Relational Methodologies and Epistemology in Economics and Management Sciences

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Chapter 5
A Comparison between International Trade and R&D Collaboration Networks in the European Aerospace Sector

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ABSTRACT

Do trading countries also collaborate in R&D? This is the question that, facing with a number of methodological problems, here it is dealt with. Studying and comparing the international trade network and the R&D collaboration network of European countries in the aerospace sector, social network analysis offers a wide spectrum of methods and criteria either to make them comparable or to evaluate its similarity. International trade is a 1-mode directed and valued network, while the EU-subsidized R&D collaboration is an affiliation (2-mode) undirected and unvalued network, and the elementary units of this latter are organizations and not countries. Therefore, to the aim to make these two networks comparable, this paper shows and discusses a number of methodological problems and solutions offered to solve them, and provides a multi-faceted comparison in terms of various statistical and topological indicators. A comparative analysis of the two networks structures is made at aggregate and disaggregate level, and it is shown that the common centralization index is definitively inappropriate and misleading when applied to multi-centered networks like these, and especially to the R&D collaboration network. The final conclusion is that the two networks resemble in some important aspects, but differ in some minor traits. In particular, they are both shaped in a core-periphery structure, and in both cases important countries tend to exchange or collaborate more with marginal countries than between themselves.

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INTRODUCTION

This paper deals with an interesting scientific issue, whose analysis requires to face with difficult methodological problems. The scientific issue is understanding if – and to what extent – international trade relationships are distributed in a similar way to international R&D collaborations. More specifically, the question is the following: is there a significant similarity between the structure of trade exchanges and of R&D collaborations? Clearly, this question is more meaningful when the scope is restricted to a specific sector, and especially if that sector is high-tech, because it is reasonable to expect that in this case R&D efforts and exchanges are more necessary than in low-tech sectors. Therefore, we have chosen the European aerospace sector. A positive answer would tell us that firms and research institutions (university and research centers) tend to collaborate in international R&D with the same countries with which they trade, and vice versa. Our work seems to confirm this outcome, and thus, it opens the road to possible explanations.

The aim of comparing the network of international trade and that of R&D collaboration networks is rather challenging from a methodological point of view, because it implies to make two sets of data manipulation and other methodological choices. Firstly, these two networks have a different nature, and so they should be "prepared" to be compared. Secondly, their comparison addresses to the classical problem of comparing complex systems: similar in terms of what? To say, in terms of structure is not enough, because this can mean a lot of different things and have a lot of aspects.

The paper proceeds as follows: in the next section is reviewed theoretical background on both international trade networks and R&D collaboration networks, even though such review is generic, because unfortunately our work has no predecessors with which directly contrast our results. Due to the considerable methodological problems raised by the comparison between trade and collaboration networks, the third section is quite long. Indeed, the secondary aim of this paper is just giving a methodological contribute to face with this kind of problems. Then, in the fourth section, results are articulated between aggregate and synthetic indexes, followed by strict topological analyses, like simple matching, assortativity, and core-periphery analysis. In the final section are discussed the main implications of this work and possible further developments.

THEORETICAL BACKGROUND

It is unlikely that a country is self-sufficient in any industry, because an industry is diversified in many different products, and a country's industry can hardly produce all of them, no matter how developed or specialized that country is. Moreover, it's practically impossible that a country can produce all the components and raw materials for a given industry, and in the required amount. International trade theory made these points clear since long (Bowen *et al.*, 2012; Ethier *et al.*, 1995; Feenstra, 2003; Feenstra & Taylor, 2010; Milberg & Winkler, 2013). More recently, evolutionary economic geography (Boschma & Frenken, 2006; Boschma & Lambooy, 1999; Boschma & Martin, 2007; Essletzbichler & Rigby, 2007; Frenken & Boschma, 2007; Martin & Sunley, 2007), and more particularly the theoretical perspectives of global value chain (Gereffi, 1999; Gereffi *et al.*, 2005; Humphrey, 1995; Humphrey & Schmitz, 2002), and of international knowledge networks (Cappellin & Wink, 2009; Gross Stein *et al.*, 2001; Lundan, 2002; Maxwell & Stone, 2007) have underlined that industry's trade patterns depend not only on trade barriers, transportation costs, labor costs and other traditional variables investigated by international economics. They depend also – and in some cases, like high-tech industries, primarily – on the dynamics of international innovation diffusion, technological trajectories, and the like. Hence, it could be reasonably wondered to what extent, in a given sector, international trade patterns resemble R&D collaboration patterns and, when differ, in which ways they do. In this work we deepen this issue, evidencing conceptual and methodological issues related to this comparison.

Social network analysis has been applied to both research fields. The very long research tradition on international trade patterns has been enriched by a streamline which, starting almost 20 years ago from Snyder & Kick (1979), applied social network analysis (Kali & Reyes, 2007; Kali *et al.*, 2007; Kick & Byron, 2001; Kim & Shin, 2002; Mahutga, 2006; Rauch, 1999, 2001; Roth & Dakhli, 2000; Smith & Nemeth, 1988; Smith & White, 1992; Snyder & Kick, 1979; Su & Clawson, 1994; van Rossem, 1996). Further, during the second half of past decade, a number of papers investigated world trade web from the so-called econo-physics perspective (Barigozzi *et al.*, 2010a, 2010b; Bhattacharia *et al.*, 2008a, 2008b; Chakrabarti *et al.*, 2006; Cockshott *et al.*, 2009; Fagiolo *et al.*, 2009; Garlaschelli & Loffredo, 2004a, 2004b; Li *et al.*, 2003; Ruzzenenti *et al.*, 2010; Serrano & Boguñà, 2003; Serrano, 2007; Serrano *et al.*, 2007), which basically is the application of advanced mathematical and statistical methodologies to social sciences, and especially to economics (Chatterjee & Chakrabarti, 2008). Likely and hopefully in next years we will witness to a fruitful breeding between the two perspectives, as it is the spirit of this and other recent papers (Arribas *et al.*, 2009; Kastelle, 2009; Reyes *et al.*, 2008, 2009).

Among the many forms of inter-organizational alliances (Carayannis *et al.*, 2008; Gilsing *et al.*, 2007; Glaister *et al.*, 2004; Jarillo, 1988; Kim & Parkhe, 2009; Nault & Tyagi, 2001; Nooteboom, 1999; Pyka & Küppers, 2002; Reid *et al.*, 2001; Sampson, 2007; Shilling & Phelps, 2007), R&D collaboration networks are getting more and more attention from scholars in evolutionary economics and management and organization sciences, especially when focusing innovation and knowledge networks. Among the many formal and informal types of inter-organizational alliances, EU-subsidized Research Joint Ventures (EURJVs) present distinguishing features (Caloghirou *et al*., 2004), which have been recently extensively and growingly investigated (Almendral *et al.*, 2007; Biggiero & Angelini, 2015; Billand *et al*., 2008; Breschi & Cusmano, 2004; Maggioni *et al*., 2007; Heller-Schuh & Barber, 2009; Protogerou *et al*. 2010a, 2010b; Roediger-Schluga & Barber, 2008).

METHODOLOGICAL ISSUES

The main conceptual and methodological problems related to search for similarities and differences between trade and collaboration patterns come from the fact that in the former case firms do exchange final products or components, while in the latter case firms are not the only actors, because even university departments or research centers are involved in research collaboration. Moreover, projects (R&D collaboration alliances) in our empirical field are subsidized by EU Framework Programs, therefore submitted and (mostly) composed by EU member states. It is interesting to understand whether the trade network differs from the R&D collaboration network, once inter-firm trade and inter-organizational collaboration have been expressed in terms of inter-country exchanges. However, while in the former case raw data preparation from single commodity import-export transaction to country aggregation is made by an international organization (UN), in the latter case data preparation from single consortium participants to country aggregation rests on individual researchers, and it is quite challenging. As it will be clear in what follows, the fulfillment of the methodological requirements to compare an undirected and unvalued two-mode network like the R&D collaboration network with a directed and valued one-mode network like the international trade network is rather difficult, and opened to diverse options, fruitful for deepening into network analysis methodological problems.

Data Extraction, Preparation and Manipulation

For some indexes are designed to be applied only to undirected or unvalued networks, and for network relations can be operazionalized in different ways comparisons can be difficult, misleading or even impossible without an appropriate and accurate data preparation. Hence, in what follows we will detail the procedures we have chosen to adequately prepare data to compare the R&D collaboration network and the international trade network in the aerospace (AS) sector[1] between European countries during the Sixth Framework Programme, that is 2002-2006.

