The World-Trade Web as a Weighted Complex Network

Topological Properties, Dynamics, and Evolution

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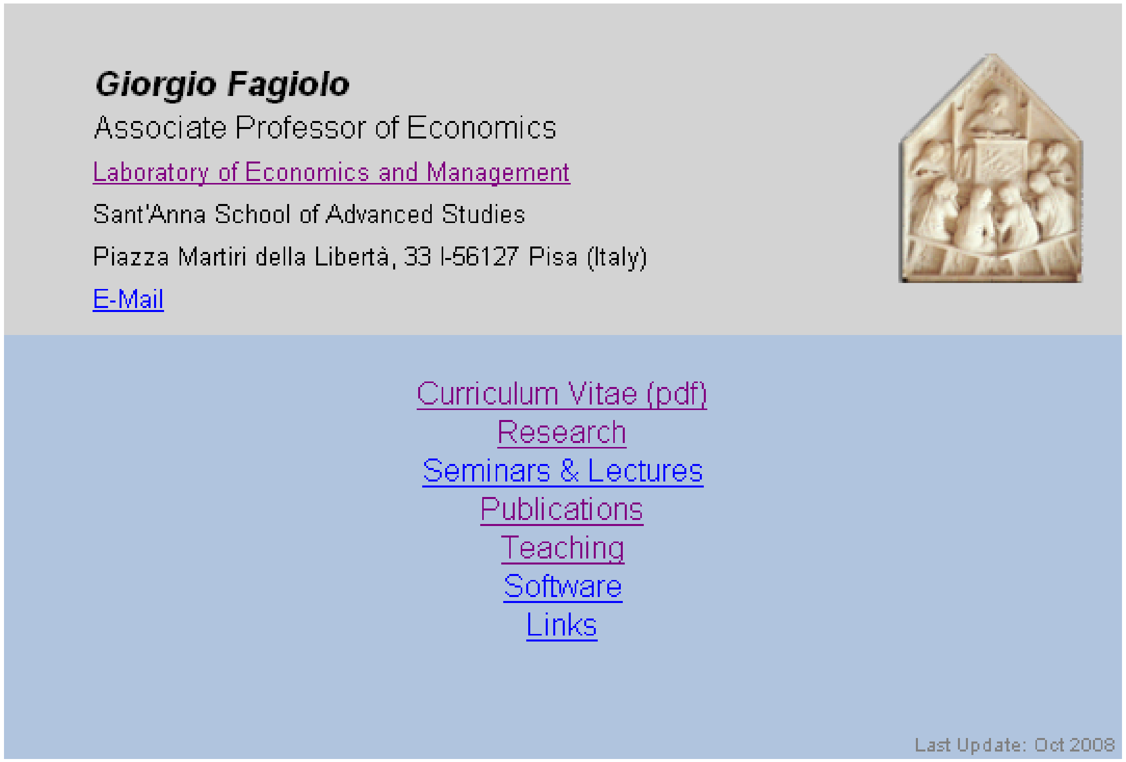
Outline of the Talk

- **Motivations**
  - Why a complex-network approach to the empirics of international trade?
  - Values added vs. standard int'l trade empirical analyses
- **Related Literature**
  - Political sciences
  - Econophysics
- **Data, Methodology, and Results**
  - The network of international (total) trade, aka ITN,WTN or WTW
  - Topological properties, dynamics, and evolution
- **The Agenda: Current and Future Work**
  - Commodity-Specific WTW Networks (Multi-Graphs)
  - Comparing Trade with Other Related World Networks
  - Modeling: Physics vs. Economics approaches

My Home Page



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My Research Interests

- **Networks**
  - Game-theoretic models of strategic network formation
  - Empirical properties of economic networks
- **Agent-Based Computational Economics (ACE)**
  - Methodology: Empirical validation in ACE models
  - Applications: Fiscal and monetary policy in ACE models
- **Industrial dynamics: models/empirical evidence**
  - Geography of industrial agglomeration
  - Firm size and growth dynamics: the role of financial constraints
- **Statistical properties of micro/macro distributions**
  - Household expenditure distributions
  - Country-output growth rate distributions

WTW: Background Papers

- **Main Reference**
  - Fagiolo, G., Reyes, J. and Schiavo, S. (2009), "The World-Trade Web: Topological Properties, Dynamics, and Evolution", ***Physical Review E***, 79, 036115 (19 pages).

- **Related Papers on the WTW**
  - Reyes, J., Schiavo, S. and Fagiolo, G. (2009), "Using Complex Networks Analysis to Assess the Evolution of International Economic Integration: the Cases of East Asia and Latin America, ***Journal of Int'l Trade and Economic Development***, forthcoming.
  - Fagiolo, G., Reyes, J. and Schiavo, S. (2007), "International Trade and Financial Integration: A Weighted Network Analysis", ***Quantitative Finance*,** forthcoming
  - Reyes, J., Schiavo, S. and Fagiolo, G. (2008), "Assessing the evolution of international economic integration using random-walk betweenness centrality: The cases of East Asia and Latin America", ***Advances in Complex Systems***, 11: 685-702.
  - Fagiolo, G., Reyes, J. and Schiavo, S. (2008), "On the Topological Properties of the World Trade Web: A Weighted Network Analysis", ***Physica A***, 387: 3868-3873.

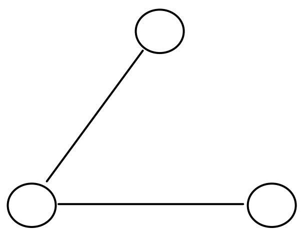
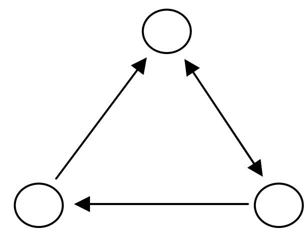
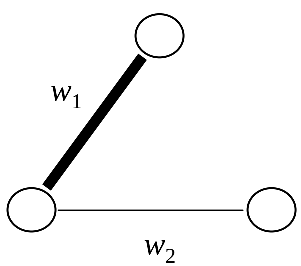
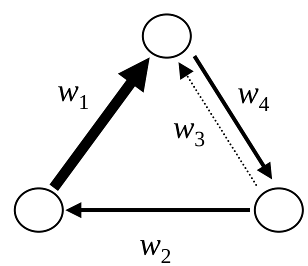
- **Methodology**
  - Fagiolo, G. (2007), "Clustering in Complex Directed Networks", ***Physical Review E***, 76: 026107 (8 pages).
  - Fagiolo, G. (2006) "Directed or Undirected? A New Index to Check for Directionality of Relations in Socio-Economic Networks", ***Economics Bulletin***, 3, 34: 1-12.

Why a Network Approach to International Trade?

- **Standard Approach to the Empirics of International Trade**
  - Trade (import-export) flows as **country-specific** variables
  - Computing country-specific trade statistics (e.g., trade openness, etc.)
  - Comparing statistics, moments of distributions, etc. across countries, geographical areas, trade agreements, …
  - Focus more on country-specific characteristics and direct bilateral-trade relationships, than on the overall structure of trade flows
- **A Network Approach**
  - Trade (import-export) flows as **relational** variables
  - Relational variables are more important than country characteristics to explain international-trade patterns
  - "System" approach: Int'l trade studied as a single observational entity
    - Web of trade relations among countries as a network
    - Countries = nodes
    - A link between two country means the existence of trade relationship (import/export)
    - Links may be binary vs. weighted, directed vs. undirected

Alternative Representations of a Complex Network

- **Two dimensions: links can be**

Links	**Undirected**	**Directed**
Binary	 BUN	 BDN
Weighted	 WUN	 WDN

Alternative Representations of a Complex Network

- **And can be characterized by means of:**

Links	**Undirected**	**Directed**
Binary	Adjacency Matrix $A = \{a_{ij}\}$ Symmetric: $a_{ij} = a_{ji}$	Adjacency Matrix $A = \{a_{ij}\}$ Asymmetric
Weighted	Weight Matrix $W = \{w_{ij}\}$ Symmetric: $w_{ij} = w_{ji}$	Weight Matrix $W = \{w_{ij}\}$ Asymmetric

A Network Approach to Int'l Trade: Values Added

- **Internationalization, Globalization, Global Crises**
  - They are all phenomena characterized by a "systemic" nature (Stiglitz, 2002; Dreher et al. 2008)
  - Understanding the topological properties of the WTW as a whole, and their evolution over time, acquires a fundamental importance in explaining such phenomena

- **From Bilateral (Direct) Trade Linkages to a Complex-Network Approach**
  - Bilateral trade linkages are one of the most important channels of interaction between world countries (Krugman, 1995) as they can help to explain how
    - economic policies affect foreign markets (Helliwell & Padmore, 1985)
    - economic shocks are transmitted among countries (Artis et al., 2003)
    - economic crises spread internationally (Forbes, 2002)
  - … But they can only explain a small fraction of the impact that an economic shock originating in a given country can have on another one, which is not among its direct-trade partners (Abeysinghe & Forbes, 2005)
  - A complex-network analysis, by characterizing in detail the topological structure of the network as a single entity, can go far beyond the scope of standard international-trade indicators, which instead only account for bilateral-trade direct linkages seen as country-specific characteristics

Early Network Representations of World Trade (1)

