The World Trade Network

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The outline of the talk

- Introduction:
  - World Trade *is* a Network
  - Network Analysis: a primer
  - What we know about the (topological properties of the) World Trade Network: a short review of the literature
- The World Trade Network:
  - Data: directed import flows, binary adjacency matrix, some weighing at the end
  - Characteristics of the network and changes in the network structure along time
- 3 Applications:
  - (1) The WTO; (2) Regionalism and (3) Gravity
- What's more

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Part I

Introduction

Trade is a network: past

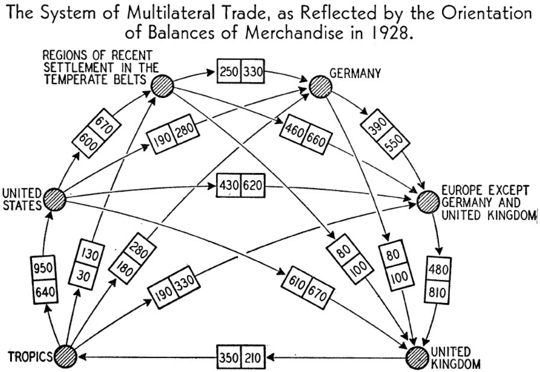


Figure: A natural way of representing international trade is through a network. The figure is from Folke Hilgerdt (1943), "The Case for Multilateral Trade", *American Economic Review*

Trade is a network: present

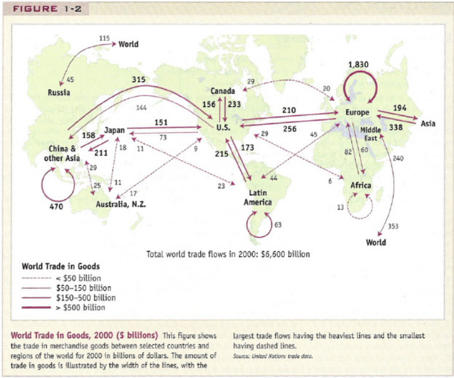


Figure: The most easy way of representing international trade is as a network. The figure is from Feenstra and Taylor (2008), *International Economics*, ch.1

Networks are not maps

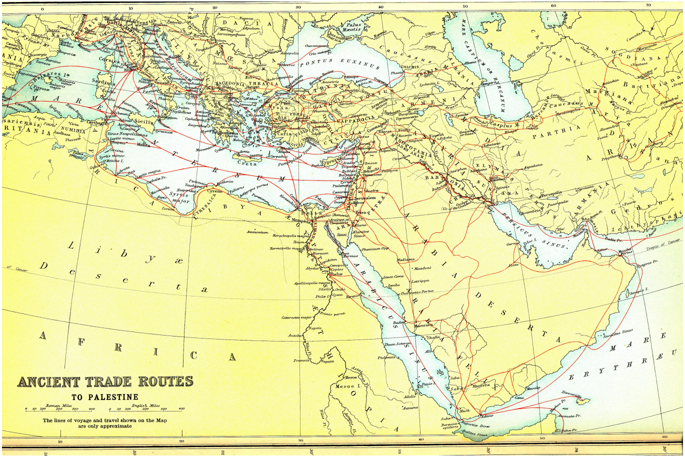


Figure: Ancient Trade Routes to Palestine.
The distance between vertices is exogenous (first nature | technology), while in networks it is determined endogenously.

Trade is a complex network

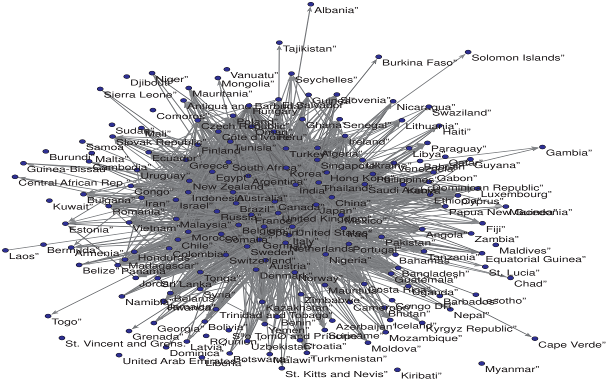


Figure: The World Trade Network in 2000. Only trade flows $> e^{10}$ are made visible.

