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The core of the global corporate network

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FINMAP –

**FINANCIAL DISTORTIONS AND MACROECONOMIC
PERFORMANCE: EXPECTATIONS, CONSTRAINTS AND
INTERACTION OF AGENTS**

DATE: 02/23/2016

TITLE

The Core of the Global Corporate Network

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Keywords: board and director interlocks, network core, network formation
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The Core of the Global Corporate Network *

Ricardo Giglio[†] and Thomas Lux^{†‡§}

February 22, 2016

Abstract

We investigate the network topology of a comprehensive data set of the world-wide population of corporate entities. In particular, we have extracted information on the boards of all companies listed in Bloomberg's archive of company profiles in October, 2015, a total of almost 100,000 firms. We provide information on board membership overlap at various levels, and, in particular, show that there exists a core of directors who accumulate a large number of seats and are highly connected among themselves both at the level of national networks and at the worldwide aggregated level.

Keywords: board and director interlocks, network core, network formation
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1 Introduction

The structure and formation of corporate networks has intrigued researchers from diverse scientific fields and the public in general for a long time. Corporate governance structures can be cast into the format of a network due to the fact that often members of a corporate board are serving on the boards of two or more companies, thus generating a network of connections between different companies. This network has been characterized as belonging to the class of *small world networks*. Consequently, only a few degrees of per-

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sonal connections are necessary to transverse the whole network¹. Some questions naturally arise: Are the network structures the result of purposeful creation of links by some influential elite? Or are they just unintended outcomes from multiple individual and isolated choices? Regardless of the academic discussion, there is also a growing public concern that a relatively small group of people have close personal inter-connections while managing/controlling together a large share of the world economy.

The basic empirical question posed by these different viewpoint is whether there is something unexpected in the network structure of board interlocks, i.e. structural features that could not be explained by a simple null model and that would require the development of more involved sociological and/or economic models of how firms choose their board members with an eye on their connections to other boards. [2] have reported strong evidence that the existence of a well connected *core* (the most highly connected component) of the German corporate network cannot be explained just by random coincidences of directors being assigned multiple positions by different companies by chance. In an update, [3] also emphasize that this unlikely concentration of multiple positions within a single subset of the largest companies survives over time, irrespective of the change of personal and even the entry and exit of firms to and from the corporate core of the economy.

Any finding of significant clustering of interlocks would, of course, only establish an empirical fact that needs to be explained. It would not yet provide an answer as to what the reasons of such a concentration of power in corporate governance structures are. Possible explanations fall into various categories: (i) corporate social interlocks could be a result of favoritism and thus would reflect existing personal relationships in the elitistic circle of a society, (ii) joint board positions could be an effective way of learning about managerial practices or (iii) could be a reflection of material entanglement of interests between firms, such as a link with its corporate clients, or firms along a supply chain. Finally (iv) board interlocks could just be the imprint of certain individuals with extraordinary capabilities as supervisors being in high demand so that they receive multiple offers to serve on corporate boards. Any of the more economically oriented explanations should, in principle, be testable by scrutinizing the hypothesis of a link between board overlaps and firm performance. However, empirical evidence on this issue is mixed [4], and some studies did rather find a negative effect of busy directors on performance criteria (such finding would be in line with decreasing returns to supervision but would demand a non-economic explanation for

¹[1] illustrates the short distances within this network with the observation that a flu virus infecting the J.P. Morgan Chase board in January could spread to 80% of the Fortune 1000 by May through monthly board meetings alone.

why interlocks exist in the first place despite the inefficiency of overburdened holders of multiple seats).

