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Comparing Sectoral International Trade Networks

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Abstract

How is the structure of trade flows for a given good organized? Is it a dense, widespread network with many links, or is it a centered network, organized around a hub that centrally coordinates the flows? Does it have a regional structure or a world-wide coverage? This paper uses the tools of network analysis to represent the different characteristics of world trade in different manufacturing industries. The structure of the Trade Networks is compared, to assess to what extent the world market characteristics differ between sectors. The results show that there is a positive correlation between the goods' complexity and the network complexity, changing the extent of the relevant market and its structure across goods.

Keywords: International Trade, Network Analysis, differentiated goods.

JEL Classification: C02, F10, F14.

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1 Introduction

How is the structure of international trade for a given good organized? This question might have a distinctive answer according to the type of goods that are traded. The existing trade models suggest that for standardized goods potential partners can be many, but eventually only one (the one offering the best price) should be selected, therefore relatively few (unidirectional) trade links will appear between countries. Instead, for goods produced in many varieties and qualities, there will be many trading partners, and many multiple links will exist. Also for goods with low transport costs, partners can be numerous, and either far away or close, while for goods with high transport cost, geographic proximity of partners will be important, and partners will be spatially selected. In high-tech, sophisticated productions, the technological proximity of partners can give rise to selected trade flows around a technologically-advanced center.

If we describe the structure of international trade flows as a network, we expect that trade in different types of goods would give rise to trade networks with different characteristics. The shape of the network is influenced by the characteristics of production and of demand, as the network is formed by the existing links between exporters and importers.[1] The role of countries in the network depends on their characteristics as suppliers (their comparative advantages, their size and factors' endowment, etc.) as well as on their preferences as buyers of the goods, giving rise to arcs (or links between vertices) in the network. According to these specificities, for some products we should expect a dense, widespread network with many arcs, and for others a less dense network, possibily centered, organized around a hub that centrally coordinates the flows. The structure of the trade network in terms of density, centralization and clustering can have a direct impact on the competition between countries and on the formation of the international price for a given good, by defining the size of the market in terms of potential demand and supply.

In this paper we show that distinctive industries give rise to trade networks with diverse structural characteristics, as a simple theoretical frameworks of trade relations would suggest. Network analysis indices are used to identify the characteristics of each trade network (Goyal, 2007; Vega Redondo, 2007). The results of this analysis are then used to characterize the market for different types of goods.

[1] The benefit of representing trade flows as a network is to give emphasis to the relationship between the countries in the network and to the structure of the system itself, which is the objective of network analysis. For a discussion on the applications of network analysis to international trade studies, see De Benedictis and Tajoli (2009).

2 Goods' characteristics and trade links

A characteristic of economic networks is that they should result from the behaviour and decisions of self-interested agents. If a link between two vertices represents an economic transaction taking place, following Jackson (2005) economic networks can be seen as a representation of the equilibrium resulting from this set of transactions. This idea applies also to international transactions between countries. The basic insight of international trade models is that a trade link between two countries occurs to exploit price differences between them. According to trade models based on comparative advantages, the more different countries are, the more likely is that they trade with each other. Furthermore, under the most strict hypotheses of these models, in the absence of transportation costs, in a framework where countries' sizes are similar, exports should come only from the country (or countries) with the lowest prices. In this homogeneous goods context, in each industry the number of incoming trade flows observed for a given country should be limited, while outgoing trade flows would come from a subset of countries, and no bi-directional links are expected. This would give rise to a trade network with a relatively low density.

In the case of differentiated goods instead, the theoretical models suggest that we should observe trade also between similar countries, and trade in the same industry can exist in both directions between a country pair. A preference for variety together with the possibility to exploit economies of scale in production will tend to increase the number of trading partners that each country has. In the case of differentiated goods in fact, under the hypothesis of love-for-variety in the preference structure and of economies of scale in production of each variety, each exporter will try to reach as many markets as possible and consumers will tend to have a large number of suppliers, increasing the number of trading links of a country. In a model *à la* Anderson and van Wincoop (2003), with homogeneous firms within each country and consumers' love of variety, this ensures that all goods are traded everywhere. In this model there is no geographical extensive margin, and any obstacle to trade such as distance or trade barriers affects trade volumes at the intensive margin. Therefore in such a context of differentiated goods, we should expect a very dense (even complete) trade network.[2]

On the other hand, Rauch (1999) suggests that for differentiated goods, the heterogenity of manufactured goods in terms of quality and other specific characteristics at the base of the imperfect substitutability between goods,