Looking at trade flows through the lens of Network Analysis

- Economic integration is not a characteristic of a single country, but is the result of the relations that every single country has with the economic system.
- To define relations we need to focus not on individual agents (country), but of the system of agents, ≥ 2.
- Emergence of strategic interaction in a general equilibrium context.
- Trade flows are the results of 'countries' decisions not taken in isolation: Trade creation and diversion, multinationals, preferential agreements, intra-firm flows.
- Choices of countries depends on their relative position in the network. Empirics: Taking Anderson and van Wincoop (2003) seriously. Interdependence, multilateral resistance and errors' structure.

What we do

- More specifically, in this introductory paper
  - we analyze the World Trade Network from 1950 to 2000 to assess its characteristics and its variations;
  - we apply NA to the analysis of some trade issues recently debated in the literature to show how this approach allows to get new insights.
- With the results from NA we complement some of the empirical findings of the **gravity models**, with a general perspective on the trading system.
- Interestingly, the results from the NA of the World Trade Network are related to some of the recent **models of international trade**.

Part II

Graph Theory and Social Network Analysis

Graph

$$\mathcal{G} = (\mathcal{V}, \mathcal{L})$$

unit: *vertex*, node $\in \mathcal{V}$

link: line $\in \mathcal{L}$

directed (*arc*) $\in \mathcal{A}$;

undirected (*edge*) $\in \mathcal{E}$;

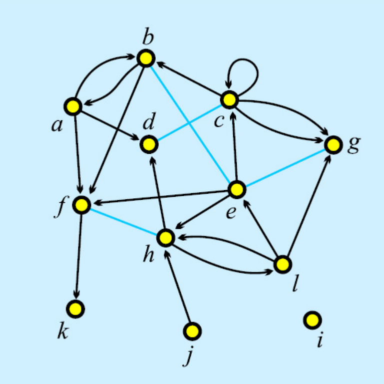
$\mathcal{L} = \mathcal{A} \cup \mathcal{E}$

$\mathcal{L}$ is a binary set [0,1]

dimensions:

$$n = \mid \mathcal{V} \mid, \; m = \mid \mathcal{L} \mid$$

example: $n = 12$, $m = 23$.



Note: We will analyze networks that do not contain *loops* $(c - c)$ and *parallel arcs* $(c - g)$.

Network: Graph + Data (on $\mathcal{V}$ and $\mathcal{L}$)

$$\mathcal{N} = (\mathcal{V}, \mathcal{L}, \mathcal{P}, \mathcal{W})$$

- $\mathcal{P}$ is the *vertex value function*: (exogenous or endogenous) properties of vertices
- $\mathcal{W}$ is the *line value function*: (exogenous or endogenous) weights of lines

Three kind of networks:

- if $\mathcal{A} = 0 \longrightarrow \mathcal{N}$ is an **undirected** network;
- if $\mathcal{E} = 0 \longrightarrow \mathcal{N}$ is a **directed** network;
- if $\exists \mathcal{W} \longrightarrow \mathcal{N}$ is a **weighted** network.

Structural properties: Degrees and Neighborhood

- **Indegree** and **outdegree**: is the number, d, of arcs received and sent by a vertex.
- **Neighborhood**: the set of vertices that are connected to any given $\mathcal{V}_i \in \mathcal{V}$ defines its *neighborhood* $\mathcal{V}_i^d \equiv \{j \in \mathcal{V} : ij \in \mathcal{L}\}$
  - A network is said to be *regular* if every vertex has the same number of links, $\mathcal{V}_i^d = \mathcal{V}^d$.
  - A *complete* network, $\mathcal{N}^c$, is a regular network in which $d = n - 1$.

Structural properties: Density and Centrality

- **Density**: is the number of lines in a network over the maximum possible number of lines
  - In a directed network $\gamma = \frac{m}{m_{\mathbf{max}}} = \frac{m}{n(n-1)}$
- Two definitions of centrality: **Closeness centrality** and **Betweenness centrality**.