The first methodological issue concerns the construction of the European R&D collaboration network. The source network is composed by two types of nodes: projects (partially) funded by EU, and organizations – mainly firms, research centres and higher education institutions – which participated to each project. This kind of network is an affiliation network (or 2-mode network or bi-partite graph) to underline the fact that it is composed by two different groups of nodes – or partitions – which can be defined as "events" and "affiliates". In our case the two partitions are "projects-events" and their "organizations-affiliates". In Figure 1 we can see, as an example, a sub-network of 2 projects and 23 participating organizations. Projects are indicated as square nodes (ISAAC and ABITAS), while circles represent organizations.

In order to express organizations in terms of their country membership – consistent with the international trade network – every node-organization of this affiliation network is replaced by its country membership attribute. In Figure 2 it is shown the previous sub-network after substituting organizations with their corresponding countries. Here squares represent projects (ISAAC and ABITAS) and circles represent countries.

According to the standard procedure to gather a 1-mode network from a 2-mode one (Wasserman and Faust, 1994), ties among "affiliates" are set if and only if they attended the same "event": thus, country "A" and country "B" will be tied if they share a joint participation to a certain project. Since in the projec-

Figure 1. Sub-network of FP6 affiliation network

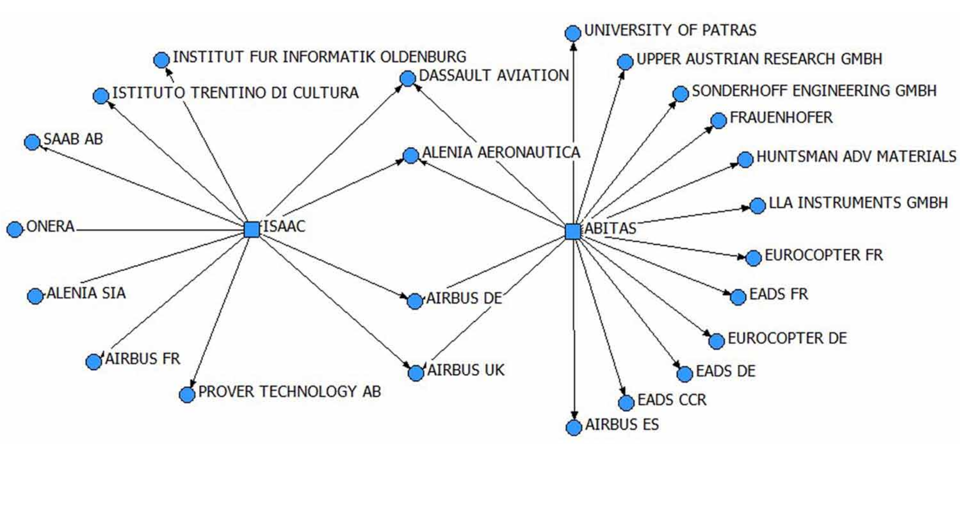
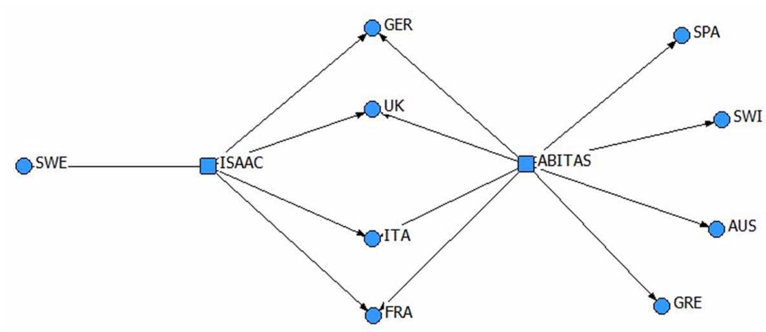


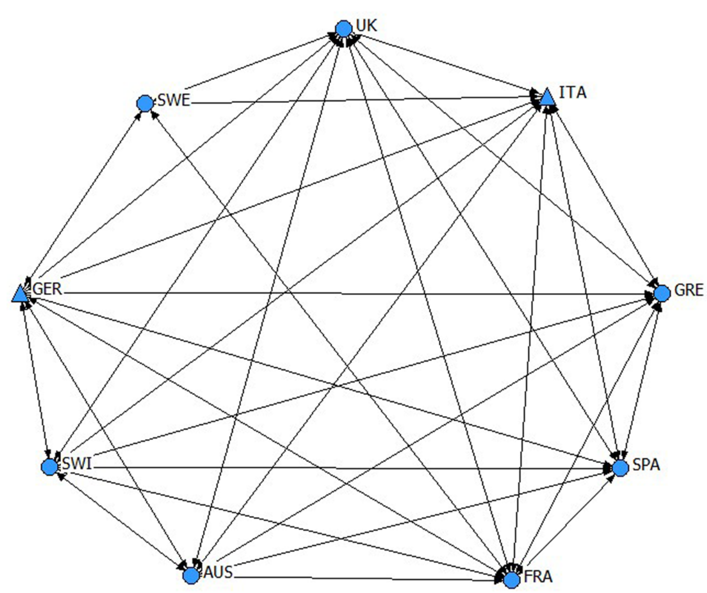
Figure 2. Countries sub-network of FP6 affiliation network



tion all the possible ties between the "attendants" of the same event (project) are present, we will define the resulting network *clique-based* (see an example in Figure 3). Notice that the same procedure can be applied to the "events" of the affiliation network, obtaining this way the network of the projects. In that case each couple of projects has a connection if the same country participated to both projects. Anyway, for this study does not aim to analyze projects' connections, events' projection will not be handled. Germany, UK, Italy and France participated to both projects, therefore they are included in both *cliques*, the one composed by the countries involved in project "ABITAS" and the one formed by countries involved in project "ISAAC". Triangles represent countries which acted as projects' coordinators.

From the previous operations it comes that there is a difference between a couple of countries which shared their partnership in many projects and a couple whose joint participation is limited to just one research project. Should we deal with this issue? How could we manage it? The answer to the first ques-

Figure 3. Clique-based collaboration network, obtained projecting the affiliation sub-network shown in Figure 1

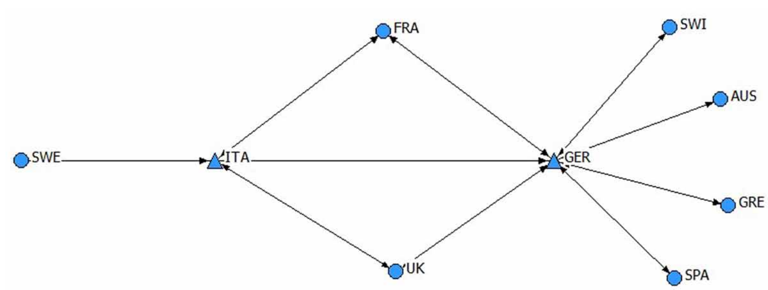


tion is positive because the reiterated effort in joint research plausibly leads to systematic knowledge exchange, while an occasional collaboration – especially if situated in a large project subdivided in different "Working Packages"[2] – could also not imply knowledge transfer.

If the first answer is straightforward, the second one presupposes a theoretical grounding. Let's make a step behind and refer to the fact that the true collaborating actors are organizations. The simplest way to weight a collaborative tie consists in assigning a value equal to the number of joint collaborations. For example, if organizations "A" and "B" jointly participated to 10 projects, then their tie will be valued 10. Anyway, it is hard to say that the amount of knowledge exchange rises linearly with the number of joint collaborations. One could argue that a certain number of collaborations should be needed to reach a sort of "critical mass" which suddenly enhances knowledge transfer. Moreover, the curve representing the dependence of transfer on the number of joint collaborations would be idiosyncratic for each couple of organizations since it would depend on their various forms of proximity (see Boschma, 2005 for a review). For instance, two organizations can be geographically close but technologically distant, or vice versa. However, for this matter is far from being well theorized and applied in a widely accepted standard methodology, we chose to simply compare the *unvalued* version of the network – in which ties just represent the occurrence of at least one joint participation for each couple of organizations (corresponding to countries) as an on/off condition – with its *valued* projection where ties are valued according to the number of joint collaborations with a direct 1:1 relationship.

Another methodological issue concerns the possibility that two organizations – and hence, their corresponding countries – participating to the same project do not directly collaborate and are not necessarily linked by an exchange relation. This is still truer for large Integrated Projects that can be composed by up to 60 partners. The best way to build the organizations network would be following the real inner collaborative structure of each project, but unfortunately this kind of information is not yet available for all the projects. However, since we know the coordinating organizations (and their country membership), the only alternative to the *clique*-based projection is considering each project as a *star* centred on its own coordinator. Notice that while in the previous (*clique*-based) projection we build the network according to all the potential knowledge exchange channels of each project, in the *star-based* network only coordinator-partner relations do exist (example in Figure 4). For each project, partner-countries (blue circles) are linked only to the project coordinator-country (green circles). The two coordinators are connected since they participated to both projects, in one as coordinator, in the other as partner and vice versa. Notice that it has a similar topology of the affiliation network in Figure 2, with the difference

Figure 4. The star-based collaboration network, obtained projecting the affiliation network shown in Figure 2



that projects names have been replaced by coordinators country. Obviously, in this case each couple of countries has a tie only if one of them coordinated the other in at least one project. The resulting network will be necessarily far less dense than the clique-based, and indeed it configures the opposite extreme respect to that. This is the rationale that will suggest us often to calculate and consider (for interpretations) the mean between the two variants.