The present paper contributes to the phenomenology of the corporate board interlocks. In particular, we revisited the network properties of corporate boards using a nearly comprehensive worldwide database. Namely, we have gathered all board members listed in Bloomberg’s archive of company profiles. The number of companies for which board information is available, amounts to almost 100,000. This is more than twice the number of listed companies worldwide. Although it seems impossible to spell out by what criteria their large data have been constructed from the even larger universe of all corporate entities worldwide, it is likely that it covers completely all firms beyond a certain size in countries that are integrated in the world economy to a certain degree and that it might constitute a more incomplete sample of the lower end of the size distribution of firms. However, we are mainly interested in those companies whose boards have overlaps with other firms and are not completely isolated. Their number in the database is almost 82,000 and since these will be the more visible ones it seems likely that the data base covers this interesting subsample to a very large extent, if not almost completely.

The paper proceeds as follows: The following section provides information on the data set used and some descriptive statistics. Sec. 3 investigates interlocks within and between countries. It is shown that there is a significant concentration of multiple positions at all levels of aggregation. It is also found that international overlaps are much more common for European countries than for Asian and American countries. Sec 4 shows that data are also characterized by a *rich club effect*, i.e. board members with a high number of simultaneous positions are significantly more likely to be connected with each other than expected under a random benchmark. Sec. 5 concludes.

2 Data description

Data was collected from the *Bloomberg* website in October 2015. More specifically, board membership information both from public and private companies was collected from specific pages such as <http://www.bloomberg.com/markets/api/management/board/DBK:GR> for Deutsche Bank, as an example. Other company specific information (such as address and sector classifications) were collected from pages such as <http://www.bloomberg.com/markets/api/quote-page/DBK:GR>, again for Deutsche Bank as an example. Board members of all companies listed were extracted and links between

boards via common members have been established. The complete list of companies is available in the <http://www.bloomberg.com/robots.txt> web file.

Board membership information was represented by means of incidence matrices, which allow for the calculation of network measures. Two directors are said to be connected if they hold seats in the same company, and two companies are said to be connected if at least one common director serves on their boards. This network can be analyzed in its bipartite form, and it can be transformed into a unipartite network of overlaps considering either directors or companies as nodes. In both cases, the incidence matrix M is the same, and the respective adjacency matrices can be computed by the projections $D = MM^T$ and $C = M^T M$.

A particular feature of the network of board affiliations D is the existence of node communities by construction (the boards), resulting in complete subgraphs in which all nodes (the board members) are connected to each other. This feature has an impact on some specific network properties: the existence of such communities produces trivially high average clustering coefficients, for example. In addition, the degree of a board member depends on the size of the boards in which she/he has a position. Hence, two members in equally connected but differently sized boards could have different degrees.

To alleviate this particular feature, we restricted attention to the more interesting cases of directors who serve in at least two boards. The subgraph formed by the network of board members holding at least $b = 2$ positions (referred to as D_2) keeps all important information with regard to overlaps in the entire network, but removes the influence of different board sizes. Thus, here only the network of members holding multiple (at least two) positions is considered. It is worthwhile to note that this definition of b -core (b for board positions) is different from that of k -core (k for degree). A k -core (or k -degenerate graph) is the (unique) maximal induced subgraph with nodes of a minimum degree of at least k . Alternatively, the k -core is the (unique) result of iteratively deleting nodes that have degree less than k , in any order.

The total number of companies in Bloomberg's database is 1,832,936 of which 66,375 (3.6%) are publicly listed, representing 99% of world's market capitalization. However, there is no board information for the majority of non-listed companies, neither for some of the listed companies. The total number of companies with board management information is 98,658 of which 60,631 (61.4%) are public and 38,027 (38.6%) are private. The number of not completely isolated companies falls to 71,562 in total, divided in 51,256 (71.6%) public and 20,306 (28.4%) private companies. When considering only the largest connected component of C there are 58,352

companies, of which 42,026 (72%) are public and 16,326 (28%) are private.

In total, there are 311,939 board members holding 586,382 board positions, yielding an average number of board positions of 1.87. If completely isolated directors are excluded (that is, members of a disconnected board), 299,982 directors with at least one connection remain. If considering only those directors holding at least two board positions (these are responsible for the links between companies), 102,901 directors remain. In addition to these restrictions, when only the largest connected component (LCC) of D_2 is considered, 85,046 directors remain.