Structural properties: Centrality (1)

The **Closeness centrality** of a vertex $\mathcal{V}_i$ is the number of other vertices divided by the sum of all distances between $\mathcal{V}_i$ and all others $\mathcal{V}_{j\neq i}$.

$$\mathcal{C}_i^c = \frac{n-1}{\sum_{j\neq i}^{n-1} \delta_{ij}}. \tag{1}$$

At the aggregate network level, if $\mathcal{C}_i^c*$ is the centrality of the vertex that attains the maximum closeness centrality score, the degree of **Closeness centralization** of a network is

$$\mathcal{C}^c = \frac{\sum_{i=1}^{n} \mid \mathcal{C}_i^c - \mathcal{C}_i^c* \mid}{(n-2)(n-1)/(2n-3)}. \tag{2}$$

The closeness centralization is, therefore, the variation in the closeness centrality of vertices divided by the maximum variation in closeness centrality scores possible in a network of the same size.

Structural properties: Centrality (2)

The **Betweenness centrality** of vertex $\mathcal{V}_i$ is the proportion of all geodesic distances between pairs of other vertices that include this vertex:

$$\mathcal{C}_i^b = \sum_{j \neq k} \frac{\delta_{jk}^i}{\delta_{jk}} \tag{3}$$

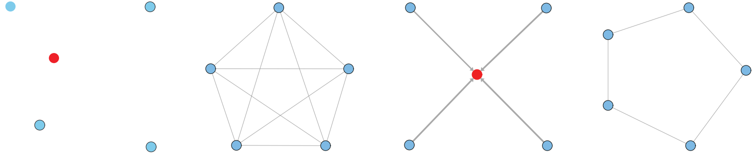
where δ_{jk} is the total number of shortest paths joining any two vertices $\mathcal{V}_k$ and $\mathcal{V}_j$, and δ_{jk}^i is the number of those paths that not only connect $\mathcal{V}_k$ and $\mathcal{V}_j$, but also go through $\mathcal{V}_i$.

The **Betweenness centralization** is the variation in the betweenness centrality of vertices divided by the maximum variation in betweenness centrality scores possible in a network of the same size.

$$\mathcal{C}^b = \sum_{i=1}^{n} \mid \mathcal{C}_i^b - \mathcal{C}_i^b * \mid . \tag{4}$$

Some families of Networks

Graphs:



Empty Graph, Complete Graph, Star Graph, Circle Graph.

Properties:

Density=0
Closeness=0
Betweenness=0

Density=1
Closeness=0
Betweenness=0

Density=0.4
Closeness=1
Betweenness=1

Density=0.5
Closeness=0
Betweenness=0

The properties of vertices are not necessarily the ones of the entire network. In this complete network all vertices have closeness centrality equal to 1, and betweenness centrality equal to 0.

Part III

A (short) review of the literature

Findings (in the literature): Topological properties

Recent applications of NA to trade flows found that the WTN is a complex network, with the following **properties**:

- **Scale-free degree distribution** (high heterogeneity) [Serrano and Boguña (*Phys. Rev. E*, 2003]
- **Small-world property** (average path length between any pair grows logarithmically with system size) [Fagiolo, Reyez and Schiavo (*S.Anna WP*, 2007)]
- **High clustering** (neighbors are likely to be connected) [Garlaschelli and Loffredo (*Physica A*, 2005)]
- **Degree-degree correlation** (hierarchical organization) [Smith and White (*Social Forces*,1992)]

Implications

Some **implications** for international trade

- Countries have a very different number of trading partners
- Countries' positions in the system are very different, and some are more central than others
- The size of the system (in terms of number of countries) is only modestly important
- Trade is partially organized in 'clubs'

Part IV

The World Trade Network

The bilateral trade flows dataset

Our **dataset**:

- From **Subramanian and Wei (2007)**, "The WTO promotes trade, strongly but unevenly", *JIE*, 72, 151-175.
  - **Aggregate bilateral imports** as reported by the importing country and measured in U.S. dollars, reported in the *IMF Direction of Trade Statistics*;
  - in the first part of the analysis we transformed the data in a **dichotomous variable**.
- **Time span** from 1950 to 2000.
- Observations for 60 to 157 **countries**.
- **Geographical partition**: macro continental regions (WB classification).
- **Institutional partition**: WTO membership

The World Trade Network properties

The **evolution** of the World Trade Network (1950-2000)