Analogously to the *clique*-based option, each edge will be weighted according to the number of times each couple of countries is linked by a coordinator/partner relation. Summarizing, *four different versions of the R&D collaboration network* are set and will be analyzed: *clique*-based unvalued, *clique*-based valued, *star*-based unvalued, *star*-based valued. Of course, since connections represent collaborative relations and suppose knowledge exchanges, ties will be undirected (or always reciprocated) in all the four networks.

Conversely, the *international trade network* is directed and valued: links represent the flows of goods and services, and nodes are countries. Ties have a direction because countries can import or export goods, in our case aerospace products, sub-products and components[3]. Hence, if France exports to Germany there will be an edge directed from the former to the latter, and if France imports from UK, a tie from the latter to the former will be drawn. The weights of the ties correspond to economic values, and the network has been built summing trade volume for each couple of European countries during the years 2002-2006, corresponding to the FP6 duration. This choice has been made to further homogenize the trade and the collaboration network, because this latter is the sum of all projects occurred during FP6.

Also this network should be prepared to carry on a comparative analysis with the collaboration networks by means of four main manipulations: i) valued ties should be dichotomized; ii) a threshold for absolute values should be set up; iii) directed ties should be reciprocated; iv) a weight for undirected (reciprocated) ties should be set up. A threshold value has to be set to dichotomize the edges of a graph, hence the value “1” (meaning presence of the relation) is assigned to the ties whose value is higher than (or equal to) it, and “0” (absence of the relation) to the ties with lower values. Criteria to set the threshold values are many: it is possible to get distribution average or median, otherwise theoretical arguments could suggest a certain value under which the relation intensity can be left out. Since AS international trade volume distributions are highly skewed and right-tailed we cannot refer to average or median as representative value to be used as threshold. Therefore, in the unvalued version of the international trade network we initially only register the occurrence of an import or export transaction; in this case we are going to dichotomize the ties using the lowest value as threshold. Thus, whatever the trade volume – except 0 – in aerospace between a couple of countries, their tie will be valued as “1”; on the other hand if no trade occurred they will not be tied. Another dichotomizing criterion we are going to use consists in setting a threshold based on trade values under 60000 US$ in the 2002-2006 period. We made this choice because, in front of about 50 million US$ average value of world bilateral trades (see next chapter), 60000 US$ can be overlooked. Of course, this is an arbitrary manipulation of real data, but it can help understanding the deep structure of trade patterns between countries that are more cohesive on economic terms. Moreover, this manipulated network doesn’t replace the one without cut-off, with whom it will be contrasted, and with whom a mean value will be calculated, when appropriate. In short, choosing 60000 US$ as the amount of total bilateral trade between 2002 and 2006 for each pair of countries, 20% of ties are turned into zeros, while those above that threshold are transformed into ones.

The third operation regards reciprocating connections, which implies choosing one of the two following options: a) one may keep only the reciprocated ties between each couple of nodes and drop the ones that are not reciprocated, then focusing the analysis only on bi-directional relations; b) alternatively, all directed relations are transformed in undirected ones, obtaining an un-directed network in which the presence of a tie points that something has flown between two nodes, no matter for directions. For we are going to compare trade and collaboration webs we are merely interested in the existence of a tie between two countries, hence trade network reciprocation will be based on the second criterion: a trade occurrence – either in exports or imports – for each couple of countries defines the presence of an un-directed tie.

The last operation is strictly descending from the previous one: a value for the undirected ties should be set up. Among various alternatives, the most reasonable was to sum their absolute values. In summary, besides the original trade network with directed and valued edges and its version with 60000 US$ threshold, *three other versions have been prepared*: directed and unvalued, undirected and unvalued, undirected and valued. The use of a version or another of the collaboration and trade networks will depend on the technique of analysis that will be applied or on the index that will be calculated.

Before explaining the indicators and methods used to run the comparative analysis[4], a remark on networks size and on the selected countries is needed. In 2002 EU-was composed by 25 member states, plus the associated candidate countries Romania and Bulgaria afterwards included. Hence, we have chosen EU-27, plus Israel, Norway, Switzerland and Turkey, which have been added, because they are important trade players in AS and, as a result of EU special agreements, their participation to FPs was facilitated respect to other "third countries". Therefore, the R&D collaboration network is composed by 31 nodes. Now, we could have chosen to compare the international trade and the R&D collaboration ego-networks of these 31 countries. However, this choice would have not been good, because while in the former case all the resulting countries would have been free to have potential trade, EU rules of Framework Programmes prevent funding projects between countries else than those 31 (except than in some special cases). Consequently, this ego-network would have been "biased" and not comparable with that of international trade. In sum, we restricted the size to those same 31 countries in both networks.

Indexes and Methods

One typical SNA measure for an overall network description is density (D), which is defined as the number of links (L) among nodes (N) normalized by all the possible links:

$$D = \frac{L}{N(N-1)}$$

If the network is undirected the total number of possible links is divided by 2 for each couple of node can be tied only by a reciprocal relation.

Among node related measures, the simplest is degree centrality (Dc), a generic measure – equal to the numbers of edges possessed by a node – that typically represents a node's prestige or visibility (Wasserman and Faust, 1994). Obviously in directed networks in-Dc and out-Dc can be calculated, the former counts a node's incoming ties, the latter its out-going ties, in this case Dc corresponds to the sum of in- and out-Dc. While Dc is a node individual measure, average degree centrality (Adc) is referred to the whole network and is calculated as the ratio between links and nodes.

Betweenness centrality (Bc) aims to measure nodes' intermediation capacity – or brokerage – and is defined as the fraction of paths passing for one node over all possible paths in the graph (Freeman, 1977; 1979). It is formally expressed as the sum of the probabilities that all the geodesics (shortest paths) between all possible couples of actors (g_{ik}) in a graph will pass for a specific node (n_i):

$$Bc(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}$$

The hierarchical degree of each network will be studied by distinguishing "dyadic" from "group" hierarchy: the former is expressed by (the complement to 1 of) reciprocity, and Krackhardt's (1994) graph hierarchy index (H_k), while the latter is captured by centralization indexes, nonlinearity of Dc distribution, and core-periphery analysis. Now we discuss all these methods, except the nonlinearity of Dc distribution, which will be discussed in the next chapter of this book[5].

Reciprocity measures the extent to which couples of nodes (dyads) are tied by symmetric relations or the extent to which to every out-going tie an in-coming tie corresponds and vice versa. When asymmetry prevails, and reciprocity is low, the network is supposed to be characterized by a certain degree of dyadic hierarchy. The index of reciprocity in the analysis that will follow is calculated according to the "dyad method" (Hanneman & Riddle, 2005): the number of dyads linked by a reciprocal – or symmetric – tie is divided by the number of dyads linked by an asymmetric tie. Alternatively, if focus was on relations rather than on dyads, reciprocity could have been calculated dividing the number of ties that are included in symmetric relations over the total number of ties ("arc method").