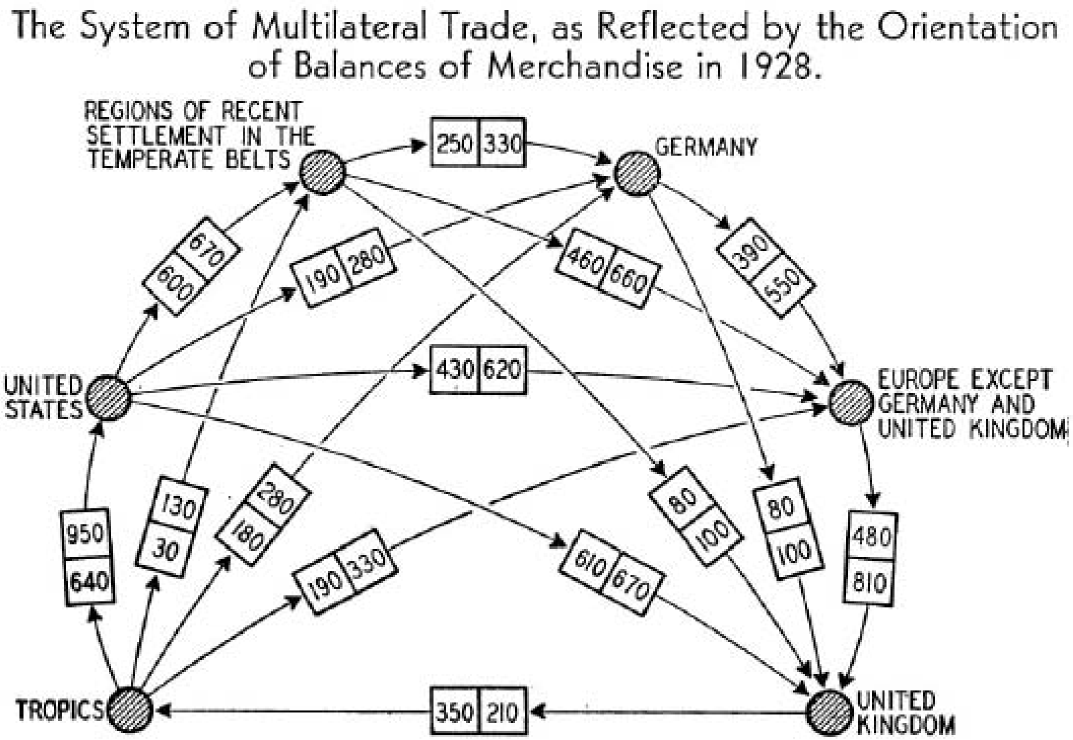


Figure: A natural way of representing international trade is through a network. The figure is from Folke Hilgerdt (1943), "The Case for Multilateral Trade", *American Economic Review*

Early Network Representations of World Trade (2)

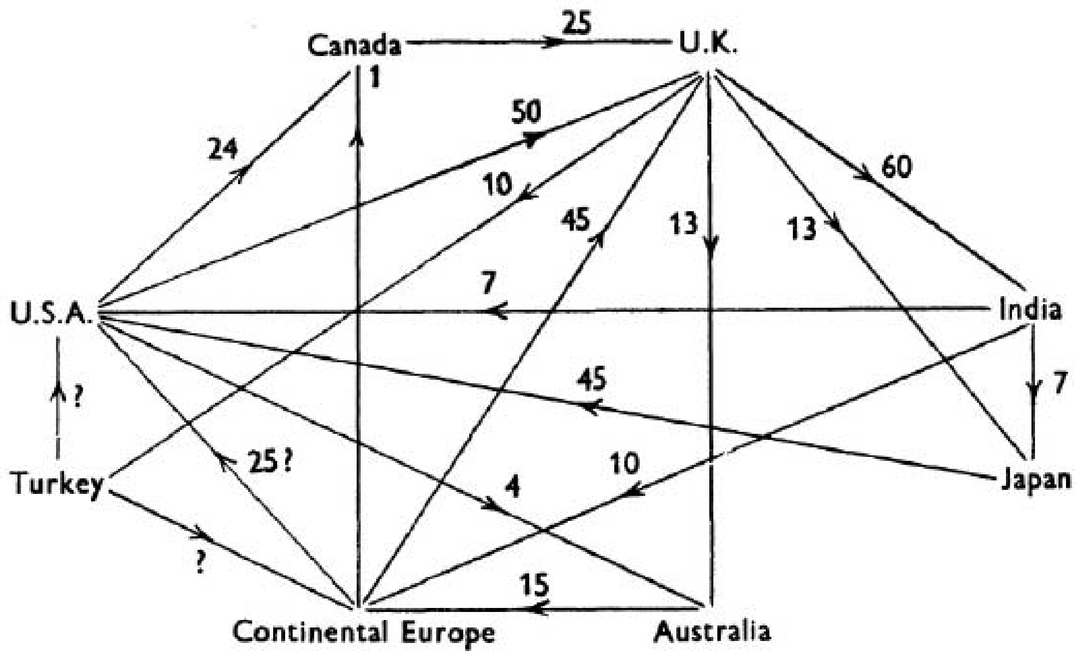


Figure: A natural way of representing international trade is through a network. The figure is from S.B. Saul (1954), "Britain and World Trade: 1870-1914", *The Economic History Review*

… and more recently

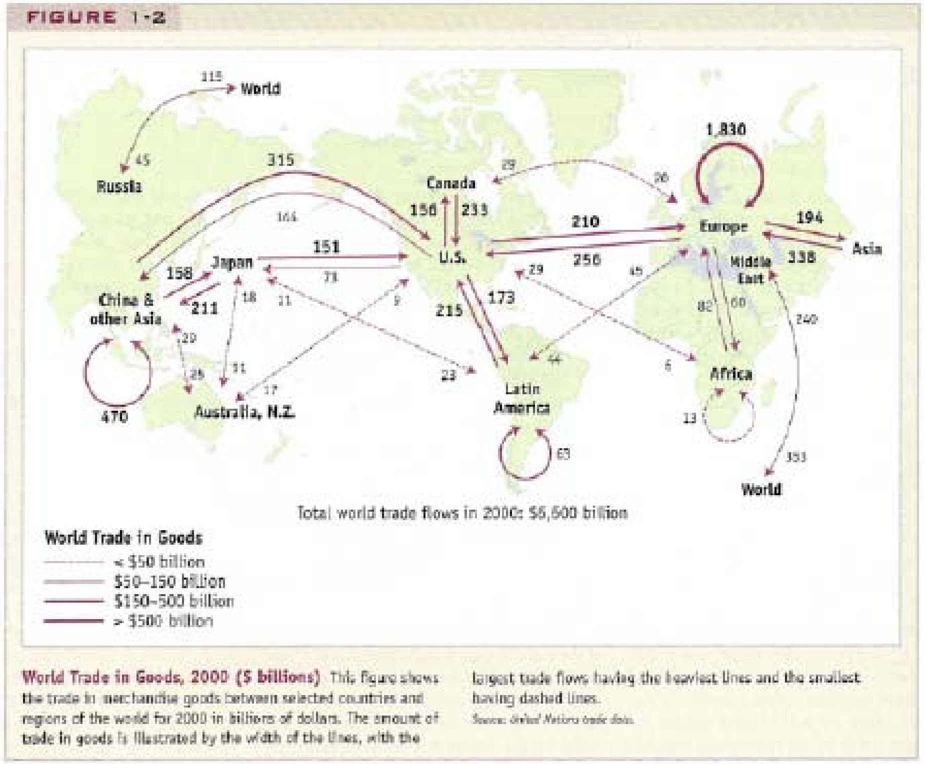


Figure: A natural way of representing international trade is through a network. The figure is from Robert Feenstra and Alan Taylor (2008), *International Economics*, ch.1

Related Literature: Not Much in Economics

- **Old tradition in political sciences**
  - Relational variables are more important than country characteristics to explain international trade patterns
  - Focus on core-periphery and world-dependency theories
    - Snyder & Kick (1979), Breiger (1981), Nemeth & Smith (1985), Schott (1986), Smith & White (1992), Sacks et al. (2001), Kim & Shin (2002), Kastelle et al. (2006), Mahutga (2006)

- **Econophysics enters the stage: Complex-network approach**
  - Explore topological properties from a purely-descriptive perspective
  - Limited economic interpretation in terms of international-trade models
  - Recent contributions
    - Li & Chen (2003), Serrano & co-authors (2003, 2007), Garlaschelli, Loffredo & co-authors (2004, 2005, 2007), Bhattacharya & co-authors (2007a,b), Fagiolo & co-authors (various papers)

Econophysics Literature: Main Results

- **Binary- vs. weighted, directed vs. undirected network analysis**
  - Fagiolo et al. (2007a,b)
    - Binary analysis tends to underestimate the importance of heterogeneity in trade relationships
    - Symmetrizing the WTW does not have significant impacts on the analysis (not much is lost as compared to a directed network analysis)
  - Topological properties of binary (undirected) WTW may be profoundly different from those obtained with a weighted-network (undirected) analysis

- **Some examples**
  - Binary WTW
    - Partners of well-connected countries hold few partners (strongly disassortative) and are poorly connected between them
    - Distribution of number of trade partners is right-skewed and presents bimodality: there is a group of countries trading with everyone else
  - Weighted WTW
    - Weakly disassortative; well-connected countries trade with partners that are strongly connected between them
    - Distributions of link weights and intensity of trade mediated by any country log-normally distributed (no bi-modalities)

Fagiolo, Reyes, Schiavo (2009), PRE

- **Exploring in more detail how topological properties evolve**
  - Garlaschelli and Loffredo (2005), Fagiolo et al. (2007a,b)
    - Have noticed that topological properties are relatively stable across time
  - Studying within-sample dynamics and out-of-sample evolution of the distributions of the main network statistics related to links (link weights) and nodes (connectivity, assortativity, clustering, centrality)

- **Some questions we ask**
  - How do the distributional properties of these statistics and their correlation structure look like? What does it mean for int'l trade?
  - Did they change in the past? How?
  - Can we make any predictions on the out-of-sample (future) behavior of such distributions?
  - Are these result robust to the weighting procedure we choose?
  - Economic implications? Internationalization, globalization?

Data

- **International trade data**
  - Gleditsch (2002) database
  - See http://ibs.colorado.edu/~ksg/trade/
- **Data structure**
  - Panel of 159 countries
  - Time periods: 1981-2000 (T=20 years)
    - Important remark: Quality of trade data is often poor!!
  - Baseline observation = Exports from country *i* to *j* in year *t* : $Exp_t(i,j)$
  - Data in current US$ (deflated)
  - Country GDPs and pcGDPs also available

Weighting Schemes

- **Symmetrizing the WTW**
  - Export matrices are sufficiently symmetric (see Fagiolo, 2006)
  - We do not loose much info by looking at the WTW as a WUN
  - WUN are easier to study; symmetrization only as a first approximation
  - From export to trade matrices: $trade_t(i,j) = [Exp_t(i,j)+Exp_t(j,i)]/2$

Which Empirical Characterization?