[2] A complete network is a network where every vertex is connected to all other vertices, displaying the maximum density, equal to 1.

gives rise to a matching process which is costly. Other models indicate that the cost of accessing to a foreign market can be relevant especially for differentiated goods. In presence of fixed costs for exporting, theoretical models show that a sharp reduction in the number of trade links between countries is observed. If these costs are specific to the exporter-importer pair, the distribution of trade links can be very heterogeneous across countries. Helpman *et al.* (2008) show that the combination of fixed export costs and firm level heterogeneity in productivity, combined with cross-country variation in efficiency, implies that any given country need not serve all foreign markets. Both the search and the access costs will tend to reduce the number of trade links for each country. Therefore, for differentiated goods we have an ambiguous result in terms of the expected number of links: importers will try to have many inward trade links to benefit from variety, and exporters will try to have many outward links to exploit economis of scale, but if they have bear the costs to access to foreign markets, they will have to select where they operate, and the number of links will be constrained by the extend of the search and entry costs.[3]

The above hypotheses suggest that the structure of the international trade networks should be less dense for homogeneous goods, and more dense for differentiated goods, even if the number of observed links will depend on the relative importance of searching and access costs with respect to the strength of economies of scale and preference for variety. This difference in network structure according to the goods' characteristics is the hypothesis we want to examine in the following section.

3 Differences in trade networks

As mentioned, in network analysis the individual country is not the basic unit of research. We look at countries as vertices in a network where arcs are given by their economic ties, measured by trade flows. Countries are connected by their trade links, and our analysis considers the structure of the network arising from these links.

More specifically, we consider the network created by trade flows of goods belonging different industries. We use bilateral trade data from the BACI database of CEPII, which is based on the UNCOMTRADE database. The database includes 222 countries, therefore our networks will have 222 vertices. We have data for 28 sectors at a level of disaggregation corresponding to three-digit of the ISIC code, and we analyze 28 distinctive networks.

[3]The matching cost could also be beared by importers in terms of higher prices, and in this case, the constraint in the number of links will come from the importing country.

We use disaggregated bilateral imports for the year 2000.[4] In each industry, each import flow is counted as one arc going from the origin to the destination country, independently from the value carried by the flow (in other words, arcs are unweighted in computing the basic network indices). The database contains a total of 259,263 disaggregated bilateral flows, representing an average of 9259 flows per sector and 1168 flows per country. These average figures hide large differences between countries and between sectors, which give rise to distinctive network structures.

3.1 Characteristics of the trade networks

The main characteristics of a network can be summarized by some indices that we computed for all the sectors in our dataset, and which are reported in Table 1. By including all 222 countries in all the 28 sectoral networks, we have networks with the same size in terms of vertices, but with a quite different number of arcs. A country (a vertex of the network) can generally be both a sender and a receiver of arcs, i.e. an exporter and an imported in each industry. The *degree* of a vertex (defined as the number of arcs connecting the vertex to the network) is in this case the number of trading partners of a country, and import flows from each partner can be counted as the *indegree*, while the *outdegree* would be the number of export flows. The average degree is computed simply as the total number of arcs divided by the number of vertices, and it is by definition the same considering indegrees or out-degrees. The mean across sectors of the average degree is 42, but there are remarkable differences from sector to sector. Given the non-normal distribution of degrees, it is also informative to look at the median of the indegrees and outdegrees, which can instead be different. Indeed, in all sectors the median indegree is much higher than the median outdegree. This confirms at the sectoral level a finding relative to the aggregated world trade network (see De Benedictis and Tajoli, 2009): exports markets are generally more limited in number than import sources, suggesting the existence of costs to reach and penetrate new foreign markets, while import sources are more highly diversified, in line with the idea of promoting competition from import sources, and these characteristics are relevant in nearly all sectors.

[4] We use import data for each of the 222 countries from all other 221 countries to connect the origin and the destination of a trade flow rather than export data, as imports are generally believed to be more reliable and complete, being recorded for most countries at the custom level to collect tariffs and other duties, for security reasons, and so on. Given the size of our dataset, the maximum number of arcs for each industry is 222*221=49062, i.e. if every country would trade with every other country, in every industry we would observe 49062 trade flows.

