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International Automotive Production Networks: How the web comes together[*]

Leticia Blázquez and Belén González-Díaz[**]

Abstract

This paper aims to contribute to the literature on New Economic Geography by providing empirical evidence for the connections between new trade theory and the spatial distribution of economic activities. To do this, we apply Social Network Analysis specifically to the World Automotive Trade Network. We explore the structural features of the auto network for the years 1996 and 2009 using data on trade flows for 172 countries. Our findings suggest that the auto network has become denser, more extensive and more integrated over time, depicting a center-periphery structure in which regional clusters play a prominent role. In this configuration, strong agglomeration forces generated by companies' desire for large and rich market access with minimum transportation costs are balanced by the search for new high-potential markets.

Keywords: World Automotive Trade Networks, New Economic Geography, Social Network Analysis, Parts and Components.

JEL Classification: F10, F14, F15.

Resumen

El objetivo de este trabajo es contribuir a la literatura basada en la Nueva Geografía Económica mediante la aportación de evidencia empírica sobre la interrelación entre las nuevas teorías del comercio y la distribución espacial de las actividades económicas. Para ello empleamos la metodología de las redes sociales aplicadas concretamente a la red mundial de comercio de la industria del automóvil. Con información estadística de los flujos comerciales de 172 países, se analizan las características estructurales más importantes de la red del automóvil para los años 1996 y 2009. Los resultados ponen de manifiesto que la red de comercio mundial del automóvil se ha hecho más densa, más integrada y más extensa con el paso del tiempo reflejando una clara estructura centro-periferia donde los clusters regionales desempeñan un papel muy relevante. En la configuración de esta red, la importancia de las fuerzas de aglomeración generadas por el deseo de las empresas de acceder a los mercados más importantes con los menores costes de transporte posibles, se ven contrarrestadas por la búsqueda de nuevos mercados con un elevado potencial de crecimiento.

Palabras clave: Red mundial del comercio del automóvil, Nueva Geografía Económica, Análisis de las redes sociales, Partes y componentes.

Clasificación JEL: F10, F14, F15.

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1. Introduction

Trade theories based on New Economic Geography (NEG) have stressed the importance of taking into account the interconnection of regions in the analysis of the spatial distribution of economic activities. They highlight how any change that directly involves only two regions are unlikely to leave the remaining regions unaffected. Additionally, NEG has emphasized that the relative position of the region/country within the whole network of interactions is a key issue faced by firms when choosing where to locate and thus also influences the way they organize their production, management and outsourcing (Krugman, 1993; Thomas, 2002; Fujita and Thisse, 2009).

One of clearest signs of how the complex interactions between countries and regions influence the way companies organize their production and vice-versa has been the emergence of international production networks in most manufacturing sectors. In this sense, the main objective of this paper is to study the structural evolution of the spatial distribution of economic activities for one of the sectors with the highest incidence of global production sharing, the automotive industry, in the light of some of the assumptions and results obtained from New Economic Geography. As alternative to more traditional theoretical models, we will use in this analysis an empirical approach by applying the methodology proposed by the Social Network Analysis.

The extent to which these sharing strategies have been implemented in the auto industry is reflected by the spectacular increase in the world's automotive trade in general during the past decade (from 1996-2009, it grew at a cumulative annual rate of 5.4 percent in nominal terms) and by the particularly high dynamism of its intermediate commodity flows, with an annual cumulative growth rate of 6.2 percent (almost two percentage points more than final goods), increasing its share of the overall world auto trade from 50 to 56 percent. These highly intense international trade flows give us a clear idea of the complexity of the auto industry organization, evidencing the relevance of its network characteristics in its analysis.

According to NEG, the spatial distribution of economic activities can be viewed as the outcome of a complex balance between two types of opposing and mutually reinforcing forces: agglomeration (or centripetal) and dispersion (or centrifugal) forces (Baldwin *et al.*, 2003; Fujita and Thisse, 2009).[1] In this regard, since the automotive industry can be considered fragmented and to operate under increasing returns to scale in a globally imperfect competitive market, the location of auto companies across space should presumably be explained primarily in terms of the search for privileged access to large, wealthy markets and the desire to relax the competitive pressures imposed by other firms.

[1] Two stable spreading equilibria result from the simplest 2x2x2 model (Krugman, 1991): agglomeration of one of the sectors in one region when transportation costs are very low, and dispersion of this sector in two regions when transportation costs are very high. In this model, Krugman basically adds the interregional mobility factor (workers and firms choose a location) to his new trade theory model (Krugman, 1980). From this stylized model, different and more complex assumptions have been added. For a discussion of the core model and several of its extensions, see, for example, Ottaviano and Thisse (2004).

Therefore, we expect larger economies in terms of population and purchasing power to attract a more than proportional share of auto companies; in other words, for the home market effect to be one the most significant agglomeration forces in the conformation of the auto network. Intermediate transportation costs incurred by the auto industry would lead firms to seek to locate close to their end markets, thus reinforcing the market effect. As a result, we also expect deeper integration within the auto network to actually lead to more regional imbalance in the spatial distribution of the industry and for some degree of economic specialization to arise. Additionally, in a highly fragmented sector like the auto industry, the presence of input-output linkages between firms is expected to be one strong agglomeration force (Krugman and Venables, 1995).

On the other hand, traditional auto markets are fairly mature and the competition between companies in their territories could be labeled as fierce. Therefore, we would expect a dispersion force generated by each firm's desire to avoid market crowding (corresponding to the price effect in spatial competition) to emerge. Fostered by this dispersion force, some firms would relocate from the traditional core to the periphery, yielding a bell-shaped curve of spatial development *à la* Kuznets.

In order to evaluate the extent to which the evolution of the auto industry structure responds to these assumptions set by the NEG, we will apply Social Network Analysis tools and graph theory to the world trade web rather than the traditional general equilibrium models applied by the NEG. The reason is that, although the contribution of NEG to introducing spatial factors into rigorous models is unquestionable, its own precursors have pointed out that these models are too stylized and simple to adequately represent the real economic geography and thus become relevant from a policy-making standpoint (Krugman, 2001, p.59).

In the analysis of these cross-border production blocks, multiple factors should be taken into account. It is not only a question of intensifying the openness of countries, but also of developing networks of direct and indirect relations between individuals, companies and countries at a distance from each other (Arribas-Pérez and Tortosa-Ausina, 2009). Network approach is an appropriate method for studying such issues as it provides a methodology that enables us to measure the nature of these relations and how and to which extent and they evolve over time in ways that other measures do not capture. By applying network analysis to international trade, we can complement other empirical analyses of trade that put countries' characteristics at the forefront (e.g. the gravity model of international trade) since it places more emphasis on the relationship between units in the graph and on the structure of the system itself than on the units' attributes, which are generally left in the background.

Although these techniques have not been very extensively used in economics to date, the approach is not new in international economics (see, for instance, the recent paper by Chinazzi *et al*., 2013) and specifically in trade analysis. Recent examples include Garlaschelli and Loffredo (2005), Kali and Reyes (2007), Kali *et al.* (2007), Arribas *et al.* (2009), Fagiolo *et al.* (2008), Fagiolo (2010), and De Benedictis and Tajoli (2011). All of these studies focus on analyzing the world trade network and accurately analyze the properties of the system in terms of trade flows, partners and links. Most of them suggest that there is strong heterogeneity between countries, with nations playing very different roles in the network structure, but there is only a very limited effort in these studies to explain these findings on the basis of trade or location theories. Moreover, none of them analyzes specifically the characteristics of sharing production networks nor considers the differentiated features of sectors which use these strategies as we do in this paper by focusing on one specific sector. The structural characteristics of the world automotive trade network have been analyzed in several meritorious studies (e.g., Humphrey and Memedovic, 2003; Sturgeon *et al.* 2008, 2009; Amighini and Gorgoni, 2010; Sturgeon and Van Bieserbroeck, 2010, 2011). However, most of these papers do not offer an empirical analysis with a solid analytical framework that makes it possible to find stronger affinities with trade theories and international economics. In this sense, this paper complements these more descriptive contributions.

The article is organized as follows. In section 2, we briefly explain the main network analysis tools and the data source used in the research. Section 3 describes the evolution of structural features of the world automotive trade network and analyzes the agglomeration and dispersion forces behind this evolution. Section 4 offers some concluding remarks.

2. Social Network Analysis and Data

Social Network Analysis is based on mathematical graph theory. In the graph representing the world automotive trade network (WATN, hereafter), the vertices of the network represent the trading countries and the lines represent the trade flows between any two partners: exports and imports. We consider the WATN from two complementary standpoints. First, we build a weighted network where each directed link represents the value of export from the country of origin (the exporter) to the target country (the importer) as reported by the importer[2]. While we are interested in comparing the structure of the WATN at two different moments in time, we also define rescaled weights relative to the total yearly trade flows.[3] In this way, trend effects are eliminated and we obtain adimensional weights that are automatically deflated, allowing for consistent comparisons across different years and commodity types (Squartini *et al.*, 2011b). Additionally, we have also explored the properties of the binary projection of the weighted generic matrix by analyzing the mere presence or absence of a trade relationship between two countries.

The sequence of binary and weighted matrices fully describes the within-sample dynamics of the WATN, and its main characteristics can be summarized by topological

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[2] The directed nature of the WATN is based in the calculus of the symmetry index, *S,* proposed in Fagiolo (2006). Since the asymmetric patterns have been statistically identified, a directed analysis of the network is necessary.

[3] $w'_{ij}(t) \equiv \frac{w_{ij}(t)}{w_{tot}(t)}$ where $w_{ij}(t)$ are exports from country *i* to country *j* in period *t* and $w_{tot}(t) \equiv \Sigma_i \Sigma_{j \neq i} w_{ij}(t)$.

measures and paths.[4] To this extent, we have calculated both aggregate and node-specific network statistics. The aggregate topological measures provide evidence for the structural properties of the whole network. In this vein, the number of partners and the interaction intensity of countries, as well as the way these patterns have changed over time, will give a clear idea about the evolution of the connectivity of countries in the WATN. The widest measure of the connectivity or cohesiveness of a network is its *density* (i.e. the fraction of all possible links that are actually present). Additionally, we have analyzed the shape of the network by measuring the extent to which it has (or has not) a center. The *degree centralization* index –C_D— (i.e. the variation in the number of trade links that a given country has established divided by the maximum degree of variation possible) provides this information. And the group *random betweenness centralization* index –*BCN*— describes and compares different networks with respect to the heterogeneity of the role of their members as intermediaries in the network.