- **How to Empirically Characterize Network Data?**
  - Two choices: Binary vs. Weighted, Undirected vs. Directed
  - Natural choice: Marriage network between individuals is undirected and (almost always) binary. But what about other networks?
  - In most situations (data permitting) all 4 specifications (BUN, WUN, BDN, WDN) can all be feasible and convey useful information, but there are trade offs
    - Only in BUNs empirical techniques and models are well developed
    - Introducing directionality dramatically expands the set of statistics that can be computed (and thus complicates handling and interpretation of results), ex: ANND/S

- **Binary or Weighted?**
  - Binary analysis almost always useful, but for some empirical networks disregarding link-weight heterogeneity introduces a strong bias in the analysis
  - “Heuristic” test: Are link weights sufficiently similar? Is link-weight distribution well-proxied by a symmetric unimodal density with “small” variance?
  - In general this is not the case and a weighted analysis is required (at the very least to complement a binary one) as it may provide useful information
  - Problem: Choosing weighting scheme is not always straightforward, unique

Undirected vs. Directed Analysis: A Simple Index

- **Undirected or Directed?**
  - Garlaschelli & Loffredo (2004) and Fagiolo (2006) propose statistics to check whether the graph is "sufficiently undirected", i.e. the adjacency or weighted matrix is sufficiently symmetric
  - The distributions of such statistics depends on the assumptions on (binary or weighted) link distributions and must be properly simulated
  - Symmetrization: Trade off between complexity of data analysis and info lost by not considering direction of flows

- **Idea**
  - The more the network is undirected, the smaller $||\tilde{W} - \tilde{W}^T||$ (appropriately normalized), see Fagiolo, 2006 (Eco Bull)

- **Technical assumption**

$$Q = \{q_{ij}\} = \tilde{W} - (1 - \tilde{W})I_N$$

- **Define**

$$\tilde{S}(Q) = \frac{||Q - Q^T||_F^2}{||Q||_F^2 + ||Q^T||_F^2} = \frac{||Q - Q^T||_F^2}{2||Q||_F^2} = \frac{1}{2}\left[\frac{||Q - Q^T||_F}{||Q||_F}\right]^2$$

Undirected vs. Directed Analysis: A Simple Index

- **Expanding the sums...**

$$\tilde{S}(Q) = 1 - \frac{\sum_i \sum_j q_{ij} q_{ji}}{\sum_i \sum_j q_{ij}^2}.$$

- **To get an index in $[0, 1]$, define:**

$$S(Q) = \frac{N+1}{N-1} \tilde{S}(Q),$$

- **We can find $(m_W(N), s_W(N))$ such that, if w~U[0,1], then**

$$S_W(Q) = \frac{S(Q) - m_W(N)}{s_W(N)} \sim N(0,1)$$

- **Otherwise:**
  - Simulate the distribution of S by bootstrapping from the observed empirical weight distribution (under different hypotheses on the degree distribution)

Weighting Schemes

- **Symmetrizing the WTW**
  - Export matrices are sufficiently symmetric (see Fagiolo, 2006)
  - We do not loose much info by looking at the WTW as a WUN
  - WUN are easier to study; symmetrization only as a first approximation
  - From export to trade matrices: $trade_t(i,j) = [Exp_t(i,j)+Exp_t(j,i)]/2$
- **Baseline Link-Weighting Procedure**
  - Each link ij_t is weighted by $w_t(i,j)=trade_t(i,j)$
    - Li et al. (2003), Bhattacharya et al. (2007a,b), Garlaschelli et al. (2007)
    - Weights are rescaled by max $w_t(i,j)$ so as to have $w \in [0,1]$
  - Adjacency matrix: $a_t(i,j) = 1$ iff $w_t(i,j) > 0$, 0 otherwise
- **Checking results under alternative weighting schemes**
  - $Trade_t(i,j)$ scaled by exporter's GDP
  - $Trade_t(i,j)$ scaled by importer's GDP
  - $Trade_t(i,j)$ scaled by sum/product of exporter's and importer's GDP
  - Main findings surprisingly robust to all these alternatives!

Network Topological Properties: Distributions

- **Link Weights**
  - (Log of) positive link weight $w_t(i,j)>0$
  - Transition between zero and positive link weights (presence/absence)

- **Node-Connectivity**
  - Node Degree (ND): Number of trade partners of a node
  - Node Strength (NS): Total intensity of trade of a node

- **Node-Assortativity**
  - Average Nearest-Neighbor Degree (ANND) and Strength (ANNS)

- **Node-Clustering**
  - Binary vs. Weighted Clustering Coefficient (BCC vs. WCC)

- **Node-Centrality**
  - (Weighted) Random-Walk Betweenness Centrality (Newman, 2005)

Links

Nodes

Network Statistics: Formal Definitions (I)

- **Let:** $A_{N,N}$=Adjacency Matrix, $W_{N,N}$=Weight matrix
  - **Node Strength**

$$s_i = \sum_j w_{ij} = W_{(i)}\mathbf{1}.$$

Node Degree: Replace W with A

  - **Average Nearest-Neighbors Strength (ANNS)**

$$anns_i = d_i^{-1}\sum_j a_{ij}s_j = d_i^{-1}\sum_j\sum_h a_{ij}w_{jh} = \frac{A_{(i)}W\mathbf{1}}{A_{(i)}\mathbf{1}}.$$

ANND: Replace W with A

  - **Binary Clustering Coefficient (CC)**

$$C_i(A) = \frac{\frac{1}{2}\sum_{j\neq i}\sum_{h\neq(i,j)} a_{ij}a_{ih}a_{jh}}{\frac{1}{2}d_i(d_i-1)} = \frac{(A^3)_{ii}}{d_i(d_i-1)}.$$

  - **Weighted Clustering Coefficient (WCC)**

$$\tilde{C}_i(W) = \frac{\frac{1}{2}\sum_{j\neq i}\sum_{h\neq(i,j)} w_{ij}^{\frac{1}{3}}w_{ih}^{\frac{1}{3}}w_{jh}^{\frac{1}{3}}}{\frac{1}{2}d_i(d_i-1)} = \frac{(W^{[\frac{1}{3}]})^3_{ii}}{d_i(d_i-1)},$$

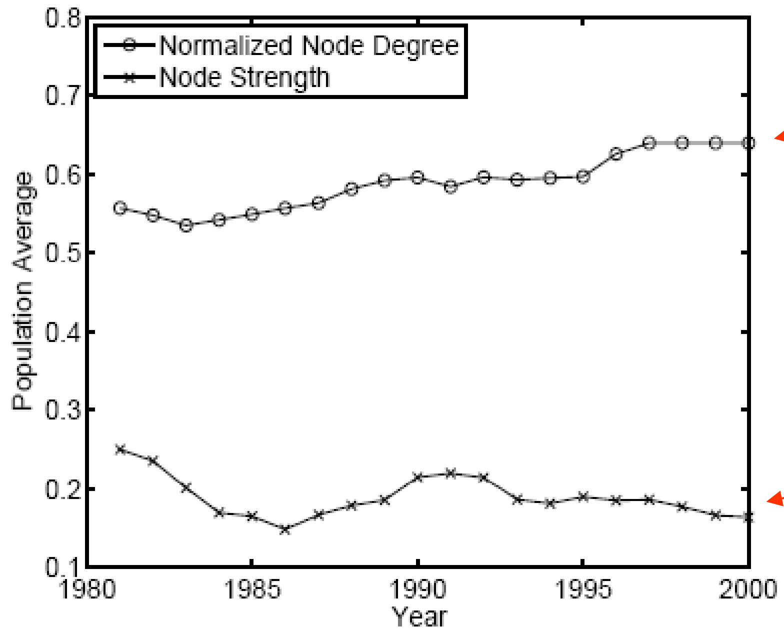
They are equivalent if W=A

Network Statistics: Formal Definitions (II)

- **Random-Walk Betweenness Centrality**
  - Based on Newman (2005), Fisher & Vega-Redondo (2006)
  - It is a measure of centrality that takes into account the whole structure of the network and extends the original definition to weighted networks
  - RWBC of a given target node is proportional to the probability that an impulse sent by a randomly-chosen source node reaches the target node, when at each step the message takes a link chosen at random with probability depending on the weight of that link

Average Node Degree and Strength

- **WTW is very dense but average node strength is small**
  - Normalized Node Degree (min=0, max=1)
  - Max Average Link Strength = N-1 = 158 (all weights equal)