These raw numbers show that engaging in board interlocks is not an activity of public companies only, but rather that there is a strong interaction between them and the private companies. Available records cover companies from 156 countries, but with a high degree of concentration of companies among a small set of them. For instance, more than 90% of the companies are from only 23 countries. The five countries hosting most companies are (in order of their number of companies) United States, Canada, United Kingdom, Japan, and China.

Table 1: Number of nodes and edges, average degree and shortest path length (\bar{L}), diameter, radius, density, number of triangles and average clustering coefficient (\bar{C}) for the LCC of the network of companies C , and for the networks of companies from selected countries.

Network	$LCC(C)$	US	UK	DE	FR	BR	RU	IN	CN
nodes	58,352	22,423	8,739	2,189	3,274	874	1,005	3,335	6,733
edges	454,352	121,227	44,507	14,916	25,958	5,273	6,41	14,09	29,776
\bar{deg}	15.57	10.81	10.19	13.63	15.86	12.07	12.76	8.45	8.84
\bar{L}	7.17	6.34	7.43	5.64	5.07	5.07	5.16	5.11	6.83
Diam.	26	26	31	17	18	12	13	15	23
Rad.	14	14	16	9	9	7	7	8	12
Dens.	0.0003	0.0005	0.0012	0.0062	0.0048	0.0138	0.0127	0.0025	0.0013
Triang.	5,953,893	956,952	394,665	237,042	386,451	58,263	81,21	104,436	237,501
\bar{C}	0.55	0.48	0.54	0.61	0.64	0.72	0.67	0.45	0.51

All those networks, national or global, feature the most common symptoms of small-worldness: communities, short diameters and average shortest path lengths. Table 1 presents some basic statistics for the LCC of the network of companies C , and also for selected countries. In addition, Table 2 presents a comparison between an Erdős-Rényi(m,n) random network $ER(m,n)$ with the same number of nodes and edges as the LCC of C , showing that the empirical number of triangles is several orders of magnitude higher than one might expect if edges were created randomly between existing nodes. Hence, local clustering (i.e. interlocks) is a pervasive feature of this network (recall that we have at this stage already removed the built-in clustering of

the board structures).

Table 2: Comparison between an $ER(n, m)$ random network with the same number of nodes and edges of the LCC of C , showing that the empirical number of triangles is of several orders of magnitude higher than one might expect if edges are created randomly between existing nodes.

	Global (LCC of C)	$ER(n, m)$
Nodes	58,352	58,352
Edges	454,352	454,352
Average degree	15.57	15.57
Density	0.0003	0.0003
Triangles	5,953,893	1,968
Average clustering coefficient	0.55	1.40e-4

3 Interlocks within and between countries

3.1 National Cores

With respect to German board membership data collected for several years, [2] point out that the pattern of accumulation of board positions by single individuals cannot be plausibly seen as a chance outcome of random draws from the pool of directors for filling the excess of board positions over the number of directors. Thus, there seem to be systematic tendencies at work responsible for the fact that a small number of individuals assembles a comparatively high number of simultaneous board positions.

Here we test whether this degree of concentration of positions is statistically significantly different from what one would get under random assignment of director positions to the pool of individuals (which by construction would mean that with X directors assigned to Y board positions and $X < Y$, a certain number of persons had to end up with multiple positions). The random benchmark used, and reproduced here, considers the Binomial probability of observing multiple board membership in an independent sequence of k Bernoulli trials with probability p , with k and p given by, respectively, the number of board positions minus the number of directors and one over the number of directors, as shown in eq. 1.

$$P(X = k) = \binom{k}{b} p^b (1 - p)^{k-b} \quad (1)$$

Figs. 1 and 2 show the relative frequency of empirical observations of multiple board membership (red circles) and the random binomial benchmark

(blue crosses) for eight selected countries. The semi-log scale reveals deviations of increasing orders of magnitude for $b > 3$, confirming that the characteristic feature presented in [2] for German data can also be seen for other (both developed and emerging) economies. Figure 3 shows that the same relation also holds for different perspectives on the global network of board members. Table 3 presents the number of directors and positions, and the values of k and p for the same selected countries and the global network.