Krackhardt's index of hierarchy (H_k) is an element of a set of four measures[6] aimed at evaluating the similarity of a network to the "ideal-typical" form of hierarchy represented by the pure "out-tree" (Krackhardt, 1994). It is defined as the complement to the extent of bidirectional paths relative to the total existing paths. It is calculated as follows: first a *N*x*N* "reachability matrix", in which the cell corresponding to each pair of nodes is filled by a one if the node in the row can reach the node in the column by a strong path (i.e. a path composed by ties going in the same direction) and a zero otherwise, is built. On this matrix the "dyad method" reciprocity is calculated and subtracted to one. Defining the number of symmetric – or reciprocal – paths as "*V*", and the number of asymmetric paths as "*maxV*" (we use Krackardt's notation), the hierarchy formula is:

$$H_k = 1 - \frac{V}{max V}$$

A set of measure of network centralization follow from node centrality measures. The first is degree centralization (Freeman, 1979) – hereafter labelled Dc CE(F), possibly distinguished into In- and Out-Dc: a measure of the dispersion of Dc indexes since it compares each actor Dc index ($C_D(n_i)$) with the maximum index present in the graph ($C_D(n^*)$). It ranges between 0 (maximum dispersion, all nodes have the same Dc as in a *clique*) and 1 (maximum centralization, a *star* graph).

$$Dc\,CE(F) = \frac{\sum_{i=1}^{g}\left[C_D(n^*) - C_D(n_i)\right]}{\left[(g-1)(g-2)\right]}$$

Next an index of centralization based on Bc (Freeman, 1977) will be calculated according to the same logic followed for the previous index (hereafter Bc–Fre). It can be simplified using normalized Bc (C'_B) as demonstrated by Freeman (1979).

$$Bc - Fre = \frac{\sum_{i=1}^{g}\left[C'_B\left(n^*\right) - C'_B\left(n_i\right)\right]}{\left(g-1\right)}$$

A different global index of dispersion - hereafter Dc CE(S), possibly distinguished into In- and Out-Dc - that relies on the concept of distribution variance had been recommended by Snijders (1981), and expressed by the following algorithm:

$$V = \left[\sum_{i=1}^{g}\left(Dc\left(n_i\right) - \bar{D}c\right)^2\right] / g$$

This index can be normalized by the maximum possible variance of the degree distribution, given the number of vertices (g) and density (d) in the graph ($V_{max}(g,d)$). The graph with maximum variance, in the case of Snijder's measure, is characterized by a set of central high degree nodes and a set of peripheral low degree nodes. This way, the assumption inherent the normalization proposed by Freeman – where, as mentioned, the graph with maximum variance is a star, no matter which is the density in the observed graph – is relaxed, and the possibility of a multi-centric graph with maximum variance is taken into account. Hence, the measure does not suffer the problem related to the incompatibility of the observed graph's density with the theoretical model's density (i.e. the star graph), and it is based on a different theoretical model (i.e. a multi-centered graph), which is more suitable for comparisons with real-world networks.

Technical details about the calculation of $V_{max}(g,d)$ in the cases of undirected, directed, or bipartite graph are reported in Snijders' contribution (1981). Here we point that the square root of the ratio of the observed variance (V) and the theoretical maximum variance of the degree distribution is expressed with an index of heterogeneity (J) that ranges between 0 and 1.

$$Dc\,CE\left(S\right) = \sqrt{\frac{V}{V_{\max}\left(g,d\right)}}$$

Another important network index is global clustering coefficient (Watts & Strogatz, 1998). It is used to measure the extent to which a network displays clustering defined as the presence of many local neighborhoods structured like a *clique*. Thus, for each node is calculated its local clustering, i.e. the density of its neighborhood; this value will range between 0 – when all the neighbors are not connected among them and the focal node is the centre of a *star* – and 1 if the focal node is embedded in a *clique*. Global coefficient is the average of local clustering. Alternatively, clustering could be explored using the transitivity measure defined as the ratio between closed triplets of nodes and triplets with at least two legs (Wasserman & Faust, 1994). This kind of clustering is used to compare empirical and random clustering in affiliation networks (Newman *et al.* 2001) and consequently check for small world properties in bi-partite graphs (Uzzi & Spiro, 2005).

The distances among the nodes of the networks can be synthesized by the average path length (Apl), that is the average of the shortest paths (geodesic) connecting each couple of nodes. Defining d as a geodesic function, the average path length is computed as:

$$Apl = \frac{\sum_{i,j} d\left(n_i, n_j\right)}{N\left(N-1\right)}$$

In order to explore *similarity* in terms of correlation and topological correspondence, Quadratic Assignment Procedure (QAP) provides standard errors to test the significance of the measure of similarity (as topological correlation) calculated in the case that there would not be any association (Hanneman & Riddle, 2005). To do so, rows and columns of network matrix are randomly permuted a large number of times (we chose 2500), the average value of association measure and the corresponding standard errors are calculated, and the final p-value is the proportion of random trials that would generate a coefficient as large (or small) as the one observed.

This method is applied on networks whose relations are operazionalized in the same way, that is, we are not going to compute the association of undirected and directed networks on the one side, or unvalued and valued on the other side. Thus, since we are not able to transform collaborative into directed ties, collaboration networks will be compared with the trade undirected networks. Also, since values distributions are highly skewed, QAP will be calculated also after transforming economic and collaboration values in logarithmic scale (base 2), so to reduce the effect high variance, which in the valued trade network is particularly high, ranging over 10 orders of magnitude.

When working with valued networks QAP is applied through the Pearson's correlation coefficient (r) of the cells of the matrices representing the networks to be compared[7]. The coefficient is calculated on each cell c_{ij} of the valued collaboration network and for each cell t_{ij} of the valued trade network and for $i \neq j$:

$$r = \sum_{i,j=1}^{n} \frac{(c_{ij} - \overline{c})\left(t_{ij} - \overline{t}\right)}{\sqrt{\sum_{i,j=1}^{n} (c_{ij} - \overline{c})^2} \sqrt{\sum_{i,j=1}^{n} (t_{ij} - \overline{t})^2}}$$

Otherwise, when handling unvalued networks, Simple Matching (SM) can be used to check for similarity, which now becomes purely topological in terms of presence-absence of a link between a dyad. The number of overlapping actual and absent ties – respectively x_{00} and x_{11} – and the number of ties occurring in only one of the two networks – x_{10} and x_{01} – are registered in a Relational Cross Table (Table 1). SM is then defined as the number of overlapping ties relative to all the possible combinations:

$$SM = \frac{\left(x_{00} + x_{11}\right)}{\left(x_{00} + x_{11} + x_{10} + x_{01}\right)}$$

Table 1. Format of a Simple Matching (SM)

	Actual links (1) and missing links (0) of network A		
		1	0
	1	x_{11}	x_{10}
Actual links (1) and missing links (0) of network B	0	x_{01}	x_{00}

This measure can be employed also to compare the same network over time, as it is done in the next chapter of this volume (see Basevi & Biggiero). For the empirical meaning of a coincidence of absent links is very different from that of actual links, we also use Jaccard's coefficient (*J*) for it is able to clean the previous measure from zeros. Here the basic rationale to modify and limit the previous indicator is that it's definitely different whether two countries are similar because no one does exchange with someone else or because both do with the same partners. This different empirical meaning is particularly related and remarkable for the very peripheral countries, which are characterized by low connectedness (centrality). The corresponding formula is the following:

$$J = \frac{x_{11}}{x_{11} + x_{10} + x_{01}}$$

Finally, a variant of this coefficient (*MJ*) originally proposed by Biggiero & Basevi in the next chapter of this volume has been used to consider at denominator also zeros' occurrences, so to take into account also the effect of possible density differences between the two networks, which otherwise would be somehow hidden by using only the *J* coefficient. Hence, the corresponding formula is the following:

$$MJ = \frac{x_{11}}{x_{11} + x_{10} + x_{01} + x_{00}}$$

Notice that the *MJ* is particularly suitable for highly dense networks. In facts, the quantity x_{00} in the denominator determines that two networks will never be equal unless both are fully connected. In other words the index will reach its maximum value of 1 only when two *cliques* are compared. Therefore, it is hardly applicable to many real networks which usually are large and sparse because the high values of the x_{00} will always determine very low values of the *MJ*. Anyway, in this special case and in analogous cases, that is when comparing two small and dense networks, the modified version of the Jaccard index is informative of topological similarity while taking into account density differences.

To check whether central and/or marginal countries prefer to link among themselves we will use the *(dis-)assortativity* indicator (Newman, 2002; 2003). A network is said to be assortative if ties exist only among nodes with a similar Dc, contrarily – when connections are set only in couple of nodes having a high Dc difference – the network is dis-assortative. In case the nodes set links independently on their Dc the network is said to be non-assortative. These kinds of mixing patterns are measured by Pearson's correlation coefficient of the degree between pairs of linked nodes. Positive values indicate a correlation between nodes of similar degree, while negative values indicate relationships between nodes of different degree. Hence, when equal to 1, the network is said to have perfect assortative mixing patterns; when 0 the network is non-assortative; while at -1 the network is completely dis-assortative. If relations in the network are valued, node's degree centrality – and consequently the Pearson's coefficient – is calculated as the sum of its ties weighted by their values (in- and out-degree centralities are considered in directed networks); otherwise the simple sum of the ties is computed.