The average degree of a network can be used to measure the cohesion of a network. Directly related to this measure is the *density* of a network, expressed as the proportion of the number of arcs in a simple network over the maximum possible number of arcs, $\delta = \frac{m}{m_{\max}}$, where $m_{\max}$ is the number of arcs in a complete network with the same number of vertices. Accordingly, a complete network, in which every vertex is connected to every other vertex, is a network with maximum density equal to 1. Looking at Table 1, we see that in all sectors the trade network is far from being complete. For comparison, in Table 1 are reported also the network indices computed for aggregate trade flows. Even at the aggregate level, the world trade network is largely uncomplete, with a density of about 0.44, but unsurprisingly at the sectoral level the density is much lower, being on average just about 0.19. This means that in a given industry, on average there is a probability of 19% that two countries i and j are linked. Clearly, countries do not import from every possible source and export to every possible market, but they select their trading partners.

The position of every vertex in a network is measured in terms of *centrality*, which indicates how closely linked is a vertex to all the other vertices (see Freeman, 1979). The centrality of a vertex can be interpreted as a measure of "'importance"' with respect to the network structure. In the trade context, centrality measures can be computed to indicate how closely tight is a country or a group of countries to the world market.

Many distinctive measures of centrality exist, which capture different aspects of the role of a vertex within the network. The simplest measure of centrality for a vertex is the number of its neighbors, i.e. its degree. The standardized *degree centrality* of a vertex is its degree divided by the maximum possible degree, $\mathcal{C}_i^d = \frac{d}{n-1}$. From the vertex measure of centrality is possible to define also the extent to which a network is centralized. The *degree centralization* of a network is defined relatively to the maximum attainable centralization. The minimum degree for any component of the network is 0 and the maximum possible degree is $n-1$. If $\mathcal{C}_i^d*$ is the centrality of the vertex that attains the maximum centrality score, the variation in the degree of vertices is the summed absolute differences between the centrality scores of the vertices and the maximum centrality score among them. So, as the maximum attainable centrality is $(n-2)(n-1)$, the degree centralization of a network is $\mathcal{C}^d = \frac{\sum_{i=1}^{n} |\mathcal{C}_i^d - \mathcal{C}_i^d*|}{(n-2)(n-1)}$, and the higher the variation in the degree of vertices the higher the centralization of a network. In directed networks, degree centralization can be measured both in terms of indegrees and outdegrees. The centrality of a network is an important indicator of the organization of the network, with a low centrality indicating that all vertices are in similar positions with respect to each other, while a high centrality indicates that the structure of the network is built around some special vertices.[5]

Degree centralization is associated to direct links, but when connections in a network acquire some relevance one should give prominence also to indirect links. This brings to the concept of *distance* in networks, namely the number of steps needed to connect two vertices. The shortest the distance between two vertices, the closest is the connection between them. The *geodesic distance* is the shortest path between two vertices. The notion of geodesic distance is at the bulk of an important definition of centrality: *Closeness centrality*. The closeness centrality of a vertex is the number of other vertices divided by the sum of all distances between the vertex and all others. It gives an indication about how far a vertex is from all the others, and it can be seen as an inverse measure of distance. A different notion of centrality is based on the intuition that a vertex is central if it is essential in the indirect link between other vertices. A vertex that is located on the geodesic distance between many pairs of vertices plays a central role in the network, and in a pure star, the core is central because it is necessary for all periphery vertices in order to be mutually reachable. This concept of centrality is based on betweenness, so it is called *betweenness centrality*. The betweenness centrality of vertex can be loosely defined as number of times that a node lies along the shortest path between two others.[6] The *betweenness centralization* of a network 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, $\mathcal{C}^b = \sum_{i=1}^{n} \mid \mathcal{C}_i^b - \mathcal{C}_i^b * \mid$. The notion of betweenness centrality has important strategic implications. The central vertex could, in fact, exploit its position to its advantage.

From the centralization indices reported in Table 1, we see that all sectoral networks are quite centralized in terms of outdegree. This measure of centralization ranges from a minimum of 0.56 to a maximum of 0.70, while at the aggregate level, the outdegree centralization of the world trade network reaches just about 0.50.[7] Betweeness centrality at the industry level is

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[5]The centrality of a pure star (i.e. a network with one central vertex connected to all the others, while all other vertices are connected only to the center and not to each other) is 1. The centrality of a regular network (i.e. a network where all vertices have the same degree) is 0.

[6]More formally, it is the proportion of all geodesic distances between pairs of other vertices that include this vertex (Vega-Redondo, 2007). The core of a star network has maximum betweenness centrality, because all geodesic distances between pairs of other vertices include the core. In contrast, all other vertices have minimum betweenness centrality, because they are not located between other vertices.

[7]See also De Benedictis and Tajoli (2009) for a comparison with the world trade network indicators at the aggregate level. See also Serrano, A., M. Boguña and Vespignani A.