Together with these aggregate measures, node-specific network statistics consider individual countries' positions within the WATN. We thus determine how many trade links a country has established (i.e. node *degree* measures), distinguishing between the number of countries that the country imports from (*indegree*) and the number of countries that receive exports from this partner (*outdegree*). Correspondingly, we can assess the weights associated with the trade links maintained by each country (i.e. node *strength* measures). The larger the node strength of a country, the higher the intensity of the interactions it mediates. In this sense, it is also interesting to identify *authorities and hubs* within the network. Using the HITS algorithm developed by Kleinberg (1999), we can determine which countries are (via strongly weighted in-links) more pointed-to by hubs, becoming authorities; and which countries point (via strongly weighted out-links) to more authorities, becoming hubs.[5]

Furthermore, in assessing the centrality of countries within the network, we examine their *closeness centrality* index –*CL*— that measures how easily a country can trade with all the others taking into account the geodesic distances between them; and their *random betweenness centrality* index that reveals how important a country is as an intermediary in the network. The binary version of the latter index –*RWBC*— would indicate the extent to which a country is crucial for the integration of the network whereas its weighted version –*RWWBC*— captures the effects of the magnitude of the relationships that each node has with its partners, as well as the strength of the node in question.[6]

[4] A more extensive and detailed description of the topological measures included in this section can be found in the seminal book by Wasserman and Faust (1994). The corresponding analytical description of this section is presented in Table A3 of the Statistical Appendix.

[5] Note that an authoritative country may also be a hub, and vice versa. It is also important to be aware that HITS hub/authority rankings tend to be strongly correlated with the out-/in-degrees of the corresponding nodes (Benzi *et al,* 2013).

[6] In particular, we use in this study the *Random-walk betweenness centrality* index proposed by Newman (2005) and Fisher and Vega-Redondo (2006).

Another important feature of network structure concerns the extent to which a given country is clustered (i.e. how much the partners of a country are themselves partners). In order to identify clusters of countries that are closely connected insofar as they all share a particular minimum degree within the cluster, we apply the so-called *k-cores* analysis.[7]

These first-order indicators indicate the extent to which the WATN shows a core-periphery structure; i.e. to which the agglomeration forces prevail in the conformation of the network. Additionally, we can analyze second-order relations, which indicate how and how much each country's partners are themselves connected within the network. In doing so, we can evaluate the influence of dispersion forces on the network shape and its evolution.

To do this, we have computed the *average nearest-neighbor degree* (ANND), i.e. the average number of partners of the neighbors (partners) of a country. We have also calculated how much the partners of a node are themselves characterized by high strength by computing the *weighted average of nearest-neighbor node degrees* (WANND) and the *arithmetic average of nearest neighbor strengths* (ANNS). Note that in both the binary and the weighted network we can consider separately the different directional trade relations, i.e. the trade relations between the country considered and its partners as well as the relationships of the trade partners of the country analyzed.

The main data source employed in the analysis has been the United Nations COMTRADE Database. The trade data used is bilateral exports/imports as reported by the importing country and measured in nominal U.S. dollars.[8] Following the HS1996 categories identified by Türkcan (2009) and the SITC Rev.2 categories recognized by Kaminski and Ng (2001) for auto P&C, we provide a more extensive and complete code list for automotive final goods and their P&C corresponding to HS1992 (Table A2 in the Statistical Appendix). With these data, we have created separate trade matrixes between countries for the exchange of automotive final goods and their corresponding parts and components (henceforth, P&C). The matrixes include 172 countries and have been constructed for the years 1996 and 2009.[9]

The use of P&C trade as a suitable proxy for participation in international production networks is commonplace. Because of their intermediate nature, P&C foreign exchanges must necessarily be targeted at assembly in the importer country or for incorporation into a further stage of production in another economy (except spare parts).

Furthermore, although in capital and technology-intensive industries such as this, the production of P&C is considered to be relatively capital-intensive while their assembly is relatively more labor-intensive (Kim, 2002; Athukorala, 2009), there are considerable

[7] A *k-core* is a maximal subnetwork in which each vertex has at least degree *k*. It therefore identifies relatively dense subnetworks and thus cohesive subgroups within the whole network.

[8] We restricted our analysis to those import flows whose values are higher than or equal to 3 per cent of the country's total imports of the specific commodity considered.

[9] The selection of the number of countries was based on the availability of data for both of the periods analyzed. See Table A1 in the Statistical Appendix.

differences between automotive P&C in terms of factorial intensity. These differences will, in turn, influence transportation costs, transaction cost and the extent to which scale economies can be exploited. These factors are very much taken into account by auto companies in their outsourcing and location decisions. It is interesting, then, to explore whether the structural transformations and changes in countries' specialization also depends on the factorial intensity of auto P&C. In order to do this and following Peneder (1999), we have differentiated four P&C subnetworks according to their factorial intensity: mainstream-driven, capital intensive-driven, technology-driven and labor-intensive-driven.[10]

The final assembly tasks should also be considered in the analysis for two main reasons. Firstly, from the standpoint of international production networks, a study of the final automotive goods export network is particularly relevant, since in doing so we are considering those countries operating in the last stages of the value chain, i.e. in assembly of P&C into the final goods and their subsequent export. Secondly, in recent years there has been a notable expansion of network activities from pure production and assembly of P&C to final assembly (Athukorala, 2011).

3. The International Automotive Production Network

3.1. First-order indicators: Agglomeration forces

The aggregate network statistics reveal that the P&C network has become denser and more extensive over time since countries have, on average, increased the number of partners with which they have trade relations (Table 1). However, the results for centrality measures permit the argument that the auto P&C network has maintained a centre-periphery structure in terms of connectivity and intensity. The higher *degree centralization* index would suggest unevenly increasing integration within the network. And the increasing *betweenness centralization* indexes, mainly the weighted index, would indicate the growing importance of hubs in the WATN.

The pattern of heterogeneity between countries within the WANT is clearly visible in Figure 1. We can appreciate a small group of highly connected countries in the centre having trade relations with the vast majority of the other countries, and with most countries having a very small number of partners that, in particular, only have trade relations with those central countries. Nevertheless, it should be noted that only the P&C export network exhibits a clear and increasingly star-shaped structure, whereas the P&C import network looks rather like a regular graph (Figures 2). It is also remarkable to note that, according to the *closeness centrality index*, distances between trading economies seem to be shortened insofar as more

[10] Peneder (1999) identified five groups rather than four. The fifth group refers to marketing-driven P&C. Since, in the case of the automotive industry, this category includes only two items which account for only 0.3% of the total trade in automotive P&C we have decided not to analyze this category separately. The mainstream-driven category refers to those items in which input combinations do not share a major reliance on any particular input factor.

Table 1. Topological Measures of the World Automotive Trade Network[a]

Binary Network Indexes	P&C		Final Goods		Weighted Network Indexes	P&C		Final Goods	
	1996	2009	1996	2009		1996	2009	1996	2009
Arcs	1129	1257	1018	1115		1129	1257	1018	1115
Density	0.038	0.042	0.035	0.037					
Average Node Degree (number of lines)	13.128	14.616	11.837	12.965	**Average Node Strength**	1.156	1.146	1.153	1.161
Indegree/Outdegree (Average)	6.564	7.308	5.918	6.482	Instrength/Outstrength (Average)	0.578	0.582	0.576	0.580
Average Nearest-Neighbor Degree (ANND)	66.94	68.16	73.398	67.399	**Average Nearest-Neighbor Strength (ANNS)**	10.239	8.362	11.3777	9.272
Degree Centralization	0.691	0.861	0.838	0.781					
Indegree Centralization	0.032	0.028	0.030	0.038					
Outdegree Centralization	0.722	0.894	0.866	0.811					
Closeness Centrality	0.487	0.509	0.503	0.510					
Input Closeness Centrality	0.087	0.084	0.060	0.072					
Output Closeness Centrality	0.093	0.092	0.062	0.078					
Random Walk Betweenness Centrality (RWBC)	0.037	0.042	0.039	0.055	**Random Walk Weighted Betweenness Centrality (RWWBC)**	0.572	3.932	2.774	3.357
Random Walk Betweenness Centralization	0.459	0.529	0.573	0.726	**Random Walk Weighted Betweenness Centralization**	19.845	166.683	184.516	181.009
Export k-cores	8 (k=4)[♦]	12 (k=4)[♦♦]	7 (k=4)[♦♦♦]	7 (k=5)[♦♦♦]					