As addressed in specialized literature on network analysis (Borgatti *et al.*, 2013; Hanneman & Riddle, 2005; Lewis, 2009; Newman, 2010; Prell, 2011; Scott, 1992; Scott & Carrington, 2011; Wasserman & Faust, 1994), there is a subtle question in analyzing networks and in interpreting the algorithms on which some indicators are built. In particular, it should be noted that some of them proceed, let say, bottom-up, in the sense that the indicator is based on an operation applied on single node and then "extended" some way to the whole network, for instance by squared distance or average difference, etc. For example, centralization and global clusterization are measured by replicating and then normalizing single node measures to all nodes. Another example is represented by the various methods to partition a network into sub-groups: cliques, plexes, cores, etc. Conversely, there are top-down techniques, which look for the best ways to disaggregate the network into sub-networks or partitions: core-periphery analysis, key-players analysis, factions, etc. The hard problem is that these top-down approaches need to calculate all possible combinations of all (groups of) nodes, that is, all permutations in the matrix which represents the network. If one wants to find optimal solutions, this operation is feasible only for small size networks, because as size grows over 15-20 nodes nothing guarantees that optimal solutions can be found. Likely, only reasonable (satisfying) solutions can be found, and sometimes, depending on the casual factors about the way the algorithm is applied, on the specific network topology, and on other contingencies of data configurations, even unsatisfying solutions can be selected. Often, software offers an estimation of results fitness, so that one can be helped trusting or discarding them.

On the other hand, just as this and the next chapter wish to show (among other aims), in many cases only these top-down subtle but delicate analysis can grasp the true peculiarities of methodological problems and methods to cope with certain networks. In fact, some network comparison – like this one between AS international trade and R&D collaboration among AS European countries and the other between AS and CEM international trade – could hide interesting properties just under semi-aggregative aspects, like those evidenced by core-periphery analysis. So, this analysis provides a contribution in this direction and its results interpretation offers an example of the related methodological problems and hopefully, besides the scientific content concerning the subject, provides a sort of guideline for this kind of analysis.

To accomplish this objective, we will analyze networks' *core-periphery structure* aiming at investigating if they could be partitioned into a group of densely interconnected nodes and an area of nodes that share few or none connections. Satisfying core and periphery partitions can be selected according to a continuous or a categorical technique (Borgatti & Everett, 1999). In this contribution we will only refer to the latter because an appropriate comparison of them would deserve a more advanced statistical deepening which is not in the aims of this book. The categorical procedure identifies the structure using a genetic algorithm that generates a so-called *pattern matrix*, that is an ideal matrix – based on the observed one – in which core and periphery partitions are perfectly distinguishable (Borgatti & Everett, 1999). Thus, in the *pattern matrix* all the nodes included in the core partition are connected among them – forming a *clique* – while nodes of the peripheral one only have ties with the core nodes (Table 2). Partitions of the *pattern* and the observed matrices are chosen by the algorithm in a way that the correlation among them is maximized. Correlation is calculated with an un-normalized Pearson's coefficient and is called *fitness*.

Table 2. An example of a pattern matrix with a core partition of 3 nodes and a periphery partition of 7 nodes

	1	2	3	4	5	6	7	8	9	10
1		1	1	1	1	1	1	1	1	1
2	1		1	1	1	1	1	1	1	1
3	1	1		1	1	1	1	1	1	1
4	1	1	1		0	0	0	0	0	0
5	1	1	1	0		0	0	0	0	0
6	1	1	1	0	0		0	0	0	0
7	1	1	1	0	0	0		0	0	0
8	1	1	1	0	0	0	0		0	0
9	1	1	1	0	0	0	0	0		0
10	1	1	1	0	0	0	0	0	0	

THE ANALYSIS THROUGH AGGREGATE AND BOTTOM-UP INDEXES

Many topological measures at network level for collaboration and trade networks are reported in Table 3. Different kinds of relations (directed/undirected, valued/unvalued) lead, for some of these measures, to differences in calculations. Krackhardt's hierarchy index (H_k) and reciprocity can be computed only for directed graphs, while centralization is split into in- and out-degree centralization (In-Dc CE and Out-Dc CE) in absolute and log2 values when relations are directed. Valued versions allow calculating total amount of trade and collaboration and their average values (AVBT and AVBC). All the other measures are computed only for dichotomous (unvalued) versions, including the distinction between Freeman's (In- and Out-Dc CE dic) and Snijders' (In- and Out-J) centralization indexes.

In general, collaboration and trade networks are widely cohesive (density), clusterized (Cl), and with very short average distances (Apl). The average degree centrality (Adc) is computed on the un-valued ties so that its value reports the average number of relations with different nodes, without taking into account the number of times the relation is replicated by each couple of countries. Accordingly, on average countries hold almost 24 collaborative ties, coordinator/partner relations are 10.71, and 18.84 the trade ties (14.84 in the network dichotomized with the threshold). In trade networks ties are often reciprocal, meaning that each couple of country is linked by both import and export relations, so that dyadic hierarchy index is almost zero.

Though dyadic hierarchy is absent, degree centralization indexes in dichotomous terms (dic) indicate that structural hierarchy is very high, and rather close between the two networks. The *star*-based network is of course far more (three times) centralized than the *clique*-based, because it is composed by "a collection of *stars*", which – jointly to the *tree* – is the hierarchy paradigm[8], and Dc centralization measures exactly how central is the most central node in relation to how central all the others are, that is how much the network is close to a pure *star*. In the trade network exports (out-) are much more centralized than imports (in-), consistently with what happens at world level (see next chapter, Biggiero & Basevi). However, for the form of the algorithm of calculation just reminded, when weights are added to the relations networks are far less centralized on a node. In fact, this measure is not so suitable

Table 3. Main topological measures

	R&D coll. *clique*-**based**	**R&D coll.** *star*-**based**	**mean**	**International trade**	**International trade (60k)**	**mean**	**R&D coll. vs. trade**	**Similarity evaluation**
Size	31	31		31	31			
N. of links	367	166	266.50	584	460	522	=	H*
Total coll/Total trade (10^6)	29873	2267	16070	38168	38166	38167		n.a.
AVBC/AVBT (10^6)	64.24	4.88	34.56	41	41.04	41.02		n.a.
Adc	23.68	10.71	17.19	18.84	14.84	16.84	>	H
H_k	n.a.	n.a.		0.00	0.00			n.a.
Reciprocity	n.a.	n.a.		0.73	0.65	0.69		n.a.
Density	0.79	0.35	0.57	0.63	0.49	0.56	>	H
In-Dc CE(F)	14.14%	11.52%	12.83%	4.06%	4.06%	4.06%	>	L
Out-Dc CE(F)				4.17%	4.17%	4.17%		
In-Dc CE(F) dic	22.53%	61.61%	42.07%	28.11%	41.89%	35.00%	>	H
Out-Dc CE(F) dic				31.56%	45.33%	38.45%		
In-Dc CE(S)	74.08%	79.31%	76.69%	36.26%	46.49%	41.38	>	L
Out-Dc CE(S)				45.80%	56.65%	51.23		
In-Dc CE(F) log2	36.27%	33.17%	34.72%	34.74%	33.39%	34.33%	=	H
Out-Dc CE(F) log2				28.21%	39.93%	34.07%		
Bc-Fre	1.35%	24.39%	12.87%	2.77%	5.54%	4.16%	>	M
Apl	1.21	1.65	1.43	1.29	1.44	1.36	>	H
Cl	0.89	0.83	0.86	0.79	0.74	0.76	>	H

*As known, directed links are double of undirected, and thus, if we figured out that the 266 links of the undirected collaboration networks could flow in both directions, we would get just about 522.

for networks where links are concentrated in the hands of a restricted group of nodes, not only in one node. Conversely, when weights are expressed in logarithmic scale (log2) – and thus, peak values are squeezed – economic centralization approaches the dichotomous version. The low values of betweenness centralization (Bc-Fre) point that, excepted for the *star*-based collaboration network, intermediation is evenly distributed in the networks. Indeed, in that network, coordinators – that is, the centers of each *star* (project) – are the natural intermediators, and those coordinating the largest and/or more central projects become the few central intermediators of the whole network.

Interestingly, if we consider Snijders' centralization (Dc CE(S)), the index level grows dramatically for all the four networks, and especially for the two R&D collaboration networks. In fact, these are multi-centered networks, a characteristic that is particularly accentuated in the star-based form. However, the gap between the two indexes is enormous for the clique-based network (23 vs. 74%), while in the star-based the gap is "only" 17 percentage points. This gives a clear idea of how much inappropriate is Freeman's index for large and multi-centered networks[9].

What can we conclude from the analysis of Table 3? The penultimate column on the right side tells us that, when applicable and in average, the indicators of the two R&D collaboration networks have major (or almost equal) values of the two trade networks – 7 out of 10 are major. However, and more noteworthy, the last column on the right shows that in the large majority of cases (7 out of 10) the differences between the average values of the two couples of networks are very small, and thus, the two pair of networks are very similar. The only two indicators according to which there is low similarity are Freeman's valued and Snijders' centralization.