Table 1: Trade networks characteristics in the year 2000

ISIC code	Industry	% on tot. trade value	Arcs	Density	Average degree	Indegree Median	Indegree st.dev	Outdegree Median	Outdegree st.dev.	Indegree Central.	Outdegree Central.	Betweeness Central.	Countries in core
311	Food products	4.5	12710	0.2591	57.25	54.50	35.96	32.00	56.21	0.4852	0.6443	0.0488	72
313	Beverages	0.7	7078	0.1443	31.88	28.50	23.69	14.00	43.36	0.4323	0.7051	0.0755	41
314	Tobacco	0.3	3651	0.0744	16.45	14.00	13.98	4.00	28.99	0.2662	0.6116	0.1031	28
321	Textiles	3.5	12829	0.2615	57.79	54.50	38.45	40.00	55.18	0.5100	0.6191	0.0459	74
322	Apparel	3.9	11475	0.2339	51.69	44.00	38.75	32.50	51.42	0.5605	0.6605	0.0618	65
323	Leather products	0.7	7842	0.1598	35.32	28.00	29.95	16.50	43.93	0.4531	0.6440	0.0611	58
324	Footwear	0.7	6623	0.1350	29.83	25.00	24.58	9.00	41.11	0.4371	0.6326	0.1040	47
331	Wood products	1.1	8884	0.1811	40.02	31.50	33.48	22.00	43.94	0.5272	0.6408	0.0705	58
332	Furniture	1.0	8522	0.1737	38.39	36.00	28.82	19.00	47.07	0.5073	0.6846	0.0993	57
341	Paper products	2.5	8984	0.1831	40.47	39.50	27.02	15.00	50.59	0.4070	0.6660	0.0779	54
342	Printing and publishing	0.7	9585	0.1954	43.18	41.00	30.83	21.00	50.22	0.4719	0.6946	0.0640	55
351	Industrial chemicals	7.9	11627	0.2370	52.37	51.00	34.06	27.00	55.70	0.4392	0.6619	0.0542	65
352	Other chemicals	4.1	11748	0.2395	52.92	55.50	30.92	26.00	57.66	0.4367	0.6685	0.0477	57
353	Petroleum refineries	2.8	5338	0.1088	24.05	20.00	18.60	7.00	37.26	0.3407	0.6271	0.1088	38
354	Petroleum and coal prod.	0.1	2689	0.0548	12.11	8.50	11.34	1.00	25.69	0.1859	0.5586	0.0689	30
355	Rubber products	0.9	8951	0.1824	40.32	42.00	25.79	11.00	53.32	0.3849	0.6758	0.0778	60
356	Plastic products	1.2	10286	0.2097	46.33	46.00	29.58	21.00	54.02	0.3985	0.6621	0.0598	64
361	Pottery, china, earthenware	0.2	6604	0.1346	29.75	25.50	24.89	10.50	41.37	0.4193	0.6466	0.0813	58
362	Glass products	0.5	7979	0.1626	35.94	35.00	24.75	10.00	49.28	0.3639	0.6775	0.0604	57
369	Other non-metal mineral pr.	0.6	7846	0.1599	35.34	33.00	24.18	11.00	47.74	0.3666	0.6893	0.0663	47
371	Iron and steel	2.9	8465	0.1725	38.13	34.00	26.24	14.50	49.63	0.3585	0.6676	0.0550	49
372	Non-ferrous metals	2.8	7619	0.1553	34.32	26.00	29.88	15.00	41.75	0.4485	0.6622	0.0937	56
381	Fabricated metal products	2.9	12195	0.2486	54.93	54.00	34.55	30.50	57.56	0.4958	0.6548	0.0481	59
382	Machinery, except electric	16.7	14304	0.2915	64.43	60.00	40.51	41.00	59.54	0.5435	0.6298	0.0437	63
383	Machinery, electric	17.1	13055	0.2661	58.81	56.50	39.18	33.50	57.71	0.5781	0.6463	0.0464	63
384	Transport equipment	14.9	11423	0.2328	51.45	51.00	33.26	30.00	54.60	0.5116	0.6797	0.0498	64
385	Prof. and scient. equip.	3.0	10430	0.2126	46.98	42.00	33.67	20.00	54.59	0.5501	0.6910	0.0660	56
390	Other manufact. products	1.8	10521	0.2144	47.39	44.50	34.32	24.50	52.84	0.5209	0.6664	0.0705	64
	Aggregate bilateral trade		21700	0.4423	97.75	101.50	53.40	88.50	59.54	0.4784	0.5011	0.0147	104

Source: our elaboration on BACI dataset, based on UN Comtrade.

also higher than at the aggregate level. This means that in general, export flows tend to be organized around some important countries (producers), that play a key role in the network structure. The extent of centralization is somewhat lower if we consider the indegrees. In this case, the range of the index goes from 0.18 to 0.57, and for every industry indegree centralization appears to be lower than the corresponding outdegree measure. This is true also at the aggregate level, but the difference is much smaller. Considering disaggregated import flows, there seems to be only a few cases in which a limited number of central markets play a key role in the network structure.