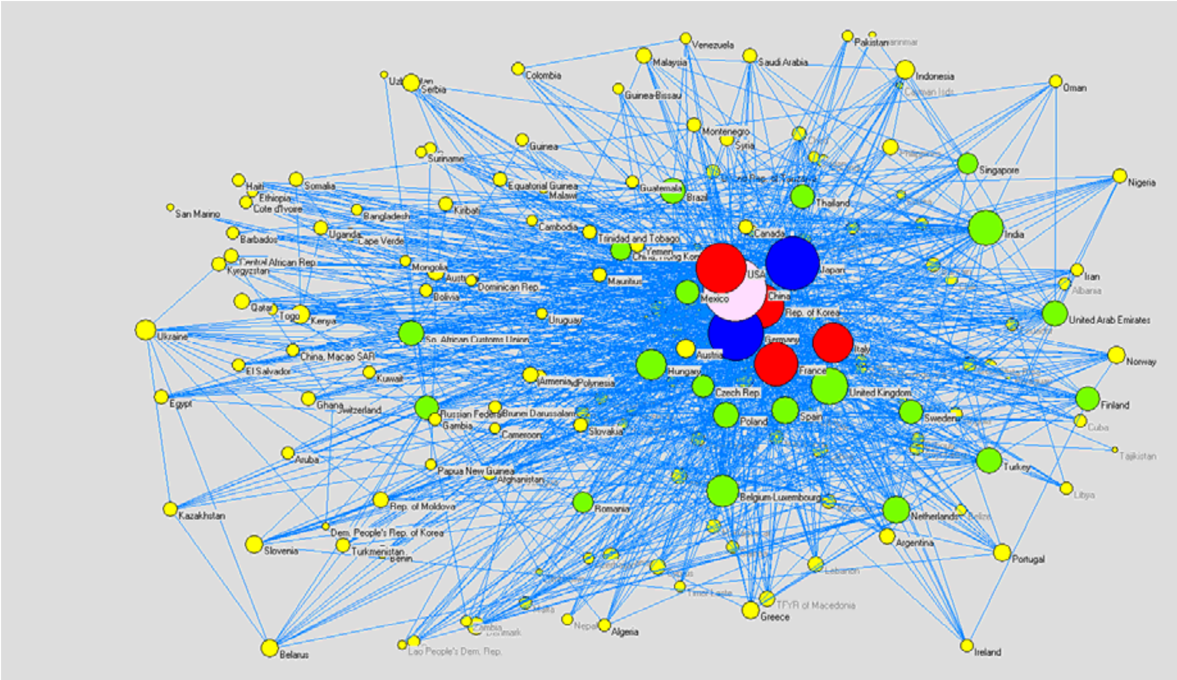
[a] There are statistically significant differences (5% significance) between the measures for P&C and Final Goods in the Indegree's indicators for 1996 and 2009 and the ANND for 1996, while for the rest (Outdegree, Degree, Instrength, Outstrength, Node Strength, ANND for 2009, ANNS, RWBC) no statistically significant differences are found between the averages for P&C and Final Goods.

[♦] The highest core of the P&C export network was formed by Belgium-Luxemburg, France, Germany, Italy, Spain, the United Kingdom, Japan and USA. [♦♦] France, Germany, Italy, Spain, the United Kingdom, Japan, USA, China, Korea, Czech Republic, Hungary and Poland.
[♦♦♦] Belgium-Luxembourg, France, Germany, Italy, Japan, Spain, United Kingdom.

Source: authors' calculation, based on UN COMTRADE.

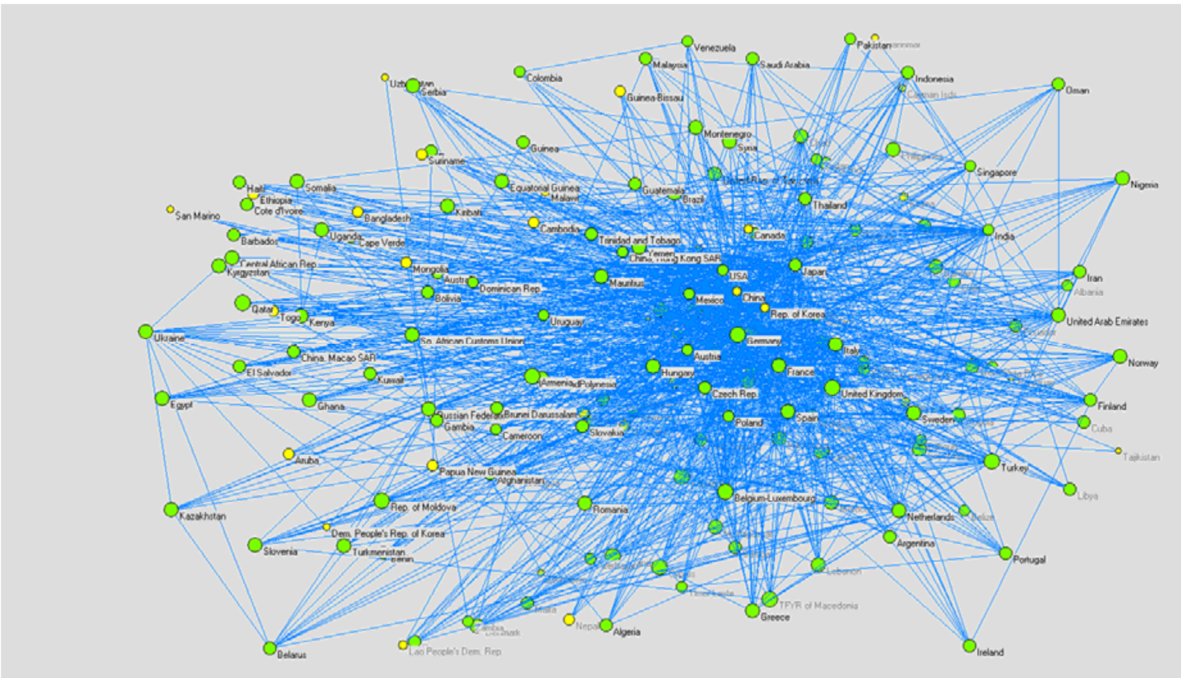
direct trading relations have emerged. Therefore, we can say that the trade integration of the P&C auto network has increased over time.

Figure 1. Automotive P&C. Outdegree Network (2009)



Source: authors' calculation, based on UN COMTRADE using PAJEK. The size of vertices is related to their outdegrees

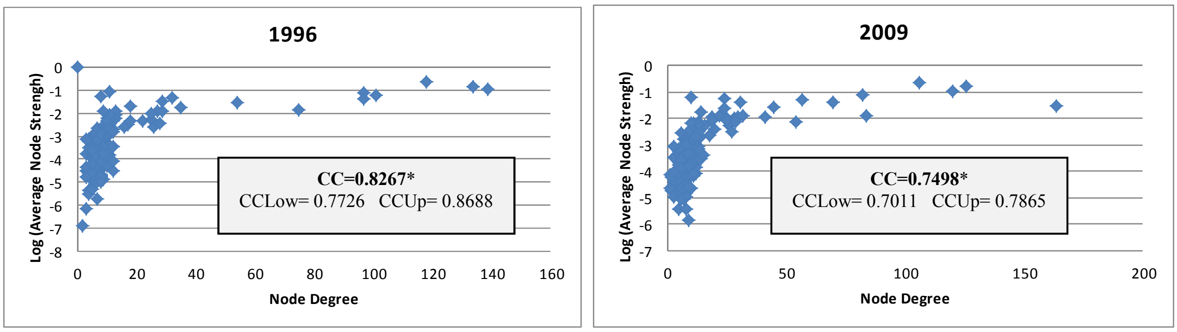
Figure 2. Automotive P&C. Indegree Network (2009)



Source: authors' calculation, based on UN COMTRADE using PAJEK. The size of vertices is related to their indegrees

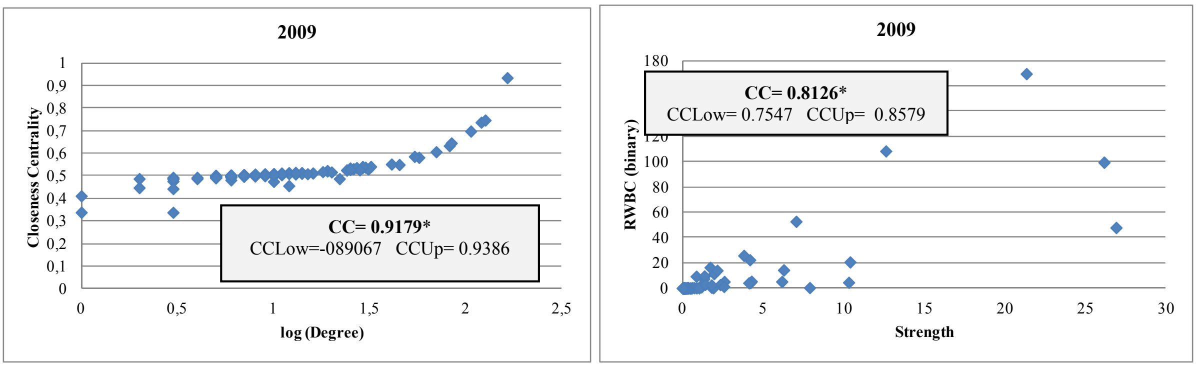
Additionally, Figure 3 shows that highly connected and integrated countries are also the most (on average) intensely connected It is interesting to observe how the variability in average strength is fairly high for those countries with a relatively low degree, while from a certain degree onwards, countries are able to maintain intense trade relationships. Moreover, we observe that not only are there few countries with a higher number of links, but there are even fewer that are intensely connected. We have also detected that those few countries with increasingly intense relationships are also the ones that play a more prominent role as intermediaries within the network (Figure 4) and that these gatekeeper countries have intensified their role over time.

Figure 3. Correlation between *Degree* and *Average Node Strength* for P&C WATN (1996 and 2009)



Source: authors' calculation, based on UN COMTRADE. CCLow and CCUp are the correlation coefficients at 5% and 95% confidence intervals

Figure 4. Correlations *Degree* vs *Closeness Centrality* and *Strength* vs *Random Walk Betweenness Centrality* (RWBC) for P&C WATN, 2009



Source: authors' calculation, based on UN COMTRADE. CCLow and CCUp are the correlation coefficients at 5% and 95% confidence intervals.

Additionally, the HITS algorithm (Table 2) and the *k-core* indicators analysis (Table 1) suggests that in this centre-periphery structure, regional, local and/or traditional ties play a very important and increasing role in the shaping of the network. The small number of central countries that are at the same time hubs and authorities indicate that these countries not only sell their P&C to those non-producer countries but that there is also an intensive flow of P&C from them towards other (less powerful) P&C producers in the centre of the network.