= network density

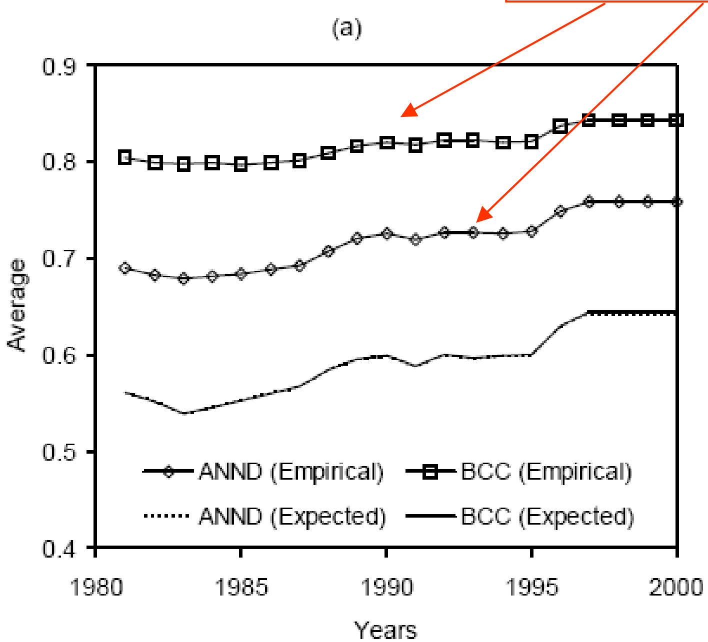
up to a $N^{-1}(N-1)=0.993$ factor

Not normalized

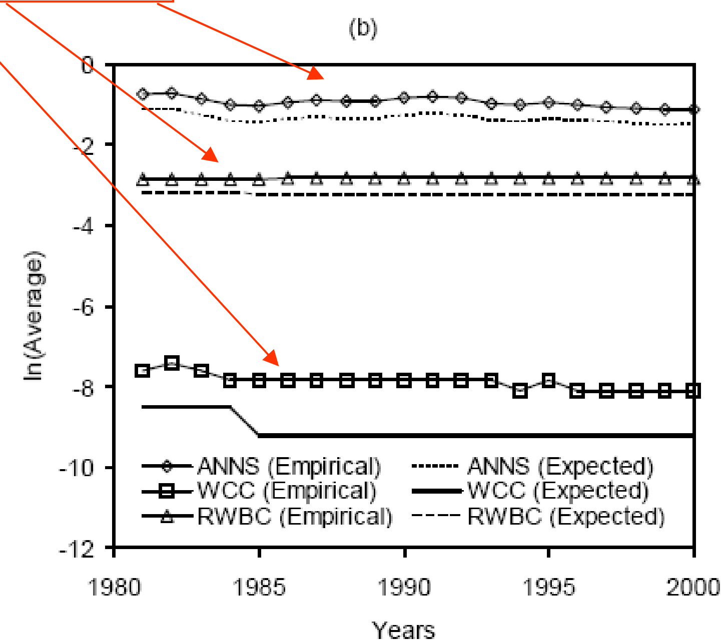
Average vs. Expected Values of Node Statistics

- **Population Averages of ANND/S, B/WCC, RWBC**
  - Are observed averages larger than expected in “statistically comparable” networks?
    - Binary: Links are randomly reshuffled while keeping the same density
    - Weighted: Observed weights are randomly reshuffled among existing links

All Averages Higher Than Expected



Binary

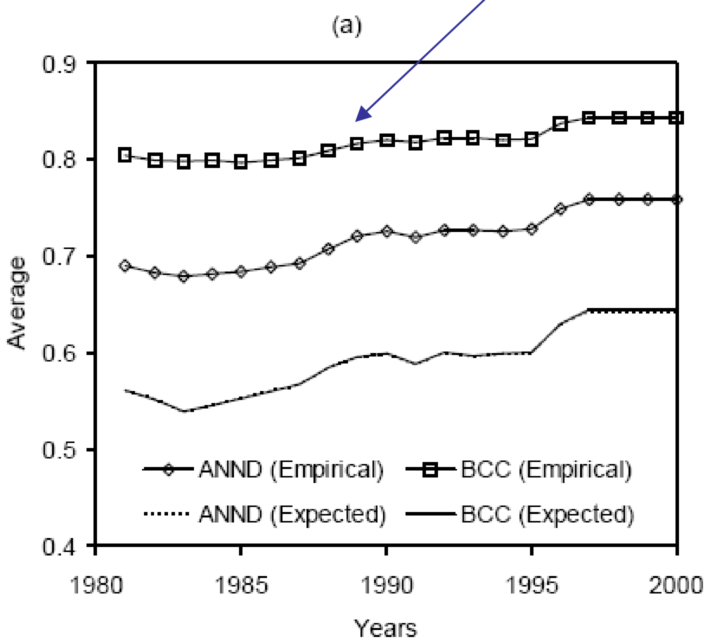


Weighted

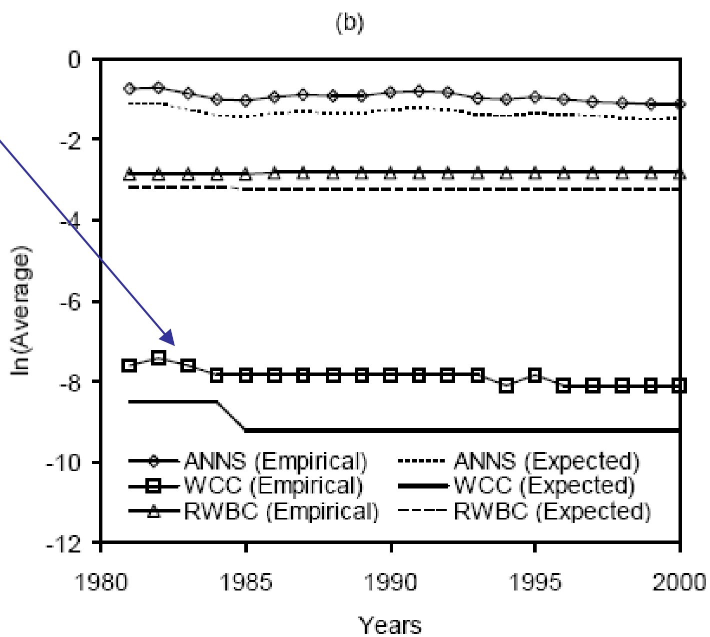
Average vs. Expected Values of Node Statistics

- **Population Averages of ANND/S, B/WCC, RWBC**
  - Are observed averages larger than expected in “statistically comparable” networks?
    - Binary: Links are randomly reshuffled while keeping the same density
    - Weighted: Observed weights are randomly reshuffled among existing links

Binary WTW very clustered, weighted WTW poorly clustered (but more than expected)



Binary

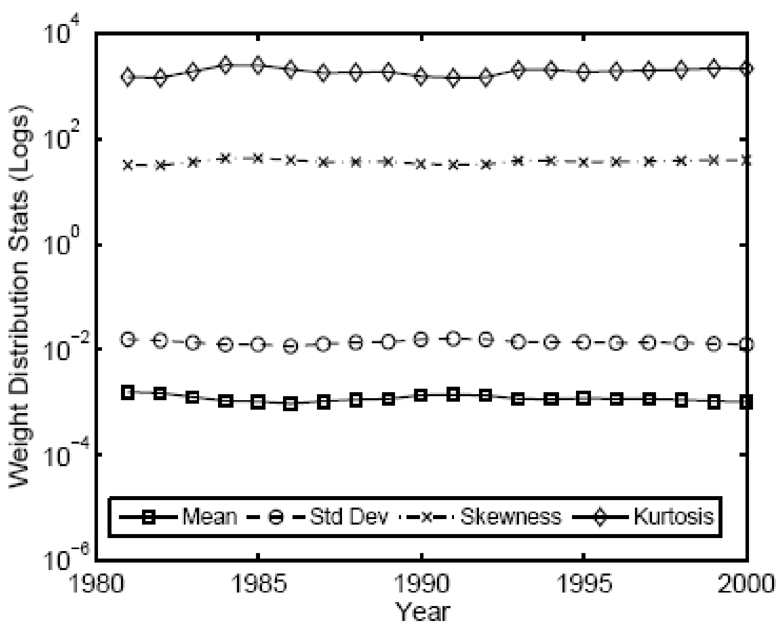


Weighted

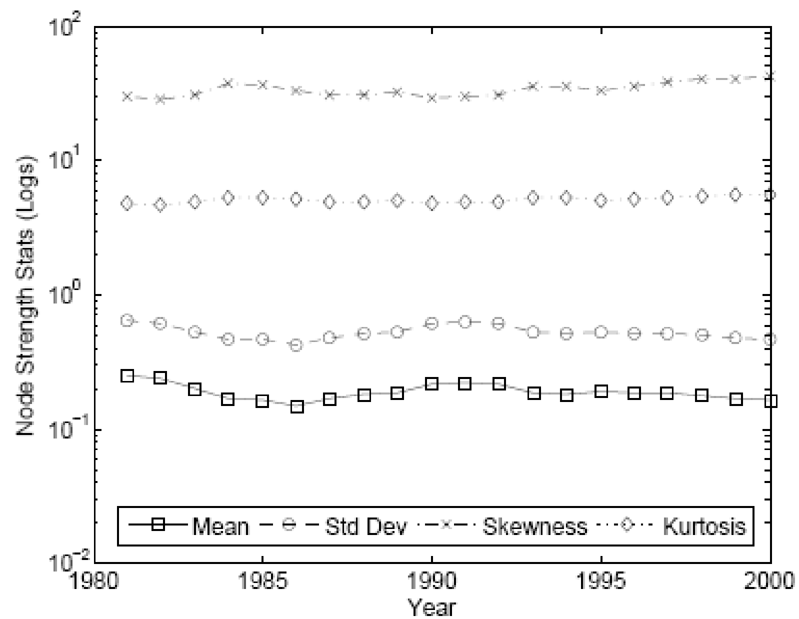
Within-Sample Moment Dynamics

- **How do distribution moments of network statistics evolve?**
  - Previous results: Averages seem relatively constant across time
  - Looking at first 4 moments: mean, std dev, skewness and kurtosis vs. time