One way to assess the distinctive position of vertices in a network is to identify the *core* of the network, if it exists.[8] A core is a relatively dense sub-network within the network, identified by a cluster of vertices with a high degree that are tightly connected to each other. In our analysis, we can see the core of the network as the core of the market in a given industry, or in other words, the sub-group of countries that, having a large number of links, tend to be the market-makers. In Table 1 is reported the number of countries identified as belonging to the core in each industry. To identify the core, indegrees and outdegrees of all countries were considered together. In other words, the core is made both by strongly linked exporters and importers. On average, about one fourth of all countries considered belong to the core, even if also in this case there are differences between industries. The network formed by this subgroup of tightly connected countries always displays a density of 0.90 or higher.

The difference between trade networks in distinctive industries can be appreciated also visually. Figure 1 shows the trade network of the machinery industry and of the fuel products industries, which are the most dense and less dense networks, respectively. While machinery is a highly differentiated industry, the fuel products industry is based on relatively homogenous raw materials.

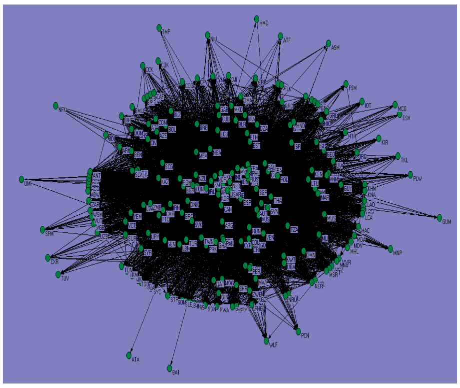
3.2 Trade networks and goods' complexity

As mentioned, the trade networks formed by trade links in distinctive industries display quite different characteristics. We can see industries with a relatively high network density, such as machinery, both electric and non-electric,

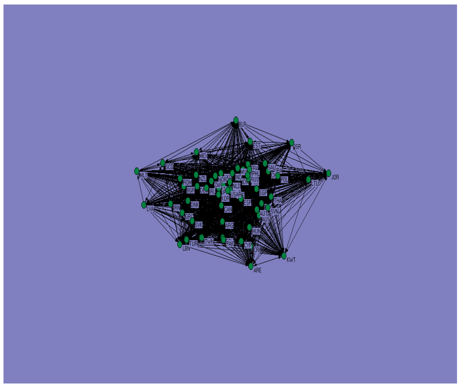
(2007) for a description of the key arcs and key nodes existing in the world trade network.

[8]In star networks there are two groups of vertices: core vertices are heavily linked to vertices in the periphery, while vertices in the periphery are generally linked only to core vertices. In a pure star the degree of the unique core vertex is n-1, and the degree of the $n-1$ periphery vertices is 1. In regular networks, the core coincides with the entire network, so it is not possible to divide vertices between a core and a periphery.

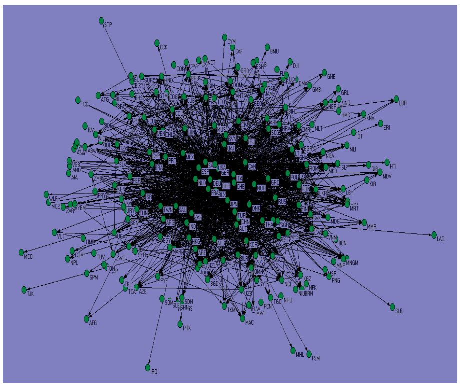
Figure 1: The most dense and least dense networks and their core



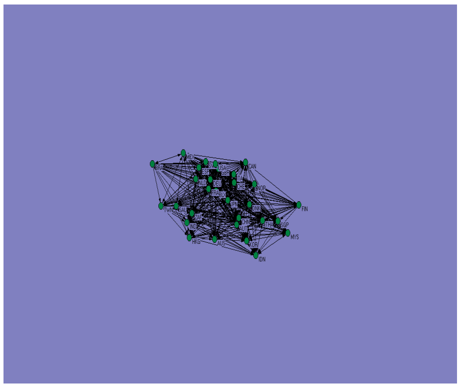
(a) Trade network for machinery (382)