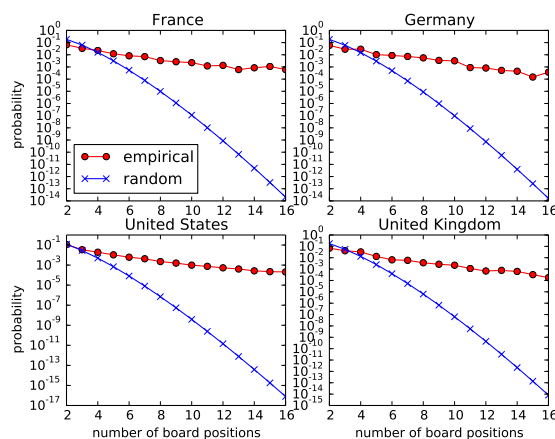


Figure 1: Relative frequency of empirical multiple board membership (red circles) and the random binomial benchmark (blue x's) for four selected developed countries.

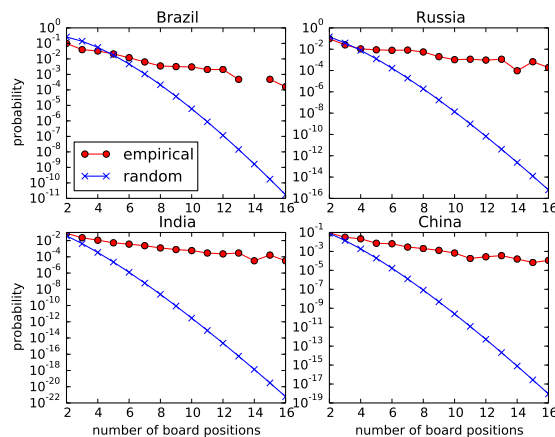


Figure 2: Relative frequency of empirical multiple board membership (red circles) and the random binomial benchmark (blue x's) for the so-called BRIC countries.

Table 3: Number of directors, positions, and values of k and p for eight selected countries and the global network. In total, there are 311,939 board members holding 586,382 board positions (A), resulting in an average number of board positions of 1.87. If completely isolated directors are excluded (that is, the only member of a disconnected board), 299,982 directors with at least one connection remain (B). If considering only those directors holding at least two board positions (these are the responsible for the links between companies), 102,492 directors remain (C). In addition to these restrictions, when only the LCC of D_2 is considered, 85,046 directors remain (D).

Network	Directors	Positions	k	p
Global (A)	311,939	586,382	274,443	3.20e-06
Global (B)	299,982	573,920	273,938	3.33e-06
Global (C)	102,492	376,430	273,938	9.75e-06
Global (D)	85,046	334,165	249,119	1.17e-05
Germany	6,742	13,453	6,711	1.40e-04
France	8,114	16,346	8,232	1.23e-04
United States	79,442	135,047	55,605	1.25e-05
United Kingdom	17,297	33,737	16,440	2.27e-04
Brazil	2,362	6,137	3,775	4.23e-04
Russia	5,827	10,491	4,664	9.79e-04
India	22,178	29,219	7,041	4.50e-05
China	27,906	42,455	14,549	3.58e-05