First 4 moments of distributions rather stable across time



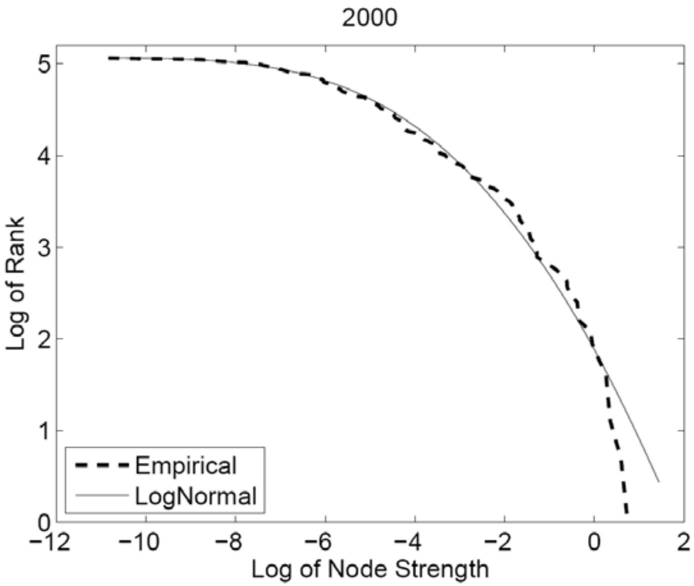
Positive Link-Weight Distribution



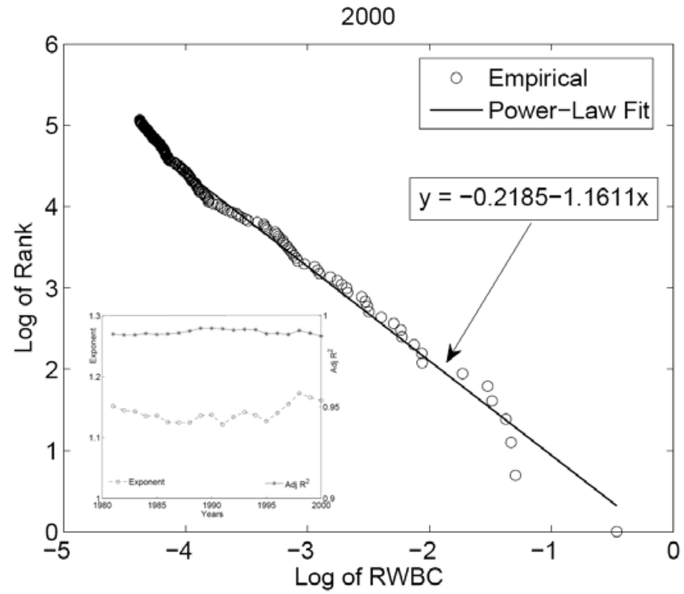
Node-Strength Distribution

Shape of Node/Link Network-Statistic Distributions

- **How do distributions of node/link statistics look like?**
  - NS, ANNS, WCC are log-normally distributed (no power law!)
  - RWBC is power-law distributed with constant exponent
    - Fat upper tail: Very central countries more likely than expected (log-normality)



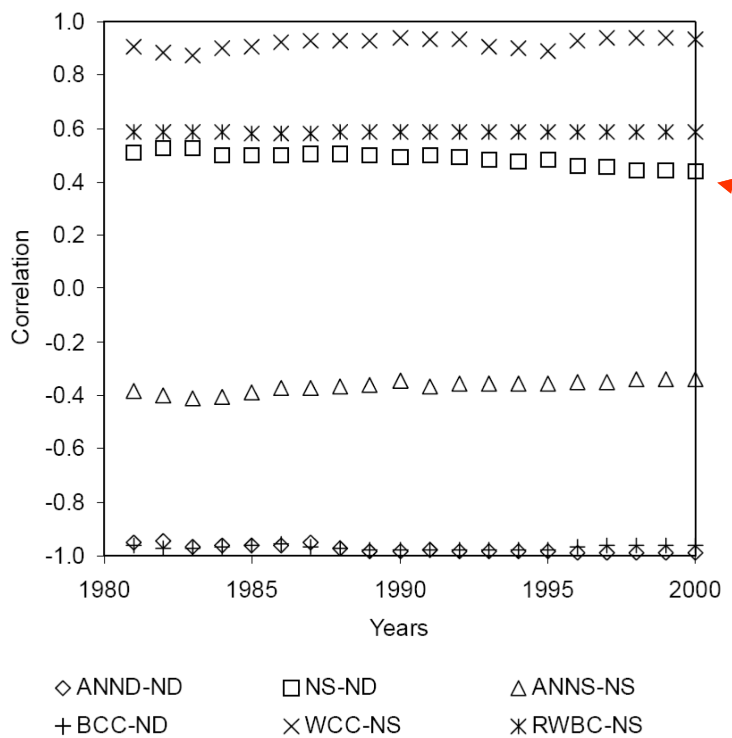
Node-Strength Distribution in 2000



Node RWBC Distribution in 2000

Within-Sample Correlation Dynamics

- **How does the correlation between network statistics evolve?**
  - Correlation structure is highly stable across time!



Correlation Coefficients

More-intensively connected countries are more central and tend to form highly-connected trade triangles

High node-degree is not highly correlated with node strength

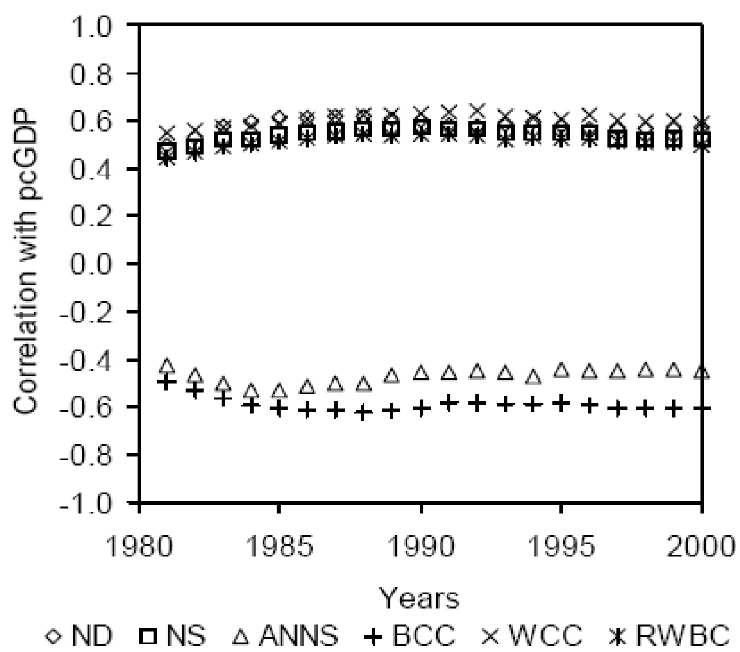
Weighted WTW is only weakly disassortative

Countries holding more partners tend to trade with countries with few partners (strong disassortativity) and do not typically form trade triangles

Binary WTW profoundly different from weighted WTW !!

Within-Sample Correlation with Per-Capita GDP

- **Are high-income countries more connected, clustered, etc.?**
  - Again: Correlation structure is rather stable across time!



High-income countries tend to hold more, and more intense, trade linkages; to be more clustered from a weighted point of view; and to occupy a more central position

High-income countries tend to trade with weakly-connected partners and to form less (but very intense) triangles

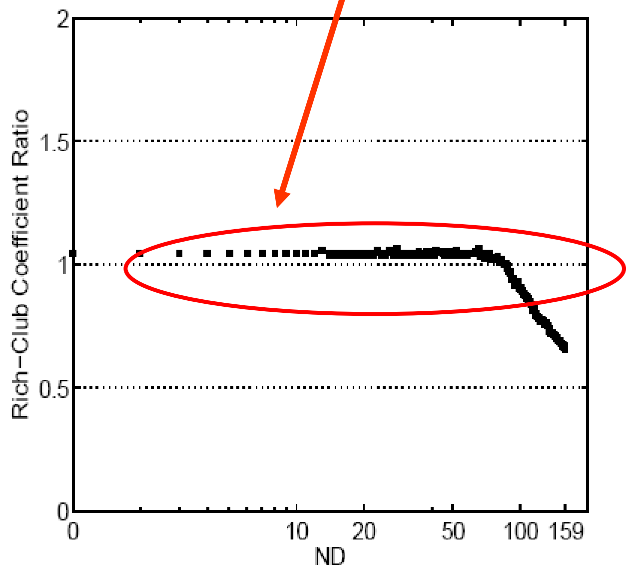
Evidence for a rich-club phenomenon?

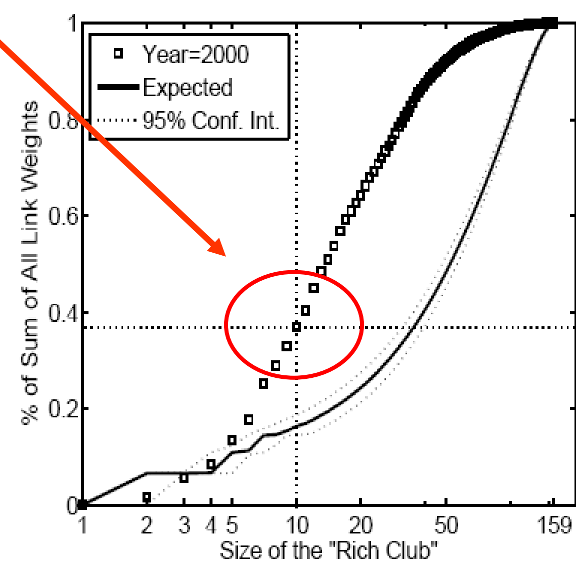
Further Results: Rich-Club Structure of the WTW

- **Computing rich-club coefficients (RCCs)**
  - Binary network: RCC measures (for each degree k) the share of links in place among the nodes with degree higher than k, divided by the expected share in uncorrelated networks (Colizza et al., 2006). If RCC>>1 grows as k increases then there is a rich-club structure
  - Weighted network: Computing the percentage of total trade flow in the network that can be imputed to the richest k nodes (as measured e.g. by NS or pcGDP)

No rich-club ordering

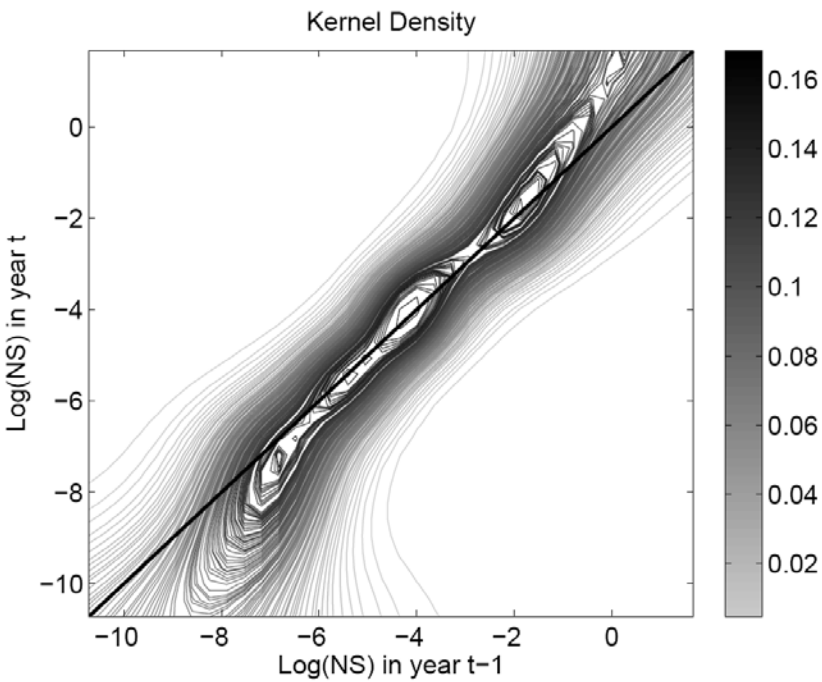
10 richest countries responsible in year 2000 for about 40% of total trade (statistical significant observation)