QAP and Assortativity Analysis

Previous measures gave us a very general networks description, and stimulated the interest in deepening the analysis of their structure. In fact when you handle quite small and densely connected networks, and this is the case, the main topological indexes could appear to some extent trivial or misleading: for example, the synthetic indexes of centralization do not say anything about the ways in which it is concretely instantiated. Hence, to go deeper we proceed to check for collaboration and trade networks association, using Pearson's correlation coefficient (*r*) for valued ties and similarity measures – i.e. Simple Matching (*SM*), Jaccard (*J*) and Modified Jaccard (*MJ*) – for dichotomous ones. Values are reported in Table 4, jointly to the statistical significance (p-value) of their difference with the values that would be obtained in the case that association would be due to mere chance. This case is calculated as the average (Avg) of 2500 random permutations performed on the matrices and its corresponding standard deviation (SD). Starting from valued networks, *r* is positive and high (Table 4), meaning that, if a trade relation were established among two countries, then also a collaborative relation of a comparable intensity should occur, and vice versa. In other words, since Pearson's index measures a linear correlation, the larger the AS trade, the higher the number of joint EU-subsidized research collaborations, and vice versa. At the same time, a lower or absent amount of trade flows are reflected by less or none joint collaboration. Notably, correlation is higher when the trade network is compared to the *star*-based collaboration network instead of the *clique*-based one. This evidence suggests that the strength of collaborator-partner relations is some more likely to vary linearly with the strength of trade relations among countries. The *r* coefficient decreases when calculated on the logarithmic transformation of the weights – to a larger extent for the comparison with the *star*-based network – suggesting that correlation was pulled by outliers. In other words it seems that the association of the two networks is large thanks to those countries whose collaborative and trade activities are far larger.

When the tie values are dichotomized, that is when only the information about the presence or the absence of links is kept, trade and collaboration networks can be still regarded as similar, but to a lesser extent (Table 4). In this case, similarity measures – (*SM*, *J*, *MJ*) – range between 0 and 1, where the former value stands for total distance among the two networks and the latter for perfect overlapping. *SM* values are quite and significantly higher than the corresponding average values obtained by random permutations in all the comparisons reported. Also in this case *star*-based collaboration network is more similar to the trade one, witnessing that coordinator/partner relations are more likely to match some kind of trade relation. Jaccard's coefficient – and even more its modified version *MJ* – accounts for a lower similarity, but still high in the comparison with the *clique*-based collaboration network than in the comparison with the *star*-based one, due to higher presence of zeros in the latter.

When the ties of the trade network are dichotomized basing on a threshold of 60000 US$ ($\geq$60k) the simple matching measure of the comparison with the *clique*-based network is quite similar to the one

Table 4. QAP correlation and pure topological comparisons

Type of relation	Networks	Measure	Value	p-value	Avg	SD
Valued	Trade un-dir vs. Coll *clique*-based	*r*	0.709	0.000	-0.001	0.056
	Trade un-dir vs. Coll *star*-based	*r*	0.798	0.000	-0.001	0.053
Valued ($\log_2$)	Trade un-dir vs. Coll *clique*-based	*r*	0.618	0.000	-0.004	0.146
	Trade un-dir vs. Coll *star*-based	*r*	0.480	0.000	-0.004	0.126
Unvalued	Trade un-dir vs. Coll *clique*-based	*SM*	0.675	0.000	0.531	0.037
		*MJ**	0.609	n.a.	n.a.	n.a.
		J	0.671	0.042	0.610	0.034
	Trade un-dir vs. Coll *star*-based	*SM*	0.701	0.033	0.630	0.039
		*MJ**	0.323	n.a.	n.a.	n.a.
		J	0.424	0.000	0.314	0.037
	Trade un-dir (≥60k) vs. Coll *clique*-based	*SM*	0.690	0.000	0.558	0.106
		*MJ**	0.540	n.a.	n.a.	n.a.
		J	0.635	0.000	0.517	0.034
	Trade un-dir (≥60k) vs. Coll *star*-based	*SM*	0.684	0.000	0.470	0.050
		*MJ**	0.320	n.a.	n.a.	n.a.
		J	0.503	0.000	0.290	0.042

*In this case random permutations are not performed. Hence average values, standard deviations and significance of the measure are not calculated.

obtained in the comparison with the trade network dichotomized without threshold: the small increment of the coefficient is reflected by the small increment of its average value. Differently, in the comparison with the *star*-based network, the small decrease of the coefficient is associated to a higher reduction of the corresponding average value. Therefore, minor transactions – i.e. those ones removed for they are lower than the threshold – in the trade network do not match the coordinator/partner links represented in the *star*-based network, or – vice versa – coordinative relations are better reflected by trade relations of higher value.

The values of *J* and *MJ* indexes are reduced in the comparison of the *clique*-based network with the trade network with threshold, compared to the ones obtained for the similarity with the trade network dichotomized without threshold. By the way, notice that the decrease of the *SM* is associated to a decrease of the corresponding average. The *J* index in the comparison of the *star*-based network with the trade network is increased respect to the one reported in the comparison with the trade web dichotomized without threshold, similarly to what happened for the *SM* and the *r*. The *MJ*, on its side, is almost unvaried for the increase of the overlapping relations among the two networks registered by the other measures of association is balanced by the increase of the absent ties due to the threshold which has been set..

The QAP analysis on valued networks points out two features about EU countries trade and collaborations networks: first, they are positively correlated, for the higher (lower) the trade volume the higher (lower) the number of joint collaborations; second, some couple of countries which have intense trade and collaborative relations increase networks correlation. When relations are dichotomized, networks are generally similar since a collaboration relation among two countries is likely to occur in presence of a trade exchange and vice versa; anyway, when considering the amount of overlapping absent relations as a factor of dissimilarity, the correspondence of trade and collaboration networks is decreased. A core-periphery analysis will allow us to deepen this evidences for – in the case that clear partitions would be appreciated – the similarity of the networks would be justified by the overlapping relations mainly occurring among core countries. On the other side, the similarity reduction due to the overlapping absent of ties should be witnessed by sparse peripheries.

At this point we want to investigate the tendency to link among central or marginal countries respect to connect central to marginal countries. In general, both collaboration and trade networks show dis-assortative mixing patterns in nodes' connectivity (Table 5), implying that central nodes are inclined to be connected with marginal nodes. In other words, countries which hold a large amount of trade or collaborative relations are more linked with marginal ones and vice versa. If only the existence of collaborations is taken into account, as reported by the unvalued versions of the networks, dis-assortativity is higher; differently, when connections are weighted, mixing patterns in connectivity are more balanced. In this case trade relations are almost non-assortative since the coefficient is close to zero. Hence, we can state that, simply looking at the likelihood of collaborating or trading, marginal and central countries are quite well mixed. This phenomenon is more evident in coordinator/partners relations of the *star*-based R&D network, while there is a higher tendency for degree assortativity in trade relations. Notice that dis-assortativity increases when small transactions are dropped from the network setting the threshold at 60000 US$ in both valued and unvalued networks. This evidence suggests that there are some "low trading" countries that are almost excluded from AS European international trade; this evidence will be further investigated using core-periphery models. Mixing patterns are pushed toward a non-assortative topology when trade volumes between each pair of countries are considered. Finally, if we compare the mean between the *star*- and the *clique*-based versions of collaboration network with the mean between the "with" and "without cut-off" at 60000 US$ versions of trade network, assortativity coefficients close further[10]. In sum, both trade and collaboration networks – with all their variants – are dis-assortative: weakly for valued and to a higher extent for unvalued versions. Moreover, they score similar values.

Table 5. Assortativity coefficients

Type of relation	Network	Assortativity Coefficient
Valued	Trade dir	-0.071
	Trade dir (60k)	-0.111
	mean	0.091
	Coll star-based	-0.316
	Coll clique-based	-0.121
	mean	-0.218
Unvalued	Trade dir	-0.248
	Trade dir (60k)	-0.316
	mean	-0.282
	Coll star-based	-0.494
	Coll clique-based	-0.283
	mean	-0.388

CORE-PERIPHERY ANALYSIS

Fitness coefficients of core-periphery analyses rounds between moderately or very high values in both valued and unvalued versions of trade and collaboration networks (Table 6) meaning that they can be satisfactorily partitioned in a group of highly interconnected nodes (i.e. the core) and an area of sparser nodes (i.e. the periphery). Also, coefficients are systematically higher for unvalued networks than for valued ones, hence we could initially state that core-peripheriness is more pronounced in simple topological configurations – that is when only presence/absence of a collaborative or trade relation is registered – while weights of the links are distributed in a more balanced way.