	1950	1960	1970	1980	1990	2000
No. Countries	60	113	130	143	145	157
No. Arcs	1649	3655	6593	8180	10289	11938
Density	0.4658	0.2888	0.3931	0.4028	0.4928	0.4874
In-Degree Closeness Centralization	0.5260	0.6005	0.5647	0.5801	0.5108	0.5159
Out-Degree Closeness Centralization	0.4743	0.5464	0.5100	0.4383	0.4688	0.4836
In-Degree St.Dev.			30.7904	37.0516	37.486	39.0725
Out-Degree St.Dev.			31.9825	32.8688	35.8637	41.4161
Betweenness Centralization	0.0417	0.0627	0.0355	0.0317	0.0161	0.0158
Total Betweenness		0.5516	0.5180	0.4425	0.4724	0.4869

Source: our elaboration on S-W data.

The World Trade Network properties

The **evolution** of the World Trade Network (1960-2000)
within a constant subset of countries

	1960	1970	1980	1990	2000
No. Countries	113	113	113	113	113
No. Arcs	3655	5807	6522	7355	6964
Density	0.289 [*]	0.459 [*]	0.515 [*]	0.581 [*]	0.550 [*]
In-Degree Closeness Centralization	0.6005	0.5190	0.4800	0.3866	0.3547
Out-Degree Closeness Centralization	0.5464	0.4920	0.3809	0.3776	0.3547
In-Degree St.Dev.	24.02	26.16	30.01	28.04	28.54
Out-Degree St.Dev.	26.31	28.78	25.91	27.84	30.72
Betweenness Centralization	0.0627	0.0308	0.0155	0.0097	0.0065
Total Betweenness	0.5516	0.4991	0.3853	0.3466	0.2685

Note: Here the network and its indices are computed including only the group of countries for which data are available over the entire time span 1960-2000.

[*] indicates that the density is significantly different from the null hypothesis of γ=1 with p=0.0002.

Source: Our elaboration on S-W data.

The World Trade Network in 1950

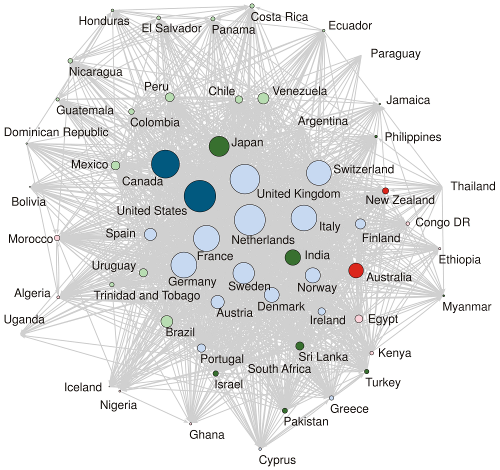


Figure: The size of each vertex is given by its betweenness index.

The World Trade Network in 2000

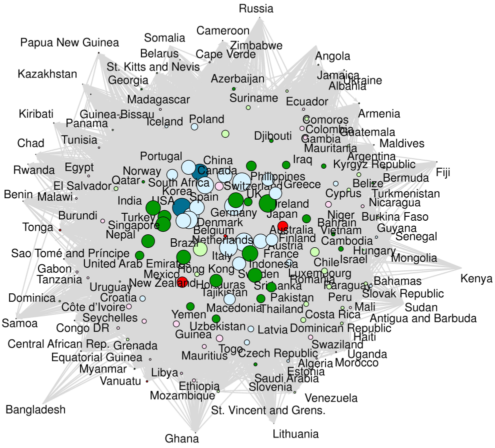


Figure: The size of each vertex is given by its betweenness index.

Correlation between GDP per capita and Betweenness centrality = 0.59; the one between GDP and