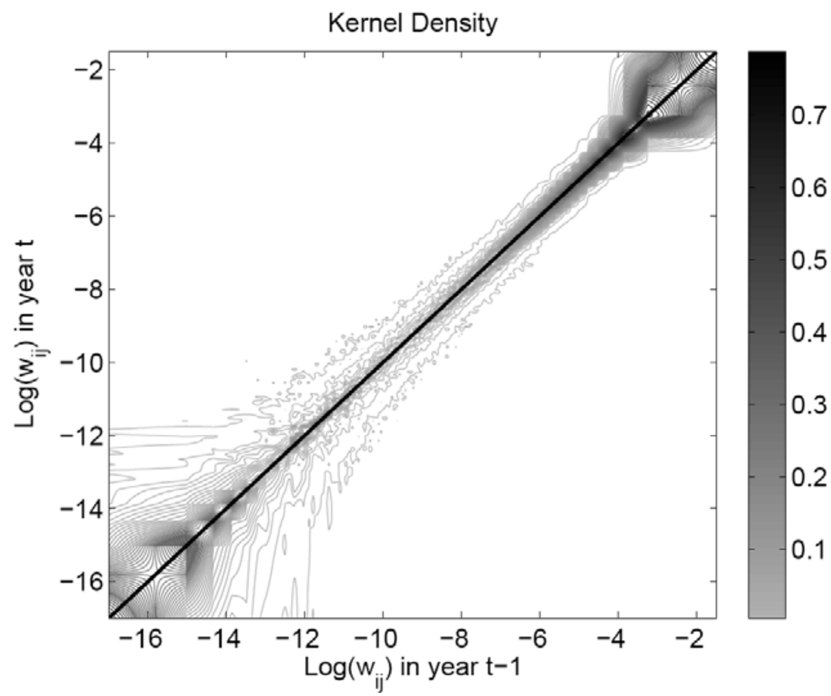


Within-Sample Distribution Dynamics (1/4)

- **Kernel-density estimates:** Prob($X_t \mid X_{t-\tau}$)
  - Contour-plots for both node-statistics and link-weight distributions
  - Concentrated close to main diagonal: stability of distributions



Log of Node-Strength (τ = 1)



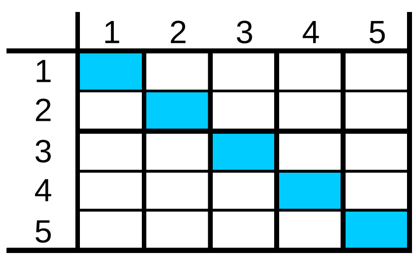
Log of Positive Link-Weight (τ = 1)

Within-Sample Distribution Dynamics (2/4)

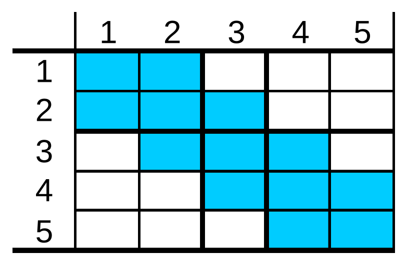
- **Estimated probability-flows between quantile classes**
  - For each node/link statistic X, estimate the transition probability $\hat{p}_{hl}^{\tau}$ of a country moving from quantile class h-th to quantile class l-th of X-distribution in τ years (given K quantile classes)
  - Computing the mass of probability close to the main diagonal of the K×K transition-probability matrix and within a window of ω=0,1,… K quantiles

$$M_{\omega,K}^{\tau}(X) = \frac{1}{K}\sum_{h=1}^{K}\sum_{l:|l-h|\leq w}^{K}\hat{p}_{hl}^{\tau}$$

- **Example: K=5 (Distribution quintiles)**



ω=0



ω=1

Within-Sample Distribution Dynamics (3/4)

- **Estimated probability-flows for node statistics (K=10: Deciles)**

$\omega = 1$	τ			
Statistic	1	4	7	10
$M^{\tau}_{\omega,K}(ND)$	0.9950	0.9881	0.9753	0.9640
$M^{\tau}_{\omega,K}(NS)$	0.9997	0.9965	0.9923	0.9875
$M^{\tau}_{\omega,K}(ANNS)$	0.9930	0.9835	0.9710	0.9579
$M^{\tau}_{\omega,K}(WCC)$	0.9980	0.9918	0.9787	0.9686
$M^{\tau}_{\omega,K}(RWBC)$	0.9990	0.9965	0.9952	0.9906
C.I. (Reshuffled)	[0.5020,0.5370]	[0.5004,0.5385]	[0.4981,0.5406]	[0.4954,0.5436]

More than 96% of countries display node statistics that persist in nearby deciles from year t-τ to year t

Observed values of the statistic M are statistically larger their expected counterpart in random graphs where binary structure is kept fixed and weights have been randomly reshuffled

Within-Sample Distribution Dynamics (4/4)

- **Estimated probability-flows for link-weight distribution**
  - Transition from zero to strictly-positive link weights

	Zero	Positive
Zero	92%	8%
Positive	5%	95%

Link birth rate

Link death rate

Weak tendency towards net link creation between 1981-2000

  - Transition between K-tiles of (log) positive link-weight distribution (K=10)

$M^{\tau}_{\omega,K}$	τ = 1	4	7	10
$\omega = 1$	0.9910	0.9733	0.9562	0.9397
C.I. (Reshuffled)	[0.5175,0.5238]	[0.5172,0.5241]	[0.5170,0.5248]	[0.5167,0.5253]

Positive link-weight distribution dynamics tend to be highly persistent

Within-Sample Ranking Dynamics (1/2)

- **Studying how rankings evolve within the sample period**
  - For each node statistic X, compute country rankings in every year
  - Check stability of rankings by computing average over the years of Spearman Rank-Correlation Coefficient (SRCC)

$$RSI(X) = \frac{1}{T-1}\sum_{t=2}^{T} SRCC_{t-1,t}(X)$$

= –1 Highest Turbulence

= +1 Complete Stability

Statistic	RSI
ND	0.9833
NS	0.9964
ANNS	0.9781
WCC	0.9851
RWBC	0.9920

$$RSI(X) \rightarrow N(0, [N(T-1)]^{-1})$$
$$\cong N(0, 3.3102E-4)$$

All rankings are remarkably (and statistically-significantly) stable

Not only the shape of the distributions are stable over time: countries also tend to keep their positions in the rankings

Within-Sample Ranking Dynamics (2/2)

- **How do rankings look like? Example: Year = 2000**

Rank	ND	NS	ANNS	WCC	RWBC
1	Germany	USA	Sao Tom & Principe	USA	USA
2	Italy	Germany	Kiribati	Germany	Germany
3	UK	Japan	Nauru	Japan	Japan
4	France	France	Tonga	UK	France
5	Switzerland	China	Vanuatu	China	UK
6	Australia	UK	Tuvalu	France	China
7	Belgium	Canada	Burundi	Italy	Italy
8	Netherlands	Italy	Botswana	Netherlands	S. Korea
9	Denmark	Netherlands	Lesotho	S. Korea	Netherlands
10	Sweden	Belgium	Maldives	Singapore	Belgium
11	India	S. Korea	Solomon Islands	Mexico	Spain
12	Spain	Mexico	Bhutan	Belgium	Australia
13	USA	Taiwan	Comoros	Spain	Singapore
14	China	Singapore	Seychelles	Taiwan	India
15	Norway	Spain	Saint Lucia	Canada	Taiwan
16	Japan	Switzerland	Guinea-Bissau	Arab Emirates	S. Africa
17	Taiwan	Malaysia	Mongolia	Saudi Arabia	Brazil
18	Malaysia	Sweden	Cape Verde	Iraq	Thailand
19	Ireland	Thailand	Grenada	Switzerland	Saudi Arabia
20	Canada	Australia	Fiji	Russia	Canada

- Apart from ANNS, all “usual suspects” are present among the top 10
- Germany scores always high
- USA and Japan are very connected, clustered and central but hold relatively less partners (low ND)
- Other countries (Italy, Switzerland, Australia) diversify more but display low NS, WCC, RWBC
- China very central and clustered
- India never in top 10
- ANNS: micro-economies tend to connect only to hubs
- Countries climbing or falling behind: the case of LATAM vs. HPAE

Application: LATAM Countries vs. HPA Economies

- **Studying how groups of countries move within rankings**
  - There seems to be some catching-up, forging-ahead and falling-behind in the rankings of network indicators
  - Can these movements in the rankings shed light on international integration of different groups of countries?