Table 2. Weighted *Hub* and *Authority* Centrality in the automotive P&C[a]

Rank	Weighted Hub Centrality		Weighted Authority Centrality	
	1996	2009	1996	2009
1	US	CHN	CA	US
2	JP	MX	US	CHN
3	MX	JP	MX	CA
4	CA	CA	UK	JP
5	DE	KO	JP	MX
6	FR	DE	DE	HK
7	IT	US	KO	FR
8	UK	FR	TH	UK
9	ES	IT	FR	DE
10	SE	PL	B&L	KO

[a]Argentina (AR); Australia (AU); Austria (AT); Belgium-Luxembourg (B&L); Brasil (BR); Canada (CA); China (CHN); Colombia (CO); Czech Rep.(CZ); Denmark (DK); El Salvador (SV); Finland (FI); France (FR); Germany (DE); Honduras HN); Hong Kong (HK); Hungary (HU); India (IN); (Indonesia (ID); Israel (IL); Italy (IT); Japan (JP); Malaysia (MY); Mexico (MX); Netherlands (NL); Panama (PA); Philippines (PH); Poland (PL); Portugal (PT); Korea (KO); Romania (RO); Russian F. (RU); Saudi Arabia (SA); Singapore (SG); Slovakia (SK); Slovenia (SI); Spain (ES); Sweden (SE); Switzerland (CH); Thailand (TH); Tunisia (TN); U.A. Emirates (AE); United Kingdom (UK); USA (US) and Venezuela (VE).

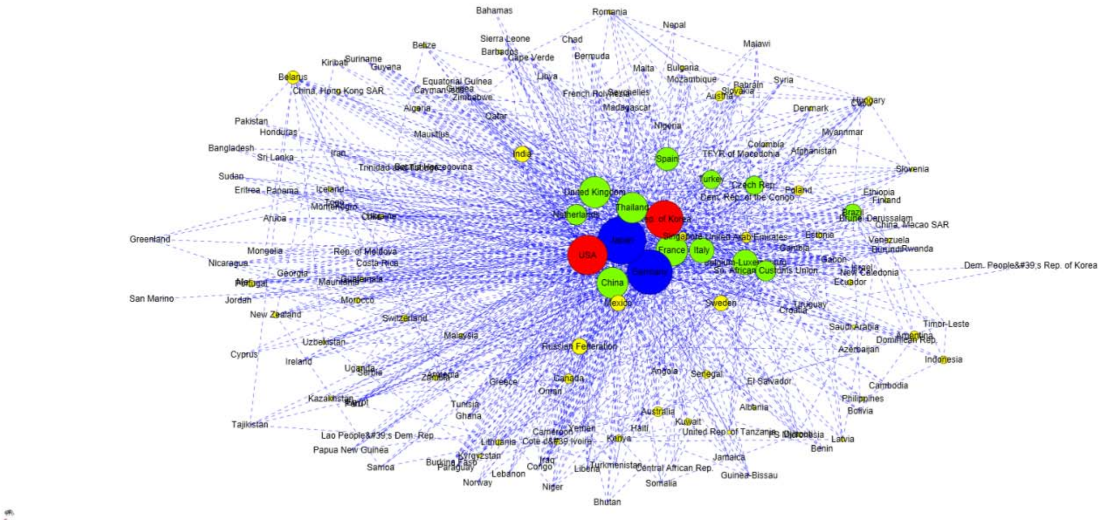
Source: authors' calculation, based on UN COMTRADE

The aforementioned structure for the P&C network is basically repeated for the final goods export network.[11] This means that only a small group of countries are highly-connected and intense exporters of final goods and those exporters have a highly diverse portfolio of partners (Figure 5). In fact, the most intense P&C importers and exporters were also the most intense exporters of final goods. And, as expected, we have found that the heaviest P&C exporters were also the most highly connected countries in the export markets of final goods. However, it seems that the heaviest exporters of final goods do not necessarily have a high number of foreign providers of P&C, even though they intensely buy P&C from them.

This parallelism in the configuration of both networks signals an important structural change in the auto network from the nineties to the present. Traditionally, the P&C sector has been less concentrated (less centralized) than the final assembly sector (Wells and Rawlinson, 1994; Sadler, 1997), but over time, the intense concentration and internationalization process experienced by the component sector in order to be able to source to assembly firms on a world-wide basis has brought the centralization indices of both networks closer. In this sense, we can observe how the P&C network had become even more centralized than the final goods network by 2009 (see Table 1). Nevertheless, P&C firms are still more geographically scattered in their production and sales patterns than final auto goods companies.

[11] No statistically significant differences were found between both networks for most of the structural indicators.

Figure 5. Automotive Final Goods. Outdegree Network (2009)



Source: authors' calculation, based on UN COMTRADE using PAJEK. The size of vertices is related to their outdegrees.

The dynamics described so far by the first-order indicators of Social Networks Analysis, in which a centre-periphery structure dominates the WATN, arise mainly from the action of the agglomeration forces. In the next section, we will analyse those centripetal forces that make this structure prevail.

When we examine in more detail the composition of the WATN centre, it seems clear that one of the main agglomeration forces that is acting in its structure is the *market effect*. The central nucleus of this star-shaped auto network was made up in 1996 of such economies as Japan, Germany and the USA (Table 3). Together with these three, Italy, France, the United Kingdom, Korea[12], Spain, Belgium-Luxembourg, and the Netherlands were the most central, reachable, and go-between countries in the network. Other important economies in the WATN, located close to large markets were Canada and Mexico, which both had very significant *outstrengths* in both the P&C and final goods export markets although they were very narrowly linked. All these economies continue to be part of this central nucleus, although together with other countries (see below). Accordingly, in 1996, the densest *k-core* was composed of a European cluster (Belgium-Luxembourg, France, Germany, Italy, Spain, and the United Kingdom) plus Japan and the USA.

One of the reasons why the composition of the WANT centre is made up of those countries is that the intermediate transportation costs in the automotive industry lead automakers to locate close to the end markets. But in addition, the exploitation of the advantages of the international division of labour requires extensive markets, with the market size determining the optimum degree of production fragmentation (Jones *et al*., 2005). Therefore, the centre-periphery structure is generated by companies' desire for large market

[12] When we say Korea, we mean South Korea.

Table 3. The Role of Countries in the International Automotive Production Network (ordered by 2009 outdegree P&C)

	1996						2009					
	Automotive Parts and Components				**Automotive Final Goods**		**Automotive Parts and Components**				**Automotive Final Goods**	
	Outdegree	Outstrength	Indegree	Instrength	Outdegree	Outstrength	*Outdegree*	Outstrength	Indegree	Instrength	Outdegree	Outstrength
China	23	0.95	6	1.20	6	0.02	*160*	16.99	4	4.35	63	0.75
Germany	123	17.86	11	8.16	127	22.11	*114*	16.53	12	9.63	125	25.44
Japan	130	16.75	9	2.18	152	18.43	*113*	10.07	7	2.55	143	17.59
USA	114	20.27	4	17.79	95	7.99	*100*	9.49	6	17.42	99	7.87
Korea	71	0.91	4	1.54	86	1.42	*80*	5.76	4	1.28	90	4.47
France	89	8.06	8	4.95	85	7.71	*72*	5.60	10	4.79	63	6.11
Italy	90	4.73	7	2.83	56	3.32	*61*	3.73	9	2.54	38	2.50
India	19	0.07	7	0.35	16	0.04	*48*	0.49	6	1.22	16	0.15
UK	94	4.39	7	6.32	77	5.54	*45*	2.35	12	1.45	61	3.97
B&L	21	1.81	8	4.21	36	5.28	*34*	1.24	11	2.97	39	3.68
Hungary	4	0.54	8	0.23	1	0.02	*32*	2.80	9	1.38	4	0.09
Netherlands	27	0.53	8	2.45	32	1.10	*23*	0.93	9	1.65	27	0.39
Poland	4	0.02	7	0.84	0	0.00	*22*	2.61	6	1.66	6	0.79
Spain	26	3.01	6	4.83	38	5.84	*22*	2.35	9	3.81	34	6.05
Brazil	18	0.62	9	1.56	11	0.39	*21*	1.02	9	1.31	19	0.91
UAE	5	0.01	11	0.41	6	0.02	*20*	0.09	9	1.26	8	0.07
Finland	18	0.42	7	0.48	4	0.05	*19*	0.30	7	0.54	1	0.00
Mexico	5	5.35	3	4.36	20	4.67	*18*	5.86	6	4.45	16	5.27
Thailand	7	0.26	2	1.75	3	0.00	*18*	0.91	7	1.23	60	1.58
SACU	0	0.00	8	0.02	0	0.00	*18*	0.07	9	0.55	26	0.26
Turkey	11	0.03	7	0.78	8	0.05	*17*	0.18	12	1.61	22	1.49
Sweden	43	2.90	11	2.21	25	0.76	*15*	0.79	9	1.15	15	0.39
Russia	19	0.25	9	0.38	20	0.13	*15*	0.29	10	1.58	16	0.15
Czech Rep.	7	0.50	6	0.53	12	0.14	*14*	2.39	8	1.72	21	1.68
Singapore	15	0.33	10	1.37	4	0.04	*13*	0.20	6	1.11	5	0.01
Romania	0	0.00	4	0.13	2	0.01	*11*	0.71	9	0.69	1	0.03
Indonesia	6	0.02	5	0.94	0	0.00	*9*	0.28	7	0.91	4	0.05
Austria	13	1.60	5	1.70	4	0.33	*8*	1.28	6	1.28	6	0.47
Canada	8	5.37	3	10.60	8	12.28	*6*	2.76	4	5.13	6	5.44
Portugal	5	0.38	6	1.09	6	0.50	*6*	0.23	7	0.63	3	0.04
Argentina	4	0.28	6	0.78	2	0.36	*4*	0.19	7	0.83	6	0.88
Slovakia	3	0.09	7	0.12	1	0.01	*3*	0.80	7	0.99	5	0.46

Source: authors' calculation, based on UN COMTRADE.

access in terms of population and purchasing power coupled with a minimization of transportation costs.[13] In fact, this comparative advantage of some economies, based more on market size than on production costs, is what, according to NEG, should be expected for industries such as this that operate in segmented markets under imperfect competition and with increasing returns to scale and intermediate transportation costs. When these economies are large enough to engage their production, the domestic market is the main consumer; however, when economies attract a more than proportional share of firms, they also become export platforms.