Countries' centrality in the world trade network

Indegree closeness centrality			Outdegree closeness centrality			Betweenness centrality		
Rank	Index	Country	Rank	Index	Country	Rank	Index	Country
				1960				
1	0.6438	UK	1	0.5987	USA	1	0.0344	France
2	0.5954	Netherlands	2	0.5861	UK	2	0.0327	UK
3	0.5866	France	3	0.5740	France	3	0.0283	USA
4	0.5822	Japan	3	0.5740	Germany	4	0.0182	Netherlands
5	0.5656	USA	3	0.5740	Netherlands	5	0.0179	Japan
6	0.5616	Germany	6	0.5624	Italy	6	0.0140	Germany
6	0.5616	Italy	7	0.5568	Sweden	7	0.0126	Italy
8	0.5387	Sweden	7	0.5568	Japan	8	0.0121	Switzerland
8	0.5387	Switzerland	9	0.5406	Switzerland	9	0.0108	Canada
10	0.5350	Canada	10	0.5354	Denmark	10	0.0097	Sweden
11	0.5244	Norway	11	0.5303	India	11	0.0091	India
12	0.5142	Austria	12	0.5156	Canada	12	0.0072	Denmark
13	0.5012	Denmark	13	0.5016	Norway	13	0.0070	Austria
13	0.5012	Greece	13	0.5016	Spain	14	0.0068	Norway
15	0.4858	Finland	15	0.4928	Austria	15	0.0053	Morocco

Countries' centrality in the world trade network

Indegree closeness centrality			Outdegree closeness centrality			Betweenness centrality		
Rank	Index	Country	Rank	Index	Country	Rank	Index	Country
2000								
1	0.8920	USA	1	0.8636	USA	1	0.0149	USA
1	0.8920	Germany	1	0.8636	UK	1	0.0149	Germany
3	0.8808	UK	1	0.8636	France	3	0.0141	UK
3	0.8808	France	1	0.8636	Germany	4	0.0141	France
5	0.8752	Italy	5	0.8580	Italy	5	0.0134	Italy
5	0.8752	Netherlands	5	0.8580	Japan	6	0.0132	Japan
7	0.8590	Japan	7	0.8523	Netherlands	7	0.0130	Netherlands
7	0.8590	Spain	7	0.8523	Spain	8	0.0121	Spain
9	0.8537	Canada	9	0.8413	India	9	0.0115	Canada
10	0.8434	Belgium	10	0.8360	Denmark	10	0.0106	Korea
11	0.8186	Korea	11	0.8306	Switzerland	11	0.0104	Belgium
12	0.8138	Thailand	11	0.8306	Canada	12	0.0096	Malaysia
13	0.8091	Portugal	11	0.8306	Korea	13	0.0093	Australia
14	0.8044	Malaysia	14	0.8254	Malaysia	14	0.0092	Denmark
15	0.7998	Switzerland	15	0.8202	Sweden	15	0.0091	Thailand

Changes in the network structure

From the network indices we observe that

- Density increases over time $\rightsquigarrow$ countries are more tightly interconnected
- Centralization decreases over time $\rightsquigarrow$ less polarized trading system (more ‘globalization’ in the proper sense of the world)
- Average degree increases (slowly) over time $\rightsquigarrow$ more trading partners but still selection
- Differences in distribution of export (outdegree) and import (indegree) $\rightsquigarrow$ the number of importing partners is higher than exporting partners.
- Structural (geodesic) distance often not related to geographical distance.

Part V

Applications

Properties of the WTO network

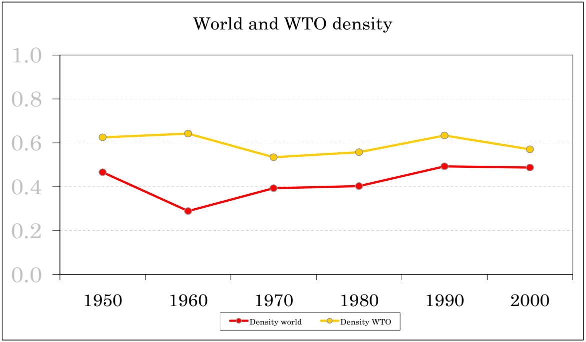
	1950	1960	1970	1980	1990	2000
Countries	24	35	75	85	98	124
Arcs	345	764	2966	3979	6021	8699
Share of total recorded arcs	20.92	20.9	44.99	48.64	58.52	72.87
Density	0.6250	0.6420	0.5344	0.5573	0.6334	0.5704
In-Degree Centralization	0.3006	0.308	0.4308	0.4239	0.3496	0.4168
Out-Degree Centralization	0.2552	0.2474	0.4034	0.3275	0.3183	0.384
In-Degree St.Dev.	6.6946	9.5961	19.1034	23.2229	24.9187	30.6184
Out-Degree St.Dev.	5.9499	8.4936	19.3716	20.2412	22.4931	31.2289

Figures and indices refer to the countries member of the WTO in each given year.