(b) Core of the machinery trade network



(c) Trade network for fuel products (354)



(d) Core of the fuels trade network

Source: our elaborations using the software Pajek on BACI trade data for the year 2000 and industries with a much lower density, such as tobacco or petroleum and coal products. There are industries with a similar distribution of indegrees and outdegrees, such as textiles and apparel, and there are industries where the patterns of inward and outward linkages are very different, such as some industries based on raw materials. Are these characteristics related to the type of goods traded and to the specific features of demand and supply for those goods? We expect this to be the case, given that economic networks, differently from random networks, arise because of the effects of cooperative forces or competitive forces at work between units of the network, which influence the network structure (see Vega Redondo 2007). A random distribution of linkages between countries and a random structure is therefore very unlikely. In particular, we want to assess whether the network structure is associated to the extent of differentiation and complexity of the goods, assuming as discussed in Sect. 2 that differentiation is important in determining the potential number of transactions and the extent of the market.

Measuring differentiation in a group of products is not an obvious task. Here we follow the approach introduced by Rauch (1999) and further developed by Nunn (2007). In the work by Rauch, goods are classified in three groups: those traded on organized exchanges, those not traded on organized exchanges but having a "'reference price"', and all other commodities. Homogeneous and differentiated goods are distinguished according to the existence of a reference price. If such a price exists (as in the first two groups), the good is classified as homogeneous, as it can be priced without seeing the good itself and checking its characteristcs. If such a price does not exist, the good is classified as differentiated. Moving from this distinction, Nunn (2007) assigns to goods an index of "'complexity"' or contract-intensity, which measures the fraction of differentiated intermediate inputs used to produce the good, the higher the intensity of differentiated inputs used in production, the higher the complexity of the good.

We use Nunn's indicator of complexity to rank the 28 industries in our sample.[9] This indicator is presented in Table 2.

According to Rauch (1999), search costs should act as a barrier to trade for differentiated products, therefore if these costs are relevant we should not see a large number of trade links for industries with a high value of the index, i.e. using a large fraction of differentiated inputs. On the other hand, the need to diversify inputs to obtain the one which is most appropriate

[9]Both Rauch (1999) and Nunn (2007) use two classifications, defined "'liberal"' and "'conservative"', to assign products to different groups. The two classifications are highly correlated, but here we used Nunn's liberal classification and the index represents the fraction of differentiated goods, according to this liberal classification, over total inputs value.

Table 2: Index of complexity: fraction of differentiated inputs over total inputs in production

ISIC code	Industry	Index of complexity
311	Food products	0.3306
313	Beverages	0.7129
314	Tobacco	0.3166
321	Textiles	0.3761
322	Apparel	0.7454
323	Leather products	0.5706
324	Footwear	0.6504
331	Wood prod., excep. furniture	0.5162
332	Furniture	0.5677
341	Paper and products	0.3481
342	Printing and publishing	0.7128
351	Industrial chemicals	0.2403
352	Other chemicals	0.4897
353	Petroleum refineries	0.0577
354	Petroleum and coal prod.	0.3952
355	Rubber products	0.4073
356	Plastic products	0.4077
361	Pottery, china, earthenware	0.3288
362	Glass and products	0.5574
369	Other non-metallic mineral prod.	0.3766
371	Iron and steel	0.2422
372	Non-ferrous metals	0.1604
381	Fabricated metal products	0.4347
382	Machinery, except electrical	0.7636
383	Machinery, electric	0.7400
384	Transport equipment	0.8587
385	Professional and scient. equip.	0.7847
390	Other manufactured products	0.5468

Source: Nunn(2007).

for a specific variety of the final product, and the production of a large number of varieties of the goods will tend to produce a large number of trade links. We then test whether goods' complexity is associated with the characteristics of the trade network, and in particular its complexity. Table 3 presents the correlations between Nunn's complexity index and the networks' characteristics.

From Table 3 we see that goods' complexity is positively correlated to the network density and to other indicators of complexity in the network structure. In particular, the index of complexity displays a relatively high correlation with the measure of indegree centrality and with the standard deviation of the indegree distribution. Goods' complexity appears associated with an uneven distribution of markets' prominence. Imports of complex goods are not homogeneously distributed across countries, and they are more concentrated than their exports. This result is in line with the positive but very low correlation between complexity and the size of the core sub-group of countries. Considering the indegree centralization index, the positive and significative correlation with the goods' complexity seems to indicate that for highly complex goods, an important role is played by some central and well-connected markets where these goods are imported. As mentioned, outdegree centralization is always quite high, but it is seems to be very weakly related to the goods' complexity.