Moreover, the parallelism in the configuration of P&C and final good networks seems to indicate that a second agglomeration force is a consequence of the *relational form of the linkages* between P&C suppliers and between them and assemblers, caused by the high complexity and modularity of the auto P&C. In this sense, carmakers' preference for developing local supplier bases through a mixture of encouraging follow-sourcing by major transnational companies in P&C, where large suppliers follow their customers' investment abroad, and the upgrading of existing local suppliers (Humphrey and Memodovic, 2003), foster the synchronized structural evolution of the final and P&C networks. These strategies are also reflected in the increasing role of (regional) hubs in the network that we have seen in the previous section. The increasing role of the central countries as intermediaries in the network is a consequence of the development of central sector-specific knowledge and innovative activity in these economies. Most of the sector's economic activity must pass through their territory because most of the critical technical and engineering tasks are developed within or near them (Sturgeon *et al*., 2008).

In order to further investigate the results of the development of these input-output linkages within the WATN, and the extent to which it reflects companies' search for the exploitation of spatial heterogeneity among regions in terms of more efficient production through specialization and trade (as classical international trade theories would posit), Table 4 offers the traditional Balassa indexes applied to P&C exports and imports and also to final auto goods exports. For P&C exports, values higher than one indicate specialization in the production and export of these P&C. In the case of imports, values higher than one mean specialization in P&C assembly, since imported P&C will necessarily be incorporated into other higher added-value P&C or into final goods. When the import specialization is indeed part of a vertical specialization strategy, meaning that the destination of the final goods is export, then the country also benefits from a comparative advantage in the export of final goods. According to this argument, we can classify countries into three main categories or groups. The first group (G1) is made up of pure producers and exporters of P&C. The second group (G2) contains those countries that are specialized in labour-intensive assembly tasks. The third group includes those countries that are dually specialized (Kaminsky and Ng, 2001).

[13] In this respect, it is important to bear in mind the explanation of the *distance puzzle* given in Arribas *et al*. (2011) from the construction of international trade integration indicators; the authors find that the role of distance in bilateral trade, on average, still matters despite the reductions in the cost of trade, although it varies across countries.

This latter behaviour could result from two circumstances. The first possibility is that the country imports P&C that are transformed into other more downstream P&C, which are then exported (G3). The second possibility is to export upstream P&C, which are transformed into more complex P&C abroad and re-imported from the country for assembly into the final product, which is then exported (G4). Bearing in mind its shortcomings, the analysis of the trade balance can be an indicator of which of the two situations prevails.

Table 4. Specialization of main countries in the automotive sector

		1996			2009		
		P&C		Final Goods	P&C		Final Goods
		Import	Export	Export	Import	Export	Export
G1	Japan	0.44	1.40	1.65	0.70	1.37	2.47
	Korea	0.59	0.52	0.87	0.59	1.38	1.17
	China	0.42	0.48	0.02	0.52	1.02	0.07
G2	UK	1.06	0.82	1.04	1.10	0.86	1.35
	USA	1.12	1.35	0.60	1.19	0.94	0.82
	B&L	1.33	0.55	1.73	0.88	0.47	1.06
G3	Hungary	0.76	3.15	0.58	2.00	3.48	0.80
	Mexico	2.01	2.40	2.20	1.72	2.42	2.27
	Czech Rep.	1.03	1.25	0.83	1.71	2.08	1.70
	Poland	1.20	0.63	0.70	1.43	1.78	1.10
	Germany	1.03	1.31	1.72	1.33	1.20	1.96
	France	0.89	1.27	1.20	1.04	1.16	1.26
G4	Brazil	1.42	1.89	0.67	1.14	1.83	1.39
	Spain	1.99	1.45	2.65	1.68	1.21	2.71
	Canada	2.56	1.42	3.29	1.57	1.20	2.39
	Sweden	1.51	1.88	1.18	1.27	1.16	1.02
	Argentina	1.46	1.53	1.77	1.97	1.07	3.58
	Thailand	1.18	0.55	0.05	1.01	1.04	1.22
	Turkey	0.94	0.74	0.34	1.33	1.02	1.87

Source: authors' calculation based on UN COMTRADE.

In Table 3 we see that Japan was in the mid-nineties and still is a pure producer of P&C which are destined for both export and domestic assembly. The final automotive goods produced at home are of course very much consumed domestically, but they are also heavily targeted at export. Its industry has followed a clear vertical specialization strategy at the highest technological stages. On the other hand, countries such as the United States and the United Kingdom seem to follow a very different strategy: they are specialized in the assembly of P&C, which they mostly import or re-import (the latter is very much the case with the United States), mainly into final goods that they either consume domestically or export. Of course, the large US domestic market absorbs a relatively higher proportion of the final national automotive production, although we should bear in mind that this country is the third largest world exporter of automotive final goods. It is also interesting to observe how in the mid-nineties the United States was dual specialized, while today it has lost its comparative advantage as a producer and exporter of P&C and is increasingly focused on the assembly of final goods to be sent abroad. We can also see this effect in the downward movement in the hubs-centrality index ranking (Table 2)

The other prominent countries in the WATN both in 1996 and 2009 show a dual specialization and all of them are also specialized in final exports. It therefore seems that these economies have advantages in all stages of the value chain, and the companies located in these countries follow vertical specialization strategies. However, there are some differences between them. Countries such as Germany, France and Mexico import P&C, which are either transformed into other more downstream P&C destined for foreign markets or are assembled into the final product in their territories and then exported. In this sense, Germany's role is remarkable. Not only does it import P&C to be transformed into higher added-value goods, but it is also the main exporter of final goods, so it plays a prominent role as an assembler. On the other hand, economies such as Spain and Canada, though also dually specialized, show higher advantages in assembly. They export P&C that are transformed into higher added-value P&C abroad and then re-imported for assembly into the final goods, which are then consumed domestically or exported. They can be considered export platforms of final automotive goods.

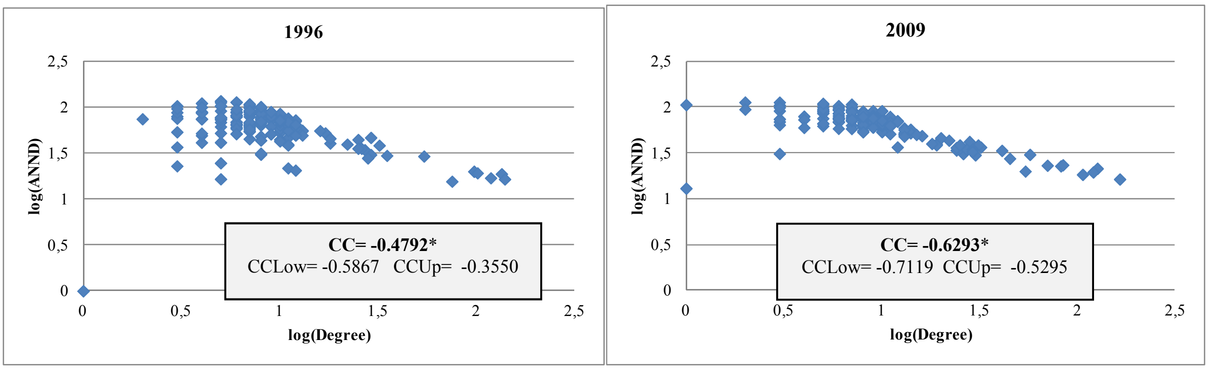
Once again, we can see how the combination of the market effect and the relational linkages between the different stages of the value chain make countries like the United States, the United Kingdom, Germany, Spain and Canada very powerful assemblers despite not being economies with low labour costs or having, a priori, apparent labour cost advantages in the world economy.

3.2. Second-order indicators: Dispersion forces

According to the first-order aggregate network indicators in Table 1, it seems clear that in 2009 the WATN continued showing a clear centre-periphery structure. However, it is also possible to appreciate that the *average nearest-neighbor degree* (ANND) is much higher than the a*verage node degree* and has increased slightly over time. This difference indicates that the central, highly connected countries are increasingly extending those relations towards poorly-connected countries. In other words, the automotive network is gradually expanding around the world, including new countries that traditionally did not use to actively take part in the network.

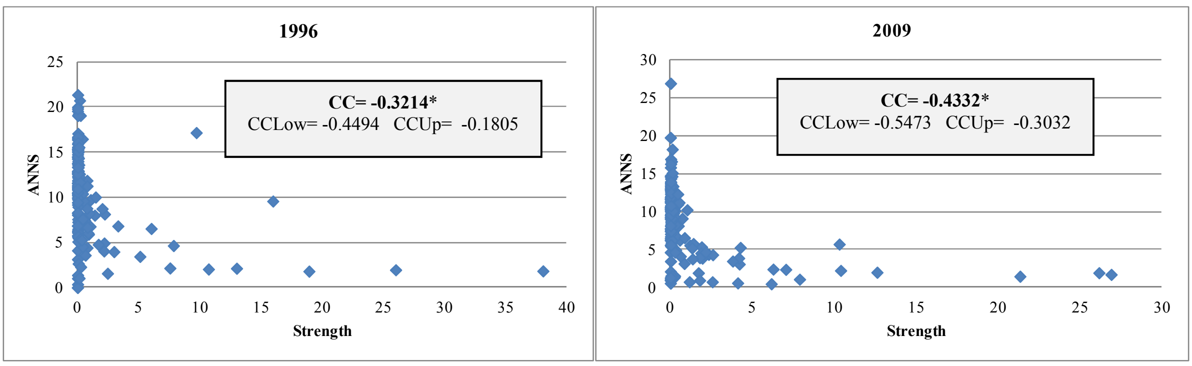
This is also confirmed by the moderate although gradually disassortative nature of the binary network insofar as the correlation between ANND and *node degree* is not very high (Figure 6). The directional analysis ratifies this disassortativity. Nevertheless, when the weighted network is considered, the correlation between *node strength* and the *average* *nearest-neighbor strength* (ANNS) is negative and increasing but fairly weak in magnitude (Figure 7). This means that partners of countries with intense relationships do not necessarily have intense trade links themselves. In other words, not all countries in the network have strengthened their links to the same degree; only one group of countries has intensified their flows. Additionally, the non-correlation between the *node degree* and the *weighted average nearest-neighbor degree* (WANND) indicates that well-connected countries' partners do not necessarily have intense trade links with all their partners. That is to say that what we perceive is an incipient strategy in which by expanding their production networks to new, low-trade countries, companies are trying to take advantage of scale economies and lower labour costs, especially for the most standardized and low added-value P&C, while the bulk of P&C is still produced and sold by a small number of central countries. With this strategy, companies are trying to minimize the spatial differentiation for those activities that are common to the whole range of products that they sell and that are concentrated in clustered locations near to the companies' headquarters and traditional large markets. At the same time, they are trying to differentiate their products to better fit their consumers' preferences and minimize transportation costs, so they are choosing to locate some parts of the process close to the final markets.