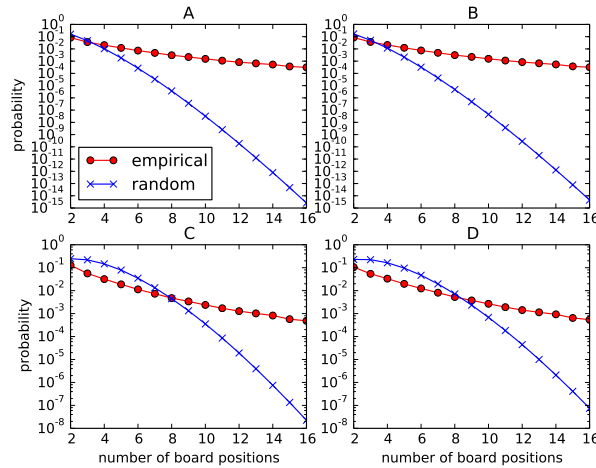


Figure 3: Binomial benchmark and empirical frequencies of multiple board positions. (A) all directors, (B) directors with at least one connection, (C) directors holding at least two board positions, and (D) only the LCC is considered.

3.2 Interlocks between countries

According to [5], the literature provides support for the idea that within each advanced capitalist country the directors of the largest corporations form close communities. In this section, international interlocks are analyzed, that is, the fact that some directors serve on boards of different nationalities. In the remainder of this section, a network is defined with countries as nodes, and weighted edges defined by the number of directors holding simultaneous positions in companies from both countries. In this sense, directors whose positions are restricted to companies of the same country are discarded. Figure 4 illustrates this network and its most important actors (nodes are sized and colored by their corresponding eigenvector centralities). The network is composed of 156 nodes (countries), 1,912 weighted edges summing up to 53,074 connections. This very dense network shows that in fact all countries represented in Bloomberg’s data set, are connected to some other countries via international board overlaps. We observed that the largest industrialized countries in Europe and North America assume the most central positions together with Hong Kong, China and India.

Table 4 presents a different perspective, not based on centrality, but rather on the relation between national and international interlocks. The first column shows the fraction of foreign interlocks over all multiple board positions of directors on the board of any country, while the second shows the normalized Shannon entropy of the distribution of connections as a measure of how diversified or *globalized* a country is in its interlocks with other countries. The normalized Shannon entropy of a discrete random variable X with N possible values x_1, \dots, x_n and probability mass function $P(X)$ is given by

$$H(X) = \frac{-\sum_{n=1}^N P(x_i)\log(P(x_i))}{\log(N)} \quad (2)$$

where H ranges from 0 (when all connections have the same country as an end-point) to 1 (when the connections are equally distributed among all countries). In order to avoid that very small countries (such as Myanmar, Gabon, and Oman) dominate the top of the list (sorted by ratio between foreign and domestic interlocks) only because they have very few companies, we have arbitrarily removed all countries with less than 400 personal interlocks.

The highest fraction of interlocks is observed for smaller European countries: Luxembourg, The Netherlands, Switzerland, and Belgium. However, also larger European countries like Germany, France and Italy are characterized by a relatively high degree of international interconnectedness of their business elite whereas the lower half of the spectrum is exclusively