The only negative correlations appear for the betweeness centrality measure. It is evident that the centrality measures capture distinctive network characteristics. The higher betweeness centralization measure for less complex and less differentiated goods (often based on the use of raw materials) suggests a different structure of links. These are goods that display fewer bi-directional links, giving rise to stronger betweeness centralization.

These correlations can be better appreciated looking at the relation between the index of complexity and network indicators in Figure 2.

We can see a remarkably similar pattern (as expected) for the relationship between the complexity index and density and the in- and outdegrees. This non-linear pattern seems to indicate that as the complexity of the goods produced in a given industry increases, the number of links in the network initially increases, as the number of countries exporting the goods and importing the goods rises. But eventually, as complexity increases even further, and differentiation requires a high level of specialization, the number of countries trading these goods declines to some extent. For the most complex goods, the trade networks are also very dense and complex.

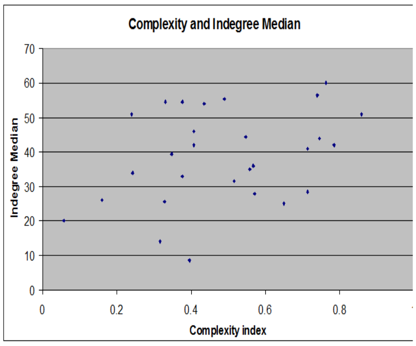
In we look at the countries with the highest centralization indices, we can observe that in terms of indegree, the largest industrialized countries rank in the top positions in every sector. Market size in terms of GDP and GDP per

Table 3: Correlation between complexity and network indicators

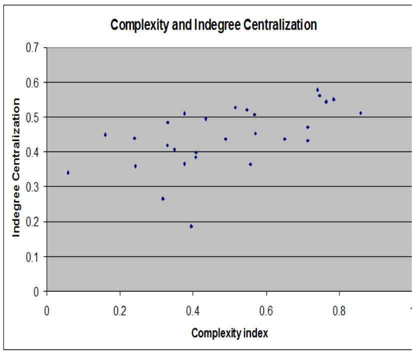
	Index of complex.	Density	Indegree Median	Indegree st.dev	Outdegree Median	Outdegree st.dev.	Indegree Central.	Outdegree Central.	Betweeness Central.	Countries in core
Complexity	1	0.3738	0.3464	0.4257	0.3905	0.3400	0.5708	0.3134	-0.3303	0.2363
Density	0.3738	1	0.9807	0.9427	0.9470	0.9493	0.7978	0.3094	-0.7507	0.8639
Indegr.Med.	0.3464	0.9807	1	0.8676	0.8972	0.9661	0.7083	0.3385	-0.7551	0.8275
Indegr. s.d.	0.4257	0.9427	0.8676	1	0.9340	0.8526	0.9204	0.3034	-0.6410	0.8897
Outdegr.Med.	0.3905	0.9470	0.8972	0.9340	1	0.8076	0.8066	0.1233	-0.7187	0.8081
Outdegr. s.d.	0.3400	0.9493	0.9661	0.8526	0.8076	1	0.7156	0.5074	-0.7116	0.8328
Indegr.Centr.	0.5708	0.7978	0.7083	0.9204	0.8066	0.7156	1	0.4059	-0.3910	0.7586
Outdegr. Centr.	0.3134	0.3094	0.3385	0.3034	0.1233	0.5074	0.4059	1	-0.0982	0.3007
Between. Centr.	-0.3303	-0.7507	-0.7551	-0.6410	-0.7187	-0.7116	-0.3910	-0.0982	1	-0.6089
Core countries	0.2363	0.8639	0.8275	0.8897	0.8081	0.8328	0.7586	0.3007	-0.6089	1

Source: Our elaboration on BACI data for the year 2000.

