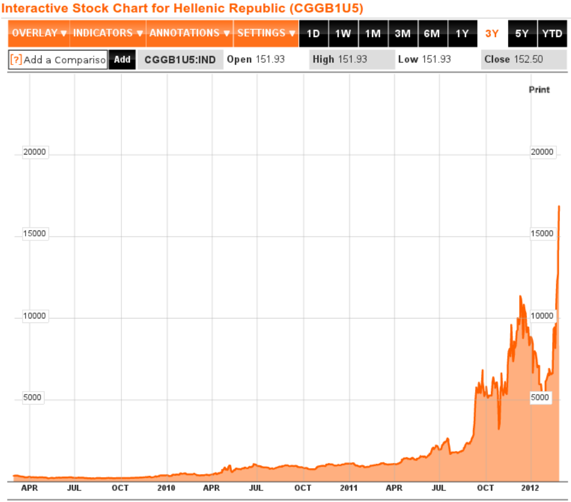
Credit Default Swap (CDS)

Definition

A credit default swap (CDS) is an agreement that the seller of the CDS will compensate the buyer in the event of a loan default. The buyer of the CDS makes a series of payments (the CDS "fee" or "spread") to the seller and, in exchange, receives a payoff if the loan defaults. In the event of default the buyer of the CDS receives compensation (usually the face value of the loan), and the seller of the CDS takes possession of the defaulted loan (Source: Wikipedia).



Source: Bloomberg



Source: Bloomberg

Asset-backed security (ABS)

Definition

An asset-backed security is a security whose value and income payments are derived from and collateralized (or *backed*) by a specified pool of underlying assets. The pool of assets is typically a group of small and illiquid assets that are unable to be sold individually. Pooling the assets into financial instruments allows them to be sold to general investors, a process called securitization, and allows the risk of investing in the underlying assets to be diversified because each security will represent a fraction of the total value of the diverse pool of underlying assets. The pools of underlying assets can include common payments from credit cards, auto loans, and mortgage loans (mortgage-backed securities - MBS), to esoteric cash flows from aircraft leases, royalty payments and movie revenues (Source: Wikipedia).

Collateralized debt obligation (CDO)

Definition

Collateralized debt obligations (CDOs) are a type of structured asset-backed security (ABS) with multiple *tranches* that are issued by special purpose entities and collateralized by debt obligations including bonds and loans. Each tranche offers a varying degree of risk and return so as to meet investor demand. CDOs' value and payments are derived from a portfolio of fixed-income underlying assets. CDO securities are split into different risk classes, or tranches, whereby *senior* tranches are considered the safest securities. Interest and principal payments are made in order of seniority, so that junior tranches offer higher coupon payments (and interest rates) or lower prices to compensate for additional default risk.
In simple terms, think of a CDO as a promise to pay cash flows to investors in a prescribed sequence, based on how much cash flow the CDO collects from the pool of bonds or other assets it owns. If cash collected by the CDO is insufficient to pay all of its investors, those in the lower layers (tranches) suffer losses first (Source: Wikipedia).