Figure 6. Correlation between *ANND* and Node *Degree* for P&C WATN (1996 and 2009)



Source: authors' calculation, based on UN COMTRADE. CCLow and CCUp are the correlation coefficients at 5% and 95% confidence intervals.

Figure 7. Correlation between *ANNS* and Node *Strength* for P&C WATN (1996 and 2009)



Source: authors' calculation, based on UN COMTRADE. CCLow and CCUp are the correlation coefficients at 5% and 95% confidence intervals.

Therefore, the analysis of the second-order relation measures indicates that even together with dominant agglomeration forces, the search for new and remote markets with high potential in terms of demand that would allow companies to avoid market saturation in traditional markets are acting as a powerful dispersion force. In the next section we analyse these centrifugal forces in more detail.

When we analyse the composition of the WATN centre in 2009 and compare it with that of 1996, we observe that, although the prominent countries in the networks have maintained their importance within the WATN, significant new players have entered that have redistributed the auto market.

In this vein, China had emerged overwhelmingly in the P&C network centre in 2009: it had risen to the top positions in all centrality indexes. Not only had it increased its links spectacularly over the period but those links were strong enough to overtake Germany in *outstrength* (see Table 3). It is also worth mentioning the escalating behaviour of Korea. This country was already highly connected in 1996 although its intensity was weak, but by 2009 its numerous trade links had translated into high export intensity. Additionally, some Eastern European countries, such as Hungary, Poland, and the Czech Republic have also gained importance in the P&C export network, forging numerous and intense trade links. Note that Poland and Hungary were among the most important intermediary economies in the network in 2009 and display two of the highest weighted hub-centrality scores (Table 2).

Therefore, in spite of this process of relocation towards new large and/or low-cost peripheral countries and the loss of production and trade flows among some core and traditional peripheral countries, we cannot say that we are witnessing a deindustrialization process in the sector *à la* Kuznets. When firms set up their operations in new places, they rarely abandon their home bases completely; they remain rooted there to serve the home market and to supplement offshore production through exports. Intermediate transportation costs and location hysteresis, plus the weight of history, play a prominent role in keeping companies tied to the same country (or region) for long periods of time. The existence of longstanding regional clusters that try to obtain the maximum agglomeration rents is clear evidence of this. What has happened is that these new groups of countries have joined the old clusters and the latter have created new links with them, expanding the scale and scope of the network. In 2009, some of these countries were part of the densest and most cohesive group of exporters, as revealed by the *k-core* analysis (Table 1).

Additionally, we should note that only large (huge in some cases) emerging markets with an intermediate level of development or economies that are very close to and/or integrated in large markets are being included in the more extensive and integrated auto network. In this sense, the market effect has maintained the traditional imbalances in the spatial distribution of the automotive industry.

This reorganization of the auto market that is balancing agglomeration and dispersion forces is observed in all factorial P&C networks (Table 5 and 6). Two common dynamics, regardless of factorial intensity, have been observed. The first is an intense transfer of activity from the United States and Japan to new economies, mainly Asian countries. As long as the North American and Asian networks are closely linked, the movement of their respective central countries has resulted in both regional networks experiencing parallel transformations. While this strategy is highly typical of American automakers, which tend to systematically break relational ties after the necessary collaborative engineering work with their suppliers has been accomplished and very frequently open re-bid processes in an effort to lower input costs, it signals a profound change in the strategy of Japanese automotive companies, which have traditionally been highly reluctant to move their production abroad and for whom predatory supplier switching used to be almost unheard of (Sturgeon *et al*., 2008). In fact, this outsourcing process has taken place in Japan later and less aggressively than among North American and even European carmakers. Nevertheless, in recent years, Japanese companies have been further expanding their already-high local capacity in North America and Europe and have relocated their plants to serve locally China, other South-East Asian countries, and other developing countries (Shimokawa, 2010).

As a result of those movements, over the period analysed, Korea and China have hosted important auto multinationals that have made them pure producers and exporters of P&C (see Table 4). Both countries are among the five countries with the highest weighted hub-centrality index (Table 2). Korea is also consolidating its position in the global network as an assembler and exporter of final goods, whereas given China's huge domestic market, for the time being most of the P&C it produces and imports are assembled inside the country and targeted at satisfying its own demand. Nevertheless, the high number of trade links that the country is creating leads us to expect the export market to be a future goal of the assemblers settled in China. Figures for *instrength* in Table 3 and import specialization indexes (see Table 4) indicate that the two Asian countries (and also Japan) relatively import and re-import very low amounts of components, attaching importance to the domestic component industry, which has traditionally been highly protective (Nag *et al*., 2007).

The second dynamic is a German-led extension of the European networks mainly towards the new EU members (also to China). Eastern European countries are coming to the fore in the automotive network by transforming imported P&C into other downstream P&C, which are either exported directly for assembly abroad or are assembled domestically into final goods and then exported from their territories. This is clearly the strategy of the Czech Republic. Other countries, such as Hungary, mainly transform imported P&C into higher added-value P&C, which are re-exported back for assembly.

Table 5. Main Destination and Origins of Automotive P&C. Central Countries in Automotive Network[a]

Automotive Total P&C																							
Germany								Japan								USA							
Exports				Import				Export				Import				Export				Import			
1996		2009		1996		2009		1996		2009		1996		2009		1996		2009		1996		2009	
UK	13,0%	FR	8,6%	FR	12,9%	CZ	10,2%	US	37,1%	CHN	20,6%	US	35,2%	CHN	43,7%	CA	46,3%	CA	35,9%	JP	28,2%	MX	24,8%
FR	10,1%	ES	7,1%	AT	12,3%	AT	8,8%	TH	9,6%	US	20,4%	DE	9,1%	KO	9,3%	MX	18,5%	MX	25,4%	CA	24,0%	CHN	22,9%
B&L	8,5%	UK	6,8%	IT	9,7%	HU	8,5%	UK	4,6%	TH	7,0%	CHN	8,4%	TH	8,1%	JP	4,6%	CHN	3,3%	MX	21,8%	CA	12,4%
ES	8,2%	US	6,7%	UK	9,6%	FR	8,0%	ID	4,2%	DE	4,0%	SE	6,6%	US	7,1%	KO	2,9%	DE	3,2%	DE	5,9%	JP	10,7%
US	7,2%	CHN	6,5%	ES	7,4%	PO	7,8%	DE	3,9%	KO	3,7%	TH	5,9%	DE	6,4%	DE	2,3%	UK	2,6%	BR	2,3%	KO	10,3%
IT	6,4%	AT	5,8%	JP	6,3%	IT	7,2%	HK	3,7%	CA	3,4%	PH	5,7%	PH	4,5%	UK	2,2%	JP	2,1%	FR	2,2%	DE	5,6%
AT	5,8%	B&L	5,3%	US	4,5%	UK	5,6%	CA	3,5%	UK	2,8%	MY	3,6%	ID	4,4%	AU	2,0%	AU	2,0%	CHN	2,2%	BR	1,3%
SE	5,0%	IT	5,2%	HU	4,4%	CHN	4,8%	KO	3,4%	MX	2,6%	KO	3,5%	MY	2,1%	BR	1,6%	VE	1,8%	UK	2,1%	UK	1,2%
NL	4,1%	CZ	4,9%	CZ	3,6%	ES	4,6%	SG	2,8%	ID	2,5%	FI	3,2%	FR	1,8%	AT	1,4%	BR	1,6%	KO	1,6%	FR	1,1%
CH	2,2%	PO	4,7%	PT	3,5%	SK	3,9%	AU	2,6%	BR	2,5%	UK	2,9%	UK	1,8%	HK	1,2%	FR	1,6%	IT	1,5%	IT	1,1%
PT	1,9%	HU	3,9%	B&L	3,4%	JP	3,3%	CHN	2,4%	FR	2,4%	IT	2,3%	MX	1,5%	B&L	1,2%	KO	1,3%	SE	0,8%	TH	1,0%
MX	1,9%	MX	3,4%	NL	2,7%	RO	3,1%	B&L	1,6%	AE	2,0%	ID	2,1%	NL	1,2%	FR	1,2%	SG	1,1%	TH	0,7%	MY	0,7%

[a]Argentina (AR); Australia (AU); Austria (AT); Belgium-Luxembourg (B&L); Brazil (BR); Canada (CA); China (CHN); Colombia (CO); Czech Rep.(CZ); Denmark (DK); El Salvador (SV); Finland (FI); France (FR); Germany (DE); Honduras HN); Hong Kong (HK); Hungary (HU); Indonesia (ID); Israel (IL); Italy (IT); Japan (JP); Malaysia (MY); Mexico (MX); Netherlands (NL); Panama (PA); Philippines (PH); Poland (PL); Portugal (PT); Korea (KO); Romania (RO); Russian F. (RU); Saudi Arabia (SA); Singapore (SG); Slovakia (SK); Slovenia (SI); Spain (ES); Sweden (SE); Switzerland (CH); Thailand (TH); Tunisia (TN); U.A. Emirates (AE); United Kingdom (UK); USA (US) and Venezuela (VE).