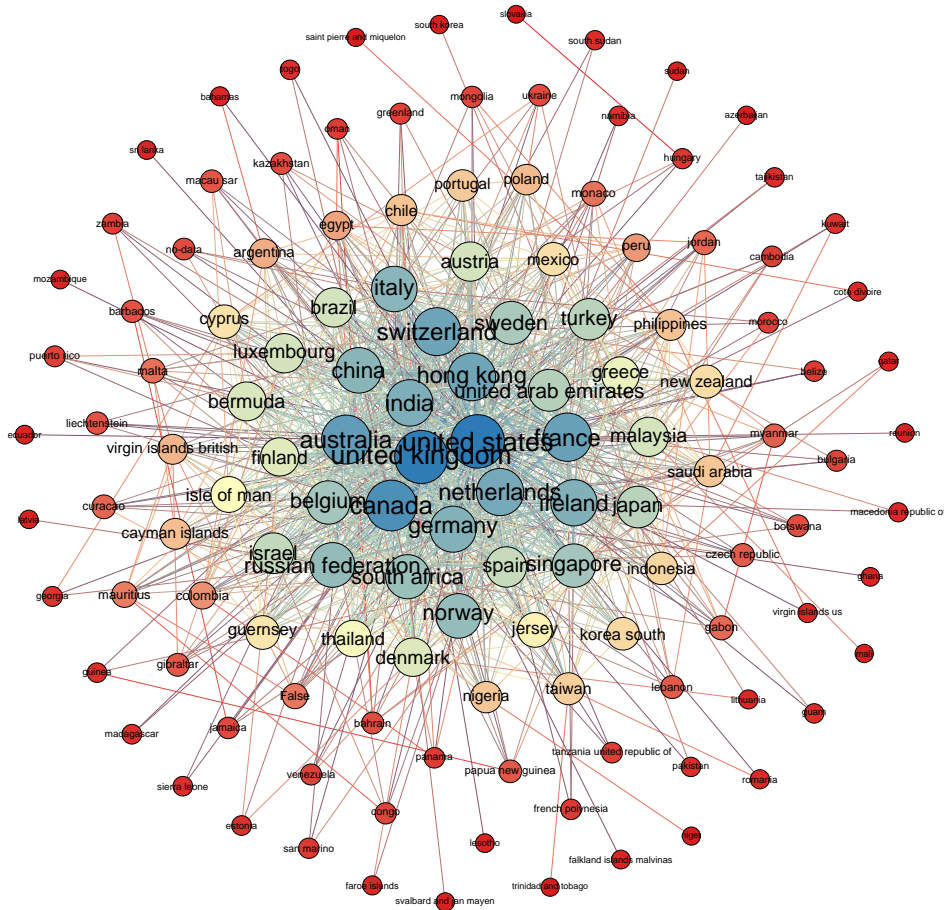


Figure 4: Country level aggregation of international interlocks. The weighted connection between two countries is defined by the number of directors holding simultaneous positions in companies from both countries. Directors whose positions are all in companies of the same country are discarded. Nodes are sized and colored by eigenvector centrality.

Table 4: Top and bottom ten and additional selected countries ordered by the ratio between the number of foreign and domestic interlocks, shown in the first column, while the second presents the entropy of the distribution of connections as a measure of how *globalized* a country is in contrast to strong local connections to one of few other countries. The Netherlands, Luxembourg, and Belgium, for instance, are characterized by more international interlocks than domestic ones. This fact, along with a high entropy value (as a measure of diversification of connections), indicates these are the most open countries.

Country	Ratio	Entropy
Belgium	1.856	0.640
Luxembourg	1.850	0.676
Netherlands	1.811	0.641
Switzerland	1.712	0.627
Portugal	1.679	0.733
Poland	1.664	0.744
Cyprus	1.607	0.685
France	1.583	0.606
Finland	1.515	0.603
Denmark	1.502	0.620
...
France	1.471	0.594
Germany	1.317	0.593
Italy	1.317	0.611
United Kingdom	1.127	0.532
...
Israel	0.818	0.480
Thailand	0.813	0.540
Australia	0.796	0.474
China	0.737	0.433
United States	0.696	0.435
India	0.679	0.463
Canada	0.676	0.401
Taiwan	0.543	0.415
South Korea	0.481	0.462
Japan	0.380	0.371

populated by the large Asian countries, the U.S. and Canada. While we would expect a size effect to play a large role in the U.S., the differences between the roughly similar size spectrum of Asian and European countries appears as the most striking outcome of this analysis. This fact, along with a high entropy value (as a measure diversification of connections), indicates the later are the most open countries as concerns the internationalization of

their business elite.