- **Reyes, Fagiolo, Schiavo (2008, 2009)**
  - Use complex network analysis to assess the degree of international integration of Latin American (LATAM) and East Asian (HPAE) countries
  - Investigate the evolution of trade integration in the last 25 years for the two regions
  - Draw some (tentative) conclusions in terms of development and growth policy

Application: LATAM Countries vs. HPA Economies

- LATAM and HPAE countries have be the object of much research in economics
  - They represent two groups of emerging markets
  - They featured different macroeconomic performance in the last 25 years: *Economic Miracle* Vs *Lost Decade*
  - HPAE displayed high growth rates and low inflation (stability)
  - Per capita GDP in LATAM was 4 times higher in the 70s: the gap closed by 2000
  - Average annual growth of per capita GDP has been 10% in HPAE, 4% in LATAM

Application: LATAM Countries vs. HPA Economies

- **Trade openness**
  - HPAE
    - Early liberalization in key sectors
    - Consistent set of outward oriented policies
  - LATAM
    - Import substitution policies
    - Liberalization in late 1980s
    - Openness has increased since then
    - Trade over GDP moved from 25% in 1990 to 50% in 2004
  - Has international integration increased as well?

Application: LATAM Countries vs. HPA Economies

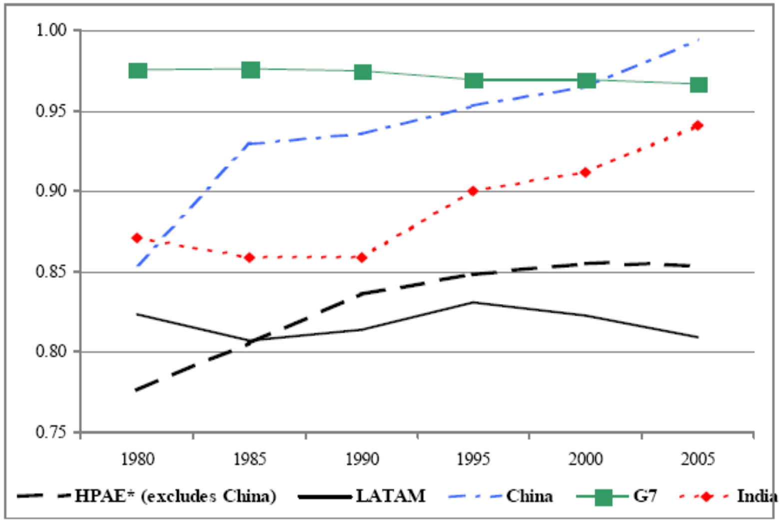
- **Data**
  - Total export from COMTRADE database
  - 171 countries
  - Period: 1980–2005

Regional Groups

HPAE	LATAM
- China	- Argentina
- Indonesia	- Brazil
- South Korea	- Chile
- Malaysia	- Mexico
- Philippines	- Venezuela
- Thailand	

Application: LATAM Countries vs. HPA Economies

- **RWBC as a Measure of International Integration**



Results

- HPAE displays an upward trend
- Asian countries overtook LATAM in mid 1980s
- A number of HPAE countries have moved from Outside to the Core of the trade web (Korea, China) or the Inner Periphery (Thailand)
- None of the LATAM countries has experienced this kind of dynamic

- Standard measures of openness (trade/GDP) suggest that
  - HPAE economies are more open
  - LATAM countries have increased their international integration since the late 1980s
- Network analysis confutes this view
  - In terms of all network indicators used, LATAM countries never display any increase in integration
  - HPAE on the other hand are characterized by an upward trend in integration

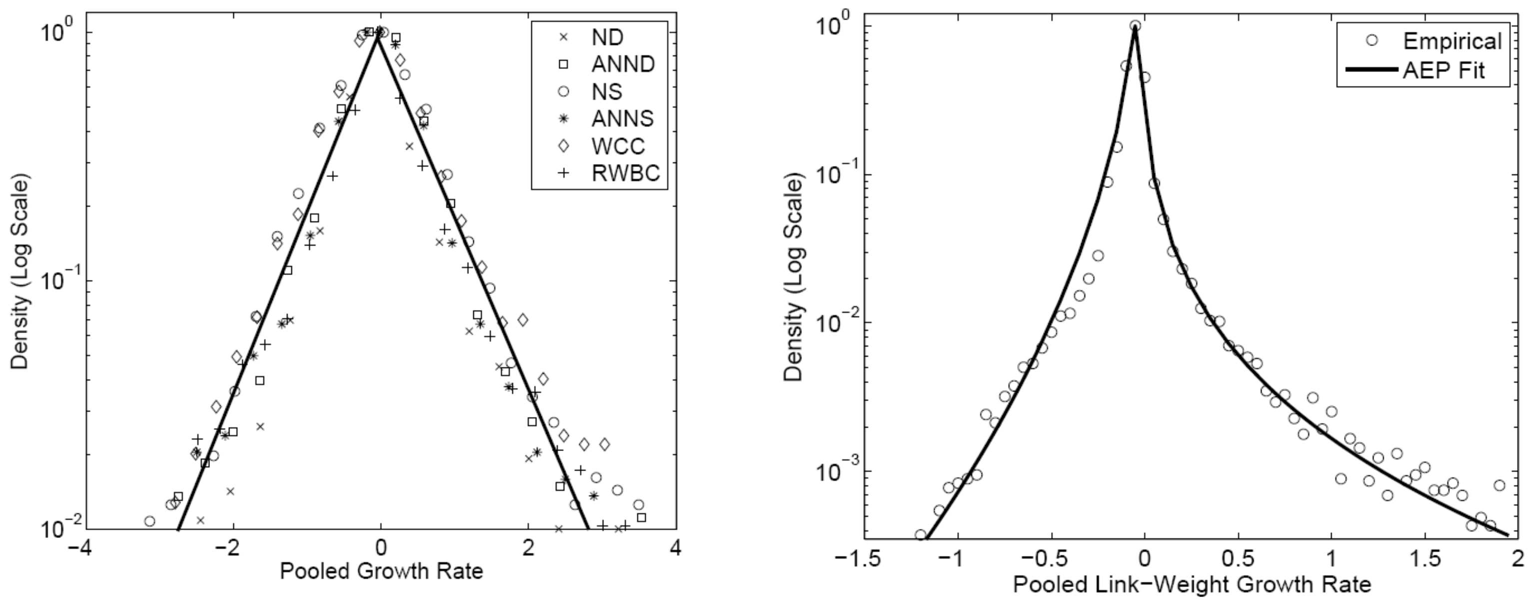
- Position within the network matters more than degree of openness
- Being at the margin of the trade network does not allow to fully enjoy the benefits of international integration
- This can have a cost in terms of growth and development as the case of LATAM countries shows
- Policies oriented toward strengthening of international engagement can yield a prize (e.g. firm subsidies conditional on export intensity or number of destinations)
- Regional integration beneficial if used to reinforce (not as a substitute of) global integration

Within-Sample Growth Dynamics

- **Characterizing auto-regressive structure of within-sample dynamics of node/link statistics: For each statistic X**
  - Computing autocorrelation coefficients (ACF): $\hat{r}_i(X)$
  - Fitting Gibrat-like models: $\Delta log(X_i^t) = \beta_i log(X_i^{t-1}) + \epsilon_i^t$
  - Both on individual nodes/links (distribution) and on pooled sample
- **Results**
  - First-order ACFs are very close to (but statistically smaller than) one
  - Gibrat's coefficients β's are close (but significantly less than) zero
  - Thus: growth processes are highly-persistent in time but entities with larger size (higher statistic value) tend to grow relatively less
  - What happens to growth-rate distributions?

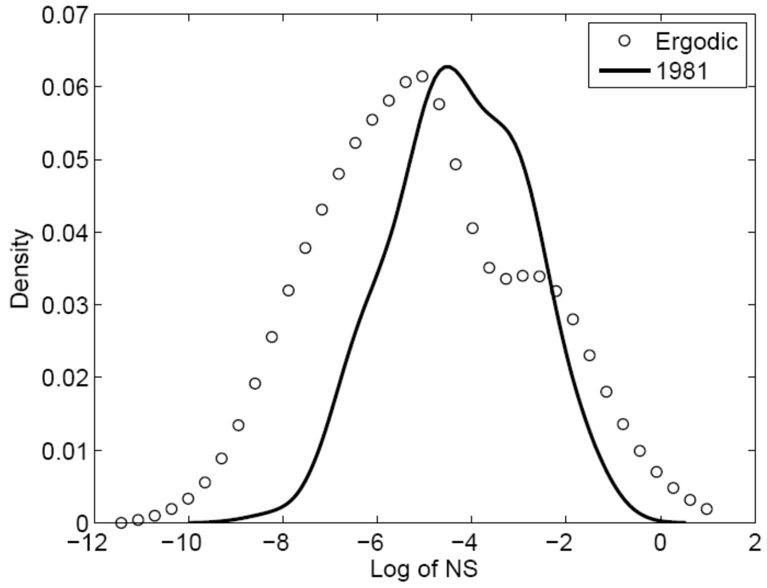
Within-Sample Growth Distributions

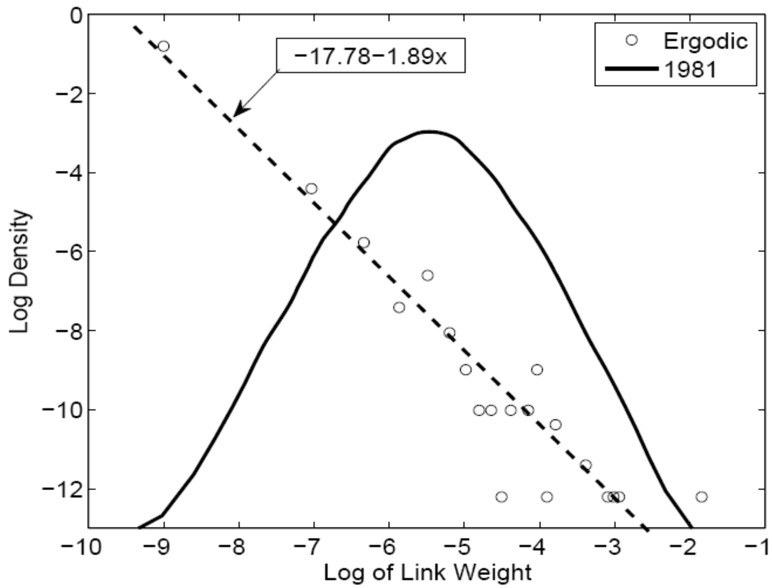
- **How do growth-rate distributions of node/link statistics look like?**
  - Node-statistic growth-rates are Laplace distributed
  - Link-weight growth-rates are still exponential but super-Laplace
  - AEP: Fat-tailed distributions with finite moments of all orders