Source: authors' calculation, based on UN COMTRADE

Table 6. Parts and Components Automotive Subnetworks

	1996				2009			
	Mainstream Driven Parts and Components Network							
	Outdegree	Outstrength	Indegree	Instrength	Outdegree	Outstrength	Indegree	Instrength
China	32	1.94	6	1.07	152	13.68	5	5.19
Germany	116	19.34	10	8.60	114	17.89	14	9.89
Japan	128	18.03	8	2.78	109	12.33	6	2.71
USA	103	19.12	8	15.30	100	12.87	7	13.37
Italy	89	7.37	7	4.01	78	5.72	10	3.33
Korea	87	2.20	4	1.96	72	3.39	5	1.85
France	94	8.07	8	6.02	69	5.54	10	5.27
UK	94	5.87	8	5.12	49	3.12	9	3.73
Belg.& Lux.	30	2.18	8	3.18	38	2.61	11	3.31
Thailand	23	0.92	5	1.43	32	1.80	8	1.11
Netherland	35	1.80	9	2.99	29	1.32	10	2.25
Poland	6	0.03	9	0.77	24	1.89	6	1.58
Spain	29	2.53	5	3.00	22	2.59	9	2.49
Czech Rep.	10	0.54	6	0.77	17	2.64	8	1.64
Mexico	7	2.42	3	3.52	11	3.09	6	3.41
Canada	4	3.86	2	6.95	7	2.48	4	4.59
	Capital Intensive Parts and Components Network							
Germany	120	20.52	9	6.95	119	24.30	11	9.60
Japan	125	17.57	7	1.25	113	13.32	9	1.80
China	7	0.12	4	1.12	110	4.79	4	6.01
USA	101	21.90	5	17.61	91	10.69	6	13.88
France	75	10.07	7	4.80	78	8.49	8	4.98
Italy	80	4.53	7	2.27	67	4.54	8	2.66
UK	89	4.00	7	9.64	54	1.77	8	4.25
Korea	23	0.51	3	1.35	45	3.33	6	1.53
Spain	19	3.48	5	5.54	37	3.44	6	5.69
Belg.& Lux.	29	1.92	8	4.99	34	1.74	9	3.43
Poland	5	0.03	6	0.56	17	2.93	7	2.20
Sweden	23	1.90	7	2.27	17	0.84	9	1.67
Czech Rep.	8	0.38	6	0.45	13	3.07	7	2.11
Mexico	1	2.39	4	5.38	11	5.00	5	5.32
Canada	6	6.44	2	12.93	3	3.17	4	6.62
	Labour Intensive Parts and Components Network							
China	17	1.85	5	0.62	140	14.59	5	3.27
Germany	114	18.47	11	10.49	108	16.19	11	13.93
Japan	118	11.28	8	2.84	96	9.05	9	2.90
Italy	99	7.91	7	2.77	86	6.35	9	2.64
USA	90	15.21	5	20.05	85	7.69	5	19.29
France	73	6.75	7	5.74	67	5.37	9	5.52
UK	75	4.25	8	5.66	41	0.39	10	4.80
Poland	7	0.62	7	2.40	25	4.71	7	1.94
Belg.& Lux.	21	3.24	8	4.81	22	1.73	10	3.37
Czech Rep.	13	1.71	6	0.69	21	4.45	7	1.70
Austria	13	1.42	8	2.33	19	2.20	7	1.28
Mexico	9	7.46	3	3.31	18	9.00	6	3.68
Spain	20	2.57	5	3.71	17	2.24	7	2.66
Hungary	4	0.85	5	0.36	13	1.61	8	1.24
Canada	9	6.82	3	9.54	9	2.85	4	4.83
Slovakia	1	0.07	6	0.13	8	2.97	10	0.94
	Technology Driven Parts and Components Network							
China	17	3.137	6	1.926	156	34.326	6	2.142
Korea	17	0.639	5	1.715	87	12.491	4	0.887
USA	122	18.082	5	23.299	71	5.088	4	22.4107
Germany	97	11.027	10	8.344	59	4.149	8	8.007
Hungary	7	1.880	6	0.318	57	7.512	8	1.444
India	11	0.046	8	0.068	49	1.476	4	1.963
Finland	43	2.425	7	0.452	47	2.213	5	0.923
Japan	109	15.146	6	3.027	45	2.187	6	3.256
France	72	5.123	11	3.437	41	1.573	9	3.913
UK	77	4.422	9	2.392	35	3.208	10	4.097
Sweden	57	7.167	10	1.176	25	1.227	8	0.572
Mexico	8	12.430	1	3.590	24	8.151	6	4.006
Spain	15	2.639	6	5.501	11	0.608	11	3.132
Austria	8	2.699	6	1.181	7	2.041	9	0.942
Poland	0	0.000	8	0.911	7	1.728	8	1.570
Canada	18	3.985	3	9.025	4	2.240	5	3.648

In general, the new countries that have joined the network over the last decade have rapidly migrated from simple labour-intensive P&C to more sophisticated technology-driven P&C. In consequence, global sourcing has caused the list of top suppliers to become more regionally balanced. However, we have observed how most developed countries, Germany in particular, have kept the production of capital-intensive products at home, which are relatively more complex and tend to have higher transaction costs.

The above analysis also reveals certain dispersion in the final goods network, in the same direction as that for auto P&C, with some emerging economies that are increasing their presence in the P&C also doing so in the final goods markets. This is the case with the Czech Republic, Poland and Brazil. However, it should also be noted that countries with a scant presence in P&C markets, such as Turkey and Argentina, are also gaining ground as final exporters. This is a common pathway in the expansion of the auto network: new countries first host assembly activities and then increase their production of auto P&C. In this process, in contrast to many other industries, in most emerging countries the agglomeration of the final sector in a particular new country (or region) does not occur because there was a previous concentration of the P&C industry in the same country or region; instead, final assembly is often the first step, while the development of a P&C sector comes later (Sturgeon and Van Biesebroeck, 2011). The relational linkages and the follow-sourcing strategy in the automotive industry then foster a circular process *à la* Myrdal (more than in other industries) in which market size and the intermediate transportation costs are the key factors. For this reason, those countries that are geographically close to large existing markets or that are large or rich enough to support vehicle assembly are becoming intermediaries in the production of certain P&C that can be exported to the rest of the world. At the same time, these new peripheral economies offer both growing domestic markets for final automotive products and low-cost production sites as workers, with strong incentives from the installation of new manufacturing companies, become more skilled and earn higher salaries, which is again a market expansion force, at least while the gap in costs between the core and periphery remains sufficiently large (Toulemonde, 2006).

4. Concluding Remarks

In this empirical paper, we have examined the evolution of the spatial distribution of economic activities for the automotive industry in the light of some of the assumptions and results obtained from New Economic Geography. For this purpose, instead of traditional equilibrium models, we have applied the tools of Social Network Analysis and graph theory to international trade flows of 172 countries for the years 1996 and 2009. In the analysis we have also distinguished the P&C auto network and the final auto goods network.

As predicted by the NEG, we have found that the structure and evolution of the world auto trade network is determined by the balance between two types of opposing and mutually reinforcing forces: agglomeration (or centripetal) and dispersion (or centrifugal) forces. Thus we have observed that over time the network has maintained a center-periphery structure in which regional, more than global, clusters have arisen and hubs are becoming increasingly important. We have detected two main agglomeration forces as drivers of this structure. Firstly, a very strong market effect, whereby companies seek access to large and/or rich markets in order to exploit the advantages of the international division of labour and minimize the intermediate transportation costs pertaining to the auto industry. And secondly, the relational form of the linkages between P&C suppliers and between them and the final auto goods assemblers that has fostered the synchronized structural evolution of the final and P&C networks, making both of them more centered.

Furthermore, over time, the companies' search for new and high-potential markets that, simultaneously, offer low production costs, hence enabling them to avoid the market saturation and fierce competition of the traditional market, is acting as a powerful dispersion force, leading the auto network to expand around the world. New countries, such as China, other Asian countries and some Eastern European countries, have entered the central nucleus of the world auto trade network, redistributing the market. However, factors such as transportation costs and location hysteresis are playing a prominent role in keeping companies tied to traditional central countries. Therefore, what has happened is that new countries have joined the old clusters, thus expanding the scale and scope of the network.

As a result, we can conclude that although agglomeration forces clearly prevail in the world auto trade network and spatial imbalance remains, centrifugal forces are expanding the network around new areas. This development is likely to foster a process *à la* Myrdal that, in turn, will boost the expansion of the auto network in the coming years.