A closer look at the sizes of the partitions shows this first insight to be partially misleading. In facts valued networks, although they fit with an ideal structure to a lesser – but still reasonable – extent, are characterized by the presence of a relatively restricted core of countries ("N. Coun." and "% Coun." in Table 6). Differently unvalued ones, are partitioned in large cores whose share of total countries ranges between 45% (in the *star*-based R&D network) and 71% (in the *clique*-based one). Hence, despite their excellent statistical fitness floating between 0.77 and 0.90, unvalued networks align to a lesser extent with the theoretical concept of core-peripheryness that figures out a topology whose structure is based on a relatively small core of nodes. We can therefore state that all valued networks show a strong, well definite, and similar partition in a small, dominant and dense core and a large (7-8 times), dominated, and sparse periphery.

A deeper and more appropriate evaluation of core-peripheriness can be done looking at the density matrices (intra-core and intra-periphery densities in Table 6, all partitions densities in Table 7). To remind what we have discussed in the methodological section, an appreciable core-periphery structure in unvalued networks should be characterized by density values close to 1 for core and close to 0 for periphery. Such a configuration is fully confirmed for the R&D and the trade unvalued networks and to a lesser extent in the un-weighted trade networks where 9-12% of the potential intra-peripheral relations are present. Some more evidences can be appreciated from the density matrices of the unvalued networks (Table 7). The cells on the main diagonal report the density of edges among nodes of the same partition (cell 1,1 for the core and cell 2,2 for the periphery), while in the secondary diagonal density

Table 6. Core-periphery structure

		Core			Periphery			Total Avg. Density	Size	Fitness
		N. Countries	% Countries	Density intra core	N. Countries	% Countries	Density intra periphery			
Trade	Valued	3	9.68	$28.64*10^{8}$	28	90.32	$56.11*10^{5}$	$76.72*10^{7}$	31	0.52
	Valued (>60k)	3	9.68	$28.64*10^{8}$	28	90.32	$56.08*10^{5}$	$76.72*10^{7}$	31	0.52
	Unvalued	20	64.52	0.92	11	35.48	0.12	0.51	31	0.77
	Unvalued (>60k)	17	54.84	0.90	14	45.16	0.09	0.46	31	0.80
R&D coll.	Valued (*clique*-based)	7	22.58	724.10	24	77.42	7.74	220.26	31	0.73
	Valued (*star*-based)	6	19.35	74.33	25	80.65	0.48	22.07	31	0.69
	Unvalued (*clique*-based)	22	70.97	0.99	9	29.03	0.08	0.61	31	0.90
	Unvalued (*star*-based)	14	45.16	0.88	17	54.84	0.02	0.40	31	0.87

Table 7. Density matrices

Type of relation		Coll *clique*-based		Coll *star*-based		Trade dir		Trade dir (60k)	
		Core	Periphery	Core	Periphery	Core	Periphery	Core	Periphery
Un valued	Core	0.987	0.687	0.879	0.349	0.924	0.591	0.897	0.475
	Periphery	0.687	0.083	0.349	0.022	0.409	0.118	0.361	0.093
Valued	Core	724.095	74.595	74.333	6.733	28.64(10^8)	11.47(10^7)	28.64(10^8)	11.47(10^7)
	Periphery	74.595	7.736	6.733	0.477	84.64(10^6)	56.11(10^5)	84.65(10^6)	56.07(10^5)

of ties between the nodes of different partitions are shown (cell 1,2 for core's out-going ties, cell 2,1 for periphery's out-going ties)[11]. Regarding collaboration networks, many ties among core and peripheral countries, about 69% over total possible ties between the nodes of the two partitions, are present in the *clique*-based version. Conversely, in the *star*-based one – where only coordinative relations are present – this kind of connections fall to about one over three potential ties (0.35).

In the trade unvalued networks (with and without threshold) export connections – i.e. core's out-going ties – are quite dense (59.1% of total possible core to periphery ties) while trade flowing from periphery to center is lower (40.9%). Notice that the density of the core in the unvalued trade network is lower when the dichotomization threshold is at 60000$ since in this case the size of the core is larger.

In the valued networks we do not have a density value lying between 0 and 1 because it is not possible to state a maximal value for tie intensity. Anyway a look at absolute densities (Table 7) confirms a core-periphery structure. *Star*- and *clique*-based valued collaboration networks are characterized by a remarkable difference of intra-core and intra-periphery densities. Moreover a large gap is appreciable among intra-core and core to periphery (and periphery to core) densities. In the valued trade network the situation is similar: intra-peripheral density is more than 10 times lower than the one of its out-going ties and connections from core to periphery are denser than vice versa, in line with what we appreciated in the trade unvalued network. International trade in AS among European countries is thus characterized by higher export loads flowing from core to peripheral actors implying that production capabilities are located in high trading countries to a larger extent.

Densities analyzed until now were not related to the total absolute density of each network, that is to the total number of actual edges, but instead related to the number of potential absolute density of each partition. Now we do the other calculation by looking at the density shares of sub-networks (i.e. the partitions) on overall networks' densities (Table 8). Therefore, shares are computed counting the number of ties included in a sub-network over the total number of ties, which are weighted by their values when the network is valued.

We can appreciate that links of the core partitions (c-c) float between a minimum share of 45% in trade valued networks (with and without threshold) and a maximum share of 63% in the unvalued *clique*-based one. The c-c shares of unvalued networks are generally higher than those of their valued versions due to the higher number of countries included in their cores (size share). The high c-c share of unvalued networks occurs at the expense of the quantity of edges included in the peripheral partition (p-p).

The portion of inter-partitions links (c-p and p-c) is instead comparable in the valued and unvalued versions. Regarding collaboration networks inter-partition shares (c-p and p-c do correspond because ties are undirected) account for about 1/5 of total density in the *clique*-based versions and 1/4 in the *star*-based one. Therefore the *cliquishness* of the former version leads to a large connected core, while

Table 8. Proportional shares of the core-periphery four combinations

Type of relation	Network	Shares of the four sub-networks				Size share	
		c-c	c-p	p-p	p-c	Core	Periphery
Unvalued	Trade	0.60	0.22	0.02	0.16	0.65	0.35
	Trade(>60k)	0.53	0.24	0.04	0.19	0.55	0.45
	Coll *clique*-based	0.63	0.18	0.01	0.18	0.71	0.29
	Coll *star*-based	0.48	0.25	0.02	0.25	0.45	0.55
Valued	Trade	0.45	0.25	0.11	0.19	0.10	0.90
	Trade(>60k)	0.45	0.25	0.11	0.19	0.10	0.90
	Coll *clique*-based	0.51	0.21	0.07	0.21	0.23	0.77
	Coll *star*-based	0.49	0.22	0.07	0.22	0.19	0.81

the latter is structured by a core composed by countries which mainly play as projects' coordinators, and a periphery of countries simply involved as partners, resembling the *star* ideal-type. In trade networks, the higher export volume flowing from central countries to peripheral ones accounts for a share difference of 5-6 points between c-p and p-c sub-networks.

Notice that the threshold of 60000$ applied to the trade network is totally irrelevant on the valued version core-periphery analysis, while leads to differences in the unvalued version. This evidence confirms that transactions lower than that threshold are substantially negligible respect to all other transactions and justifies the choice of regarding them as zero ties (i.e. absence of relation) in the unvalued version. In sum, trade and collaboration networks show a quite similar and well marked core-periphery structure: an area of densely connected countries dominates many scarcely connected (peripheral) countries. This partition is particularly strong for valued versions, and mostly in trade, likely because of their wide range of exchange values. Hence, both networks are structurally very hierarchical and very similar. Going back to the QAP analyses we performed, we can state that the similarity we appreciated should lie on this common hierarchical structure.

CONCLUSION

This chapter purposed to give a twofold contribution. From a methodological perspective it described and explained how to handle different networks data when relations are originally operationalized in different ways. We saw as trade and collaboration networks are initially not comparable since the relations of the former are directed and valued while the relations of the latter are undirected and unvalued. Moreover, the trade network is 1-mode while the collaboration is a 2-mode (affiliation) network. Therefore, techniques for modifying the nature of relations have been described and addressed to solve the many problems related to the nature of relationships (directed and valued vs. undirected and unvalued). Further, still in the dedicated methodological section, we suggested and discussed an alternative way (i.e. the *star*-based one) to project (extract from) the 2-mode into a 1-mode network, because the automatic projection (i.e. the *clique*-based one) could not be the only one appropriate.