Another interesting aspect is the average profile of the firms engaging in international interlocks. Assortativity is the preference of nodes to attach to others that are similar with regard to some attribute [6]. The classic example is the degree assortativity, given by the Pearson correlation coefficient between the degrees of nodes at either end of the edges. As a correlation coefficient, it ranges from -1 (perfect dissortativity) to 1 (perfect assortativity). Here we consider connectivity with respect to the country of origin of a board. Since most interlocks often happen within countries, we generally observe positive assortativity with respect to this characteristic. Fig. 5 presents the overall country assortativity of the network of companies for varying thresholds of minimum degree, that is, for each degree k the country assortativity is calculated considering only those nodes with degree higher than k . A consistent decrease in assortativity for growing values of k is observed indicating that the higher the number of connections, the higher the chances of engaging in international interlocks. Hence, the more interconnected a board is, the higher the chance that some of its directors will serve on boards in more than one country.

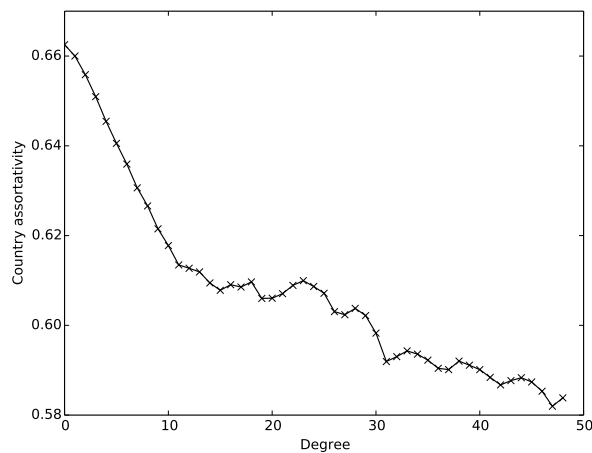


Figure 5: Country assortativity of the network of companies for varying thresholds of minimum degree, that is, for each degree k the country assortativity is calculated considering only those nodes with degree higher than k . The higher the number of connections, the higher the fraction of international interlocks.

3.3 Sector connectivity

Table 5 presents the number of positions, directors, and companies by sectors of economic activity. The last two columns show the average number of board positions per director and the average board size. It can be seen that both the banking and the insurance industries are characterized by an average board size significantly higher than the others. There is vast literature supporting the prominent role of financial institutions in the networks formed by interlocking directorates (see [1] for some examples). According to [4], financial institutions depend more on the business scan than the other companies, so for them it should be more necessary to maintain a large body of board directors.

Table 6 presents the eigenvector centrality (first column) and the diversity of connections (second column) by sector of economic activity. While the eigenvector centrality shows which are the most central sectors of activity in the network, the diversity of its connections indicates whether the sector is characterized by interlocks only with a few other related sectors or a large part of the network. The diversity of the connections is defined as the normalized Shannon entropy of the weighted connections (as defined in eq. 2). That means it will be close to 0 when the sector basically connects to one or just a few other sectors (like *Metals & Mining*, for example), and it will be close to 1 if the sector connects more or less equally to all other sectors (like *Banking*, for example).

Table 5: Number of positions, directors, and companies by sectors of economic activity. The last two columns show the average number of board positions per director and the average board size in number of positions.

Sector	Positions (1)	Directors (2)	Companies (3)	(1)/(2)	(1)/(3)
Metals & Mining	32411	12073	6089	2.68	5.32
Asset Management	18728	14219	4864	1.32	3.85
Oil, Gas & Coal	27825	12189	4455	2.28	6.25
Consumer Products	27220	16837	4423	1.62	6.15
Software	19685	13323	4227	1.48	4.66
Banking	38766	26726	4059	1.45	9.55
Real Estate	24635	14961	3845	1.65	6.41
Commercial Services	15660	13038	3832	1.20	4.09
Media	20938	13161	3817	1.59	5.49
Biotech & Pharma	22535	11806	3568	1.91	6.32
Retail - Discretionary	16240	10576	3126	1.54	5.20
Engineering & Construction Svcs	16180	11515	3068	1.41	5.27
Hardware	17042	11504	2823	1.48	6.04
Specialty Finance	13728	10532	2526	1.30	5.43
Utilities	24311	8986	2497	2.71	9.74
Chemicals	16223	11101	2436	1.46	6.66
Transportation & Logistics	13767	8577	2340	1.61	5.88
Machinery	12226	8690	2194	1.41	5.57
Electrical Equipment	12656	9071	2128	1.40	5.95
Health Care Facilities & Svcs	11549	8719	2112	1.32	5.47
Medical Equipment & Devices	10833	6321	1875	1.71	5.78
Home & Office Products	9864	7374	1819	1.34	5.42

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Table 5 – *Continued from previous page*

Sector	Positions (1)	Directors (2)	Companies (3)	(1)/(2)	(1)/(3)
Apparel & Textile Products	10672	7972	1808	1.34	5.90
Consumer Services	7633	6910	1779	1.10	4.29
Automotive	10944	6545	1589	1.67	6.89
Insurance	12506	7471	1574	1.67	7.95
Technology Services	8971	6157	1571	1.46	5.71
Gaming, Lodging & Restaurants	9614	6007	1510	1.60	6.37
Iron & Steel	9615	5712	1440	1.68	6.68
Telecom	9190	4259	1289	2.16	7.13
Institutional Financial Svcs	7444	4956	1189	1.50	6.26
Semiconductors	7896	4965	1173	1.59	6.73
Manufactured Goods	6211	4956	1135	1.25	5.47
Renewable Energy	6104	4135	1114	1.48	5.48
Construction Materials	7292	4676	1088	1.56	6.70
Distributors - Discretionary	4658	3811	1034	1.22	4.50
Retail - Consumer Staples	6667	3380	982	1.97	6.79
Recreation Facilities & Svcs	4654	3700	910	1.26	5.11
Waste & Environ Svcs & Equip	4119	3034	814	1.36	5.06
Containers & Packaging	4217	3055	682	1.38	6.18
Distributors - Consumer Staples	3095	2353	587	1.32	5.27
Passenger Transportation	4695	2260	528	2.08	8.89
Aerospace & Defense	3599	2003	489	1.80	7.36
Forest & Paper Products	2726	1770	444	1.54	6.14
Leisure Products	2350	1789	414	1.31	5.68
Transportation Equipment	2822	1547	396	1.82	7.13
Industrial Services	2371	1573	389	1.51	6.10

Table 6: Eigenvector centrality (first column) and connections diversity (second column) by sector of economic activity. While the eigenvector centrality shows which are the most central sectors of activity in the network, the diversity of its connections indicate whether the sector has only specialized local overlaps with just a few other related sectors or with a large variety of other sectors. The diversity of the connections is defined as the Shannon Entropy of the weighted connections. That means it will be close to 0 when the sector basically connects to one or just a few other sectors (like *Metals & Mining*, for example), and it will be close to 1 if the sector connects more or less equally to all other sectors (like *Asset Management*, for example).

Sector	Eigenvector	Entropy
Utilities	0.421	0.226
Banking	0.360	0.819
Oil, Gas & Coal	0.345	0.678
Consumer Products	0.226	0.855
Real Estate	0.223	0.813
Metals & Mining	0.214	0.400
Asset Management	0.206	0.865
Media	0.186	0.797
Insurance	0.183	0.849
Telecom	0.179	0.826
Chemicals	0.169	0.854
Retail - Discretionary	0.141	0.862
Biotech & Pharma	0.134	0.623
Gaming, Lodging & Restaurants	0.134	0.836
Engineering & Construction Svcs	0.130	0.875

Continued on next page

Table 6 – *Continued from previous page*

Sector	Eigenvector	Entropy
Transportation & Logistics	0.130	0.824
Software	0.126	0.724
Retail - Consumer Staples	0.122	0.837
Specialty Finance	0.108	0.894
Hardware	0.107	0.852
Iron and Steel	0.107	0.842
Commercial Services	0.106	0.907
Electrical Equipment	0.099	0.914
Automotive	0.096	0.869
Technology Services	0.088	0.888
Institutional Financial Svcs	0.084	0.871
Medical Equipment & Devices	0.080	