STATISTICAL APPENDIX

Table A1. Countries included in the analysis

Afghanistan	Croatia	Italy	Philippines	Uruguay
Albania	Cuba	Jamaica	Poland	USA
Algeria	Cyprus	Japan	Portugal	Uzbekistan
Angola	Czech Rep.	Kazakhstan	Qatar	Venezuela
Argentina	Dem. People's Rep. of Korea	Kenya	Rep. of Korea	Yemen
Armenia	Denmark	Kuwait	Rep. of Moldova	Zambia
Aruba	Djibouti	Kyrgyzstan	Romania	Zimbabwe
Australia	Dominican Rep.	Lao People's Dem. Rep.	Russian F.	SACU
Austria	Ecuador	Latvia	Rwanda	
Azerbaijan	Egypt	Lebanon	Samoa	
Bahamas	El Salvador	Liberia	San Marino	
Bahrain	Equatorial Guinea	Libya	Saudi Arabia	
Bangladesh	Eritrea	Lithuania	Senegal	
Barbados	Estonia	Madagascar	Serbia	
Belarus	Ethiopia	Malawi	Serbia-Montenegro	
Belgium-Luxembourg	Finland	MY	Seychelles	
Belize	France	Mali	Sierra Leone	
Benin	Kiribati	Malta	SG	
Bermuda	French Polynesia	Mauritania	SK	
Bhutan	FS Micronesia	Mauritius	Slovenia	
Bolivia	Gabon	Mexico	Somalia	
Bosnia Herzegovina	Gambia	Mongolia	Spain	
Brasil	Georgia	Montenegro	Sri Lanka	
Brunei Darussalam	Germany	Morocco	Sudan	
Bulgaria	Ghana	Mozambique	Suriname	
Burkina Faso	Greece	Myannmar	Sweden	
Burundi	Greenland	Nepal	Switzerland	
Cambodia	Guatemala	Netherlands	Syria	
Cameroon	Guinea	New Caledonia	Tajikistan	
Canada	Guinea-Bissau	New Zealand	Macedonia	
Cape Verde	Guyana	Nicaragua	Thailand	
Cayman Isds	Haiti	Niger	Timor-Leste	
Central African Rep.	Honduras	Nigeria	Togo	
Chad	Hungary	Norway	Trinidad- Tobago	
Chile	Iceland	Oman	Tunisia	
China	India	Pakistan	Turkey	
China, Hong Kong SAR	Indonesia	Panama	Turkmenistan	
China, Macao SAR	Iran	Papua New Guinea	Uganda	
Colombia	Iraq	Papua New Guinea	U.A. Emirates	
Congo	Ireland	Paraguay	United Kingdom	
Costa Rica	Israel	Peru	United Rep. of Tanzania	

**SACU: Southern African Custom Union: South Africa, Botswana, Namibia, Swaziland, Lesotho.*

Table A2. Automotive Commodities included in the analysis

Final Goods	Auto Parts and Components			
	Mainstream	***Technology Driven***	***Labour Intensive***	***Capital Intensive***
870310	700711	870600	870710	870810
870321	700721	851993	870790	870821
870322	700910	852520	940120	870829
870323	830210	852721	940190	870831
870324	830230	852729	940390	870839
870331	870990	853641	871690	870840
870332	400950	854430	851110	870850
870333	681310	902910	851120	870860
870390	681390	902920	851130	870870
870421	731816	902990	851140	870880
870422	732010	840734	851150	870893
870423	732020	840820	851180	870894
870431	842139	840731	851190	870899
870432	848210	840732	851220	840991
870490	848220	840733	851230	840999
870510	848240	381900	851240	870891
870520	848250	382000	851290	870892
870530	841520		853180	
870540	841583			
870590	841590			
870210	850132			
870290	850710			
870120	850730			
870130	850790			
870110	853910			
870190	853921			
842710	401693			
870410	841330			
	841391			
	841430			
	841459			
	842123			
	842131			
	848310			
	840890			
	401110			
	401120			
	401210			
	401220			
	401310			
	401699			
	842549			
	842691			
	843110			

Table A3. Definition of Topological Measures

Binary Network			Weighted Network		
Index	**Definition**	**Parameters**	**Index**	**Definition**	**Parameters**
Density	$\Delta = \frac{L}{N(N-1)}$	L: Number of arcs N: Number of nodes			
Node Degree	$k_i \equiv \sum_{j \neq i} a_{ij}$	$a_{ij} \equiv \Theta\left[w'_{i,j}(t)\right]$	**Node Strength**	$s_i^i \equiv \sum_{j \neq i} w'_{ij} = \frac{s_i}{w_{tot}}$	$w'_{ij}(t) \equiv \frac{w_{ij}(t)}{w_{tot}(t)}$ $w_{tot}(t) \equiv \sum_i \sum_{j \neq i} w_{ij}(t)$
Outdegree	$k_i^{out} \equiv \sum_{j \neq i} a_{ij}$		**Outstrength**	$s_i^{out} \equiv \sum_{j \neq i} w'_{ij} = \frac{s_i^{out}}{w_{tot}}$	
Indegree	$k_i^{in} \equiv \sum_{j \neq i} a_{ji}$		**Instrength**	$s_i^{in} \equiv \sum_{j \neq i} w'_{ji} = \frac{s_i^{in}}{w_{tot}}$	
Average Nearest-Neighbor Degree (ANND) in-in	$k_i^{in/in} \equiv \frac{\sum_{j \neq i} a_{ji} k_j^{in}}{k_i^{in}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ji} a_{kj}}{\sum_{j \neq i} a_{ji}}$		**Average Nearest-Neighbor Strength (ANNS) in-in**	$s_i^{in/in} \equiv \frac{\sum_{j \neq i} a_{ji} s_j^{in}}{k_i^{in}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ji} w'_{kj}}{\sum_{j \neq i} a_{ji}}$	
ANND in-out	$k_i^{in/out} \equiv \frac{\sum_{j \neq i} a_{ji} k_j^{out}}{k_i^{in}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ji} a_{jk}}{\sum_{j \neq i} a_{ji}}$		**ANNS in-out**	$s_i^{in/out} \equiv \frac{\sum_{j \neq i} a_{ji} s_j^{out}}{k_i^{in}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ji} w'_{jk}}{\sum_{j \neq i} a_{ji}}$	
ANND out-in	$k_i^{out/in} \equiv \frac{\sum_{j \neq i} a_{ij} k_j^{in}}{k_i^{out}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ij} a_{kj}}{\sum_{j \neq i} a_{ij}}$		**ANNS out-in**	$s_i^{out/in} \equiv \frac{\sum_{j \neq i} a_{ij} s_j^{in}}{k_i^{out}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ij} w'_{kj}}{\sum_{j \neq i} a_{ij}}$	
ANND out-out	$k_i^{out/out} \equiv \frac{\sum_{j \neq i} a_{ij} k_j^{out}}{k_i^{out}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ij} a_{jk}}{\sum_{j \neq i} a_{ij}}$		**ANNS out-out**	$s_i^{out/out} \equiv \frac{\sum_{j \neq i} a_{ij} s_j^{out}}{k_i^{out}} = \frac{\sum_{j \neq i} \sum_{k \neq j} a_{ij} w'_{jk}}{\sum_{j \neq i} a_{ij}}$	
ANND tot-tot	$k_i^{tot/tot} \equiv \frac{\sum_{j \neq i} (a_{ij} + a_{ji}) k_j^{tot}}{k_i^{tot}}$	$k_i^{tot} \equiv k_i^{in} + k_i^{out}$	**ANNS tot-tot**	$s_i^{tot/tot} \equiv \frac{\sum_{j \neq i} (a_{ij} + a_{ji}) s_j^{out}}{k_i^{tot}}$	

Table A3. Definition of Topological Measures (cont.)

Binary Network			Weighted Network		
Index	**Definition**	**Parameters**	**Index**	**Expression**	**Parameters**
			Weighted Average Nearest-Neighbor Degree (WANND)	$WANND_i = \frac{\sum_j \sum_h w'_{ij} a_{jh}}{s_i}$	
Degree Centralization ♣	$C_D = \frac{\sum_{i=1}^{N}(k^* - k_i)}{(N-1)(N-2)}$	♣ To calculate the group-level index of indegree or outdegree centralization, the denominator of expression is $(N-1)^2$. *k**: the largest observed degree			
Closeness Centrality	$CL_i = \frac{(N-1)}{\left[\sum_{i=1}^{N} d(i,j)\right]}$	*d*(*i*,*j*):number of lines in the geodesic linking actors			
Betweenness Centrality	$RWBC_i = \frac{\sum_o \sum_{o \neq t} I_i(o,t)}{N(N-1)}$	o: node "source" t: node "target" $v(o,t)) = [D - A]^{-1} f(o,t)$ $D = diag(k)$ $[D-A]^{-1}$ computed using Moore-Penrose pseudo-inverse. f(o,t) the "source" Nx1 vector such that $f_i(o,t)=1$ if *i*=o, $f_i(o,t)=-1$ if *i*=t; 0 otherwise. $I_i(o,t) = \left[\sum_j A_{ij} \lvert v_i(o,t) - (v_j(o,t)) \rvert\right]$	**Weighted Betweenness Centrality (RWWBC)**	$RWWBC_i = \frac{\sum_o \sum_{o \neq t} I_i(o,}{N(N-1)}$	o: node "source" t: node "target" $v(o,t)) = [D - W]^{-1} f(o,t)$ $D = diag(s)$ $[D-W]^{-1}$ computed using Moore-Penrose pseudo-inverse. f(o,t) the "source" Nx1 vector such that $f_i(o,t)=1$ if *i*=o, $f_i(o,t)=-1$ if *i*=t; 0 otherwise. $I_i(o,t) = \left[\sum_j W_{ij} \lvert v_i(o,t) - (v_j(o,t)) \rvert\right]$
Betweenness centralization	$\boldsymbol{BCN} = \frac{\sum_{i=1}^{N}[\boldsymbol{RWBC}(\boldsymbol{i}^*) - \boldsymbol{RWBC}(\boldsymbol{i})]}{(\boldsymbol{N}-1)}$	*RWBC* (i*): the largest realized actor RWBC index for the set of actors.			
HITS algorithm	$I\ operation: x^{\langle i \rangle} \leftarrow \sum_{j:(j,i) \in E} y^{\langle j \rangle}$ $O\ operation: y^{\langle i \rangle} \leftarrow \sum_{j:(i,j) \in E} x^{\langle j \rangle}$	$G(V,E)$*: directed graph* *V: set of countries i, j, and E: set of directed edges between countries*→$E = \{(i,j)\}$ |*i, j* ∈*V* & $i \neq j$ Country *i* associate a non-negative *authority* weight $x^{\langle i \rangle}$ and a non-negative *hub* weight $y^{\langle i \rangle}$ The weights are normalized so their squares sum to 1: $\sum_{i \in V}(x^{\langle i \rangle})^2=1$, and $\sum_{i \in V}(y^{\langle i \rangle})^2=1$ Countries with larger x- and y-values being "better" authorities and hubs respectively. If *i* points to many countries with large x-values, then it should be receive a large y-value; and if *i* is pointed to by many countries with large y-values, then it should be to receive a large x-value.			

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