We compared the two networks by means of many topological indexes, accompanied by correlation and various types of topological coincidence, and by assortativity, and core-periphery analysis. Structural differences between the two networks – and some of its potential configurations, like the star and clique-based networks for R&D collaboration, or manipulations, like the valued or dichotomous and absolute or log2 or threshold-based networks for the international trade – have been deeply investigated. All these kinds of analysis are seldom applied together, and in particular centralization is almost never calculated with the Snijders' index of centralization, which is the most appropriate for multi-centered networks. One of the methodological contributions of our paper is just that of showing concretely how much the common Freeman's index and the Snijders' index can differ when applied to multi-centered networks. Moreover, it is shown the Freeman's index is very distortive – in the sense of underestimating the true values - when applied to valued networks whose links have a magnitude ranging many orders, like occurring in international trade networks, where exchanges can vary from few dozens to billions dollars[12].

Hence, a very articulated and deep investigation, which opened also on some considerations on the use of multiple criteria in data analysis. In fact, the underlined purpose of this work is to show how complex can be the comparison of two networks like these, because they – besides the many potential differences that can be due to the many (more or less arbitrary) methodological choices to make them comparable - can be compared under many respects. Such respects are nothing else than evaluation criteria, and then it come the classical problem as concerning how to "combine" the results produced by these criteria if they do not converge in the same direction, that is, if they are contradictory.

If there is not a full convergence (or dominance) of one criterion over the others, a hard question arises: similar in terms of what? And further, when there are not previous studies of this type with whom benchmarking evaluations –like in this case - another hard question arises: where is the "similarity threshold" for each criterion (and even for each indicator)[13]? That is, under which threshold differences can be considered irrelevant? The right methodological way to correctly face with these two questions requires two operations. The first one is deciding ex-ante under which aspects the comparison is considered meaningful or just interesting (or useful) to the researcher's aims. This requirement is usually accomplished by structuring the analysis by raising research hypotheses, from which the corresponding criteria and indicators are derived. The second operation is even more complex, because very often implies the application of multicriteria decision evaluation.

Indeed, if criteria are potential substitutes or complements, then the most common methods, like the construction of a single composed function with weights for each criterion, can be employed (Keeney & Raiffa, 1976; Lee, 1972). As concerning network indicators, only very few studies investigate which ones and how they are correlated or complementary (Valente *et al.*, 2008). What is clear, anyway, is that all indicators are sensitive to density, and especially to very high degrees of density, because when density is maximum and the network becomes a single clique where every node is connected to every other, then the network is totally homogeneous, and no any partition makes sense any more. However, when density is far from maximum, and especially under 50%, then there is all the potential heterogeneity one could wish, and partition methods and centrality analysis (as well as equivalence analysis, etc.) do make sense. In this condition, though some indicators can be complementary or substitutes, many others – as well as partition methods and other types of analysis – aren't. Hence, not only the common methods of multicriteria evaluation, which are implicitly based on the assumption of substitution rates between criteria, but also outranking methods can be applied, and indeed *should* be applied when criteria are genuinely (logically or empirically) independent (Biggiero & Laise, 2003a, 2003b, 2007). Indeed, these methodological issues are deeply connected with that of complexity, because multi-criteriality is just another facet of complexity. As far as we know, recent and specialized literature on social network analysis has not yet faced with this issue.

Overlooking formal multicriteria methods, it is possible to draw a synthetic picture of the similarities and differences evidenced through the comparison. The research question from which we moved was whether, at the country level of aggregation, who trades tends also to collaborate in R&D, and vice versa. If yes, then the R&D collaboration network and the international trade network of the EU aerospace sector should be quite similar. Results showed that indeed *they are similar as a whole, and even more in their core countries, and in the dominant role they play respect to the others*. In fact, the two networks are very hierarchical in structural terms, as showed by correlation and core-periphery analyses, while not at all in dyadic terms, as reported by reciprocity and hierarchical indexes. Moreover, they have a similar level of density, average distance among nodes, and clusterization. *Conversely, they radically differ in terms of centralization, especially when using the appropriate index that is able to take into account its characteristic of being multi-centered*. Finally, both network are dis-assortative, that is, highly connected countries tend to exchange trade and knowledge more with lowly connected countries than among themselves. At first sight this is a surprising result, but a closer look it has reasonable explanations. In the R&D collaboration network the highest connected organizations – which indeed are placed into the highly connected countries of the trade network – tend to build a research consortium with lowly connected organizations, so to avoid unintentional knowledge transfer to other strong competitors, and to steer the consortium activities towards its proper research interests. Consequently, this dis-assortativity at project level is reflected also when the organizations network is re-aggregated at country level. In the international trade network highly connected countries constitute a cohesive group (a core) and of course exchange a lot among them, but each of them trade even more with peripheral countries.

Moreover, because rich countries are more likely to have strong industries and research institutions, the probability that the two networks of trade and collaboration have a similar core-periphery structure is high. As well high is the probability that the two cores composition is similar, because a certain share of R&D investments put in research institutions is made by large companies. Hence, in a single country, weak industry leads to weak trade and weak research, and consequently to small trade and small collaborations. But since density of periphery is much lower than that of core, and to the extent that the network is dis-assortative, peripheries can substantially differ. Therefore, the distinction between the two networks had to be searched into periphery, and its relationships with the core. Though core countries do exchange and collaborate a lot, *the two networks "differ in the fringe", that is, peripheral countries more often can trade without collaborate, and vice versa*. Therefore, a very good question for future studies would be unpacking the periphery and investigating more deeply core-periphery and periphery-periphery relationships, in order to understand if, over time, the driver of trade is collaboration, or vice versa.

This is an explorative work, and therefore we did not formulate and test precise research hypotheses, but rather we have contributed to show and face with methodological issues in applied research. In this respect it should be underlined that, to some extent, our results are biased by the considerable nonlinearity of these types of socio-economic networks. In fact, as it is acknowledged during last 15 years of social network analysis, many socio-economic networks – and natural networks, too - are shaped in a scale-free structure (Caldarelli, 2007), meaning that they are characterized by few highly connected hubs and many peripheral nodes. And the European aerospace R&D collaboration network is exactly a scale-free network (Biggiero & Angelini, 2015). Besides many other implications of scale-free structures, what matters here is that in these networks a core-periphery topology is somehow unavoidable.

Respect to the possibility to generalize these results, we underline that the R&D collaboration that we examined here is only that (totally or partially) subsidized by EU during the sixth Framework Programme. Therefore, non-subsidized collaboration could show a different picture. A further limit to generalizations is that, while collaboration occurs between firms and other kinds of organizations, trade occurs essentially between firms. Finally, our data concern only the European aerospace sector during six years. Hence, generalizations from our results can be done only very prudently, given the explorative nature of this analysis. However, it can help further developments either in extension – longer time span, more sectors, etc. – or in intension – more detailed analysis, i.e. unpacking core-periphery and periphery-periphery analysis.

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ENDNOTES

1. Data to build the collaboration network are gathered from the CORDIS (Community Research and Development Information Service) archive, freely available at www.cordis.eu. International trade data are gathered from the UN COMTRADE database (http://comtrade.un.org/), whose economic values are expressed in current US$.
2. Research projects funded by the FPs are usually sub-divided in Working Packages each one dealing with a different research area. They are structured with "Working Package leaders", who directly reports advancements, issues and plans to the coordinator on that research area. Consequently, and especially in large "Integrated Projects" composed by several Packages, it is hard to understand if partners working in different Packages – not as leaders – are directly involved in joint collaboration.
3. See detailed sector description in next Chapter (Biggiero and Basevi) of this volume.
4. Most of them are shared with Chapters 6, 7 and 8.
5. In fact, the size of these two networks is too small to make this kind of analysis meaningful.
6. The other ones are connectedness, efficiency and least upper bound.
7. We remind that Pearson's coefficient only reports for linear correlation.
8. To go deeper into this issue and other aspects of graph structural hierarchy, see Chapter 7 of this volume (Biggiero & Mastrogiorgio).
9. Noteworthy, the gap is much higher when comparing Snijders' (dichotomous) index with Freeman's valued index. Though the comparison is "spurious", it tells us that Freeman's index is more distortive and inappropriate when, besides the multi-centering property, there is a high variance of magnitude of links values, which in fact in international trade networks range between hundreds and hundreds million dollars. This speculation is supported also by the fact that for the two trade networks the gap is much higher and that when Freeman's index is calculated in log2 values the gap lowers.

[10] As argued in the methodological section of this paper, especially for the versions of collaboration network we can regard the *star*- and the *clique*-based as opposite extremes. A similar reasoning can be done for the two versions of the trade network, even though they cannot be taken as opposite extremes.

[11] Obviously, in collaborative networks in- and out-going densities are identical since ties are un-directed.

[12] An analogous exercise is made by Basevi & Biggiero in next Chapter, which just concerns the comparison of two international trade networks, and by Biggiero & Mastrogiorgio in Chapter 7 concerning pure out-trees.

[13] This distinction comes from the fact that one criterion could potentially be described and measured by more than one indicator.