Source: our elaboration on S-W data.

We tested and confirmed the difference between the WTO and the World Network densities

The WTO effect



Comparison of the WTO network

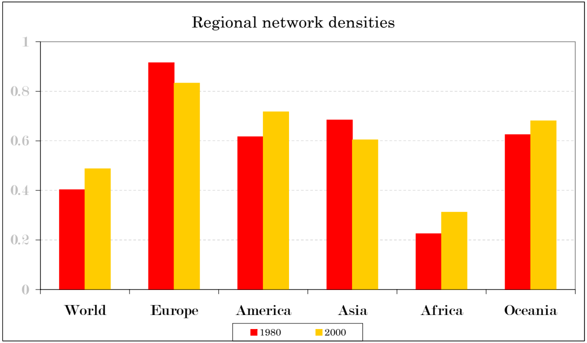
By comparing the total trade network with the WTO network we see that:

- The WTO network is much more dense $\rightsquigarrow$ WTO members are more closely interconnected.
- The WTO network is less centralized and with lower variance in degrees $\rightsquigarrow$ WTO system less hierarchical and more even that the entire system
- The heterogeneity in the WTO network is increasing quickly $\rightsquigarrow$ more difficult to negotiate (?)

Part VI

Application (2): is trade regionalized?

Continental networks



Part VII

Application (3): Gravity and Network

Gravity + Network

Dependent variable	ϕ_{ij}	ϕ_{ij}	ϕ_{ij}	ϕ_{ij}
$\bar{y}_{i(t-5)}$	1.361***	1.072***	0.721***	0.670***
	(0.113)	(0.176)	(0.187)	(0.188)
$\bar{y}_{j(t-5)}$	1.413***	1.255***	0.857***	0.774***
	(0.113)	(0.180)	(0.194)	(0.197)
distance$_{ij}$	-1.316***	-1.326***	-1.328***	-1.329***
	(0.024)	(0.027)	(0.027)	(0.027)
outdegree$_{i(t-5)}$		-0.001	-0.004**	-0.004**
		(0.002)	(0.002)	(0.002)
indegree$_{i(t-5)}$		0.004***	0.014***	0.013***
		(0.001)	(0.003)	(0.003)
outdegree$_{j(t-5)}$		0.015***	0.011***	-0.008
		(0.002)	(0.002)	(0.006)
indegree$_{j(t-5)}$		-0.015***	-0.003	0.005
		(0.001)	(0.003)	(0.008)
ego density$_{i(t-5)}$			0.021***	0.017***
			(0.006)	(0.006)
ego density$_{j(t-5)}$			0.024***	0.017***
			(0.005)	(0.006)
obs.	63724	54431	54431	54431
Log likelihood	-20333	-17212	-17196	-17189
Pseudo R^2	0.536	0.5375	0.5379	0.5381

Gravity + Network

- Network variables (general equilibrium $\simeq$ interdependence $\simeq$ peer effects) matter.
- They affect the role of GDP but not distance.
- Proximity in space lose significance.
- (N1) Positive effect of importing and negative effect of exporting with many partners
- (N2) Positive effect of 'market potential' and negative effect of competition
- (N3) Ego density is relevant and nullify the effect of competition (when density is high the probability of loosing a central position is low)

Part VIII

Conclusions and future work

Summing up

Through the use of NA we showed analytically that:

- Some structural changes occurred in the World Trade Network (not a neutral 'magnification effect')
- Increased heterogeneity between countries
- WTO plays a role in the structure of world trade
- Distance/proximity matter (structurally and geographically) and trade is to some extent regionalized
- Gravity and Networks are complementary explanations

Possible applications of NA to international trade issues

- **Impact** of emerging countries on the network structure
- Differences in network structure for **different goods** and commodities [Rauch (1999) strikes again!]
- Networks of **production**
- Sectoral networks and the dynamics of comparative advantages (**the product space**)[Haussmann, Hidalgo, Klinger and Barabasi (2007)]
- **Contagion** and business cycle transmission
- Economic integration and **growth**
- **Endogenous distance** and position measures
- Relationship between trade and **FDI networks**