Out-of-Sample Evolution

- **Can we make any prediction about the out-of-sample (limit) behavior of node/link statistic distributions?**
  - Employing kernel density estimates to find ergodic distributions
  - Result 1: Ergodic node-statistic distributions look similar to 1981 ones
  - Result 2: Positive link-weight distribution tends to a power-law!
    - Out-of-sample results hint to a polarization between few high-intensity links and many low-intensity ones
    - This is happening despite overall network architecture remains almost the same





The Agenda: Current Work (I)

- **Performing directed-network analyses on the same database**
  - Are we neglecting important information by symmetrizing the WTW?
  - A wealth of new indicators available for WDN analysis (Fagiolo, 2006)
  - Example: Comparing in/out degree/strength distributions, etc.
- **Exploring Geographical/Trade Agreement Issues**
  - Comparing network properties for groups of countries belonging to same geographical macro area or trade agreement
  - Exploring trade structure within and between regional/agreement networks (see De Benedictis & Tajoli, 2008)
- **Endogenously Detection of Trade Community Structure**
  - See Newman (2006), Reyes, Shirrell & Wooster (2009)
  - Compute community structures and compare them to those implied by various models based on regional and geographic classifications, the implementation of RTA's and/or on gravity models of trade

The Agenda: Current Work (II)

- **Comparing WTW to Other Relevant World Economic Networks**
  - Example 1: Network of bilateral asset trade
  - Example 2: Network of trade imbalances

- **Example 1: Fagiolo, Reyes, and Schiavo (2007)**
  - Data from IMF Coordinated Portfolio Investment Survey (CPIS)
  - 71 Countries, 5 asset classes (total, equities, debt, long-term debt short-term debt): building an international financial network (IFN)
  - Comparing WTW and asset-trade networks to investigate the degrees of trade and financial integration
  - Main findings:
    - WTW more densely connected than the IFN
    - Both networks display a core-periphery structure
    - IFN more hierarchically structured than WTW, with a few hubs (high-income countries) trading most of total financial assets and tightly interconnected
    - We argue that this may help to explain phases of int'l crises spreading: first in advanced countries, then in emerging markets

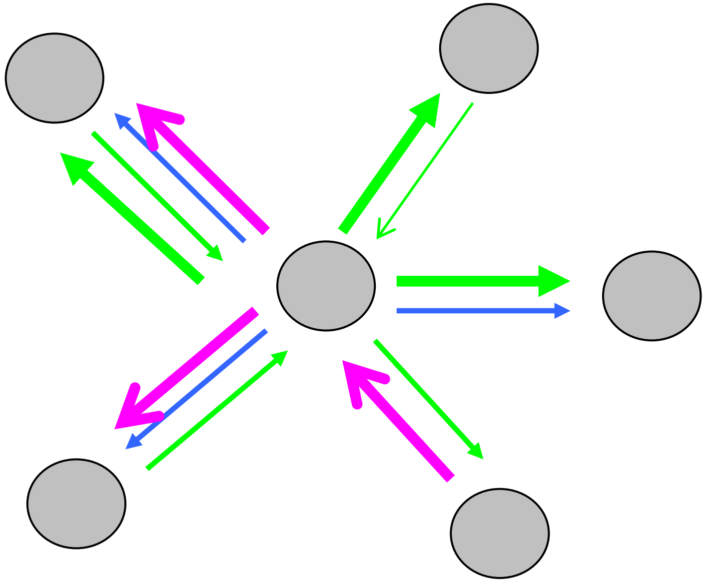
The Agenda: Current Work (II)

- **Comparing WTW to Other Relevant World Economic Networks**
  - Example 1: Network of bilateral asset trade
  - Example 2: Network of trade imbalances

- **Example 2: Fracasso and Schiavo (2009) – See Serrano et al. (2007)**
  - From trade data to trade imbalances (exports-imports)
  - Building weighted directed graphs: $w(i \rightarrow j)$ = deficit of country i vis-à-vis j
  - Investigating properties of global trade imbalance network
  - Main findings and economic implications:
    - The complexity of the network has increased: plans focusing only on industrialized countries are likely to be ineffective
    - Exchange rate movements against debtor and creditor countries have not been consistent with the simultaneous closing of all bilateral positions
    - The difficulty to orchestrate a plan involving many partners is thus matched by the apparent inability of uncoordinated adjustments to close the imbalances

The Agenda: Current Work (III)

- **From aggregate to commodity-specific trade networks**
  - See Barigozzi, Garlaschelli & Fagiolo (2009), forthcoming working paper
    - Related work: See Hidalgo et al (2007), where however nodes=products and links=proximity in production process
  - Disaggregating total trade among C commodities (colors)
  - Weighted directed multi-graph representation: up to 2C directed links with different thickness (weight) can be in place between any two countries at a given t



Basic Data Structure
A collection of (asymmetric) weight matrices

$$\{W_{1,t}, W_{2,t}, \ldots, W_{C,t}\}$$

WDNs Statistics

1. Across links/countries
2. Across products
3. Across time

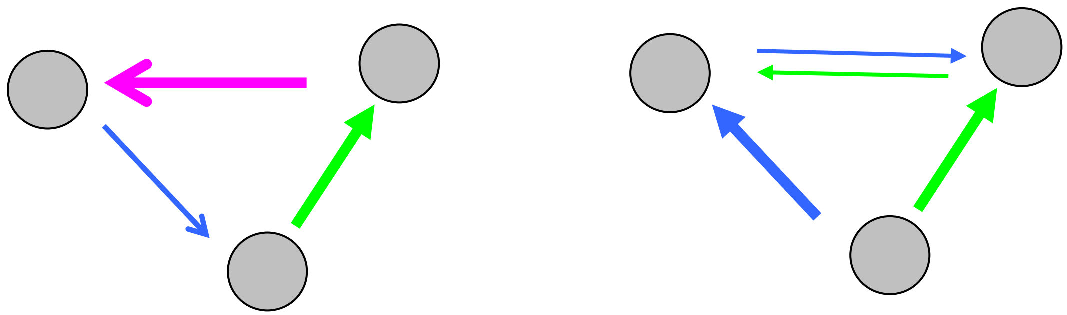
The Agenda: Current Work (III)

- **Data**
  - UN COMTRADE data bilateral data (import, export)
  - Balanced panel (173 countries) from 1992 to 2004
  - C=98 commodity classes, see the Harmonized System (HS1996)
  - Each entry of a $W_{c,t}$ matrix contains the share of trade over total trade for that year (to control for the fact the some commodities are usually more traded than other ones)

- **Some preliminary questions addressed in the paper**
  - Are commodity-specific networks connected? How large are giant components? What is the minimal set of commodity-specific networks that once aggregated are necessary to form a connected network?
  - Do averages of topological properties of commodity-specific networks differ? How does the correlation between the distributions of a given node statistics (i.e., strength) of two commodity-specific networks look like?

The Agenda: Current Work (III)

- **Some preliminary questions addressed in the paper (cont'd)**
  - Exploring Product-Specific WDNs as multi-networks
    - Restrict to economically-meaningful sub-samples of commodities, and explore the frequency of three-node relationships involving an import-export cycle of the same product or of particular patterns wherein complement and/or substitute commodities are traded



    - Identify community structures using disaggregated data
    - Introduce geographical and trade-agreement issues

The Agenda: Future Work

- **Modeling the Evolution of the WTW**
  - Very few attempts so far!
  - Two examples
- **Example 1: Models of Endogenous Network-Formation**
  - Studying the evolution of free-trade agreements in endogenous network-formation models (Goyal and Joshi, 2006; Furusawa and Konishi, 2007)
    - Pros: Link formation depends on strategic considerations and possibly country characteristics; allows for efficiency considerations and policy implications
    - Cons: Empirical validation of models with respect to observed network topological properties not always present
- **Example 2: Fitting exercises using gravity-like models**
  - Inferring observed link structure from node characteristics only (Garlaschelli and Loffredo, 2004, 2005, 2008)
    - Pros: Binary link structure can be well-described using country GDPs only and a gravity-like equation where $w_{ij}=f(GDP_i,GDP_j)$ and *no distance variables*
    - Cons: No strategic consideration, no link formation/deletion, no dynamics
    - See also Bhattacharya et al. (2007) for another example in this direction

The Agenda: Future Work

- **Remarks**
  - Models of evolving weighted networks? See e.g. Zheng and Gao, 2008 (PhysA); also Bloch and Dutta, 2009 (GEB) in the context of efficient networks
  - No successful attempt so far to write network-growth models (e.g. based on preferential attachment, etc.) able to fit WTW topological properties
  - Econophysics models are typically not enough for economists: strategic issues in link and weight formation seems indeed crucial in order to employ behavioral parameters, country characteristics, and/or control variables to "explain", predict, and perform policy exercises ("Why?", "What would happen if…", etc.)

- **Future challenges in modeling the evolution of the WTW**
  - Developing models of network formation and evolution that
    - are able to deliver as its equilibria networks with topological properties similar to those observed in the WTW (empirically-validated model)
    - are based on dynamic link formation and weight evolution mechanisms that incorporate not only random mechanisms and abstract forces (e.g., preferential attachment) but also strategic-interaction considerations based on country characteristics and international-economics principles

Conclusions: Summing Up

- **Dynamics and Evolution of the World-Trade Web**
  - Studying within- and out of- sample properties of (node/link) distribution dynamics for some interesting network properties
- **Network properties extremely stable during 1981-2000**
  - Out-of-sample results hint to a polarization between few high-intensity links and many low-intensity ones
  - This is happening despite overall network architecture remains almost the same
- **Current and Future work**
  - Directed weighted networks, geography, trade agreements, etc.
  - Studying other macro-economic networks (international finance)
  - Disaggregating into product classes
  - Merging economics and physics approaches to develop network models able to replicate WTW properties and allow for policy and prediction exercises

Conclusions