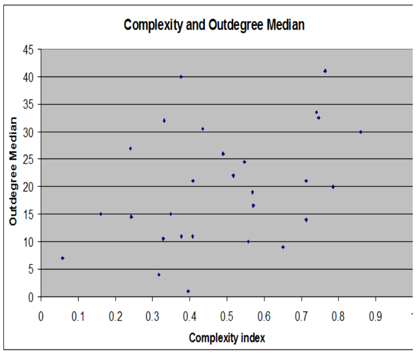
Figure 2: Relation between goods' complexity index and network indices



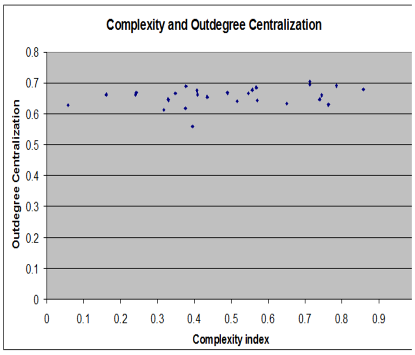
(a)



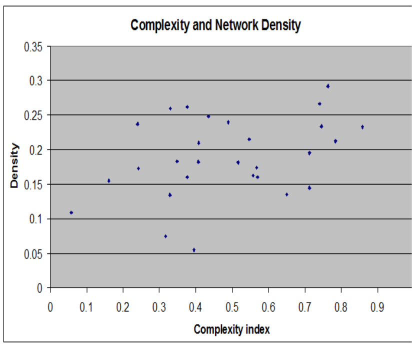
(b)



(c)



(d)



(e)

Source: our elaborations

capita unsurprisingly allow these countries to play a key role as importers. The picture changes when considering the outdegree centralization. In quite a few sectors, the highest outdegree centralization indices are found for some smaller countries and for emerging Asian economies. This indicates that the level of GDP can be a poor proxy of the role of a country as an exporter in the trade network. In the sectors where a country holds a comparative advantage, the country can play a key role in the trade network independently from its size or level of development.

4 Conclusion

Using the tools of network analysis, in this paper we examined some of the characteristics of the structure of trade flows in different industries. Through the indices describing the network's properties, such as density, degree distribution and centrality, we show that trade networks display remarkable differences.

In particular, the analysis of trade networks seems to confirm our initial hypothesis that homogenous and less complex goods give rise to less dense trade networks. This means that international competition in the world markets is not necessarily stronger in industries producing more homogenous goods.

Our results also show that generally more complex goods are associated to more complex networks. The relatioship appears to be positive, but not linear. Therefore, for complex and differentiated goods, the forces pushing countries to create more trade links tend to prevail, even if also for differentiated goods the trade network is far from being complete, as trade costs play a significant role. We can also see that the trade of complex goods is not restricted to a very small number of countries, but instead as complexity increases, the number of countries involved in trade tends to increase. This result is in line with the idea that higher complexity and higher specialization go together with a finer international division of labor, that involves an increasing number of countries.

References

[1] Anderson, J.E. and van Wincoop, E. (2003), “Gravity with Gravitas: A Solution to the Border Puzzle”, *American Economic Review*, 93(1), 170-192.

[2] De Benedictis, L. and Tajoli, L. (2008), “La rete degli scambi mondiali”, *L'Italia nell'economia internazionale. Rapporto ICE 2007-2008*, Istituto Nazionale per il Commercio Estero, Roma.

[3] De Benedictis, L. and Tajoli, L. (2009), “The World Trade Network”.

[4] de Nooy, W., Mrvar A. and Batagelj V. (2005), *Exploratory Social Network Analysis with Pajek*, Cambridge University Press, New York.

[5] Freeman, L. (1979), “Centrality in social networks: conceptual clarifications”, *Social Networks*, 23(1), 215-239.

[6] Gaulier, G. and Zignago, S. (2008), “BACI: A World Database of International Trade at the Product-level”, CEPII wp. 2008(3), July.

[7] Goyal, S. (2007), *Connections. An Introduction to the Economics of Networks*, Princeton University Press, Princeton.

[8] Helpman, E., Melitz, M., and Rubinstein, Y. (2008), “Estimating Trade Flows: Trading Partners and Trading Volumes”, *Quarterly Journal of Economics*, 123 (2), 441-487.

[9] Jackson, M.O. (2005), “The Economics od Social Networks”, in Blundell R., Newey W. and T. Persson, *Proceedings of the 9th World Congress of the Econometric Society*, Cambridge University Press.

[10] Nunn, N. (2007), ”Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade”, *Quarterly Journal of Economics*, 122.

[11] Rauch, J.E. (1999), “Networks vs. markets in international trade”, *Journal of International Economics*, 48, 7-37.

[12] Serrano, A., M. Boguña and Vespignani A. (2007), “Patterns of dominant flows in the world trade web”, *Journal of Economic Interaction and Coordination* 2, 111-124.

[13] Vega Redondo, F. (2007), *Complex Social Networks*, Cambridge University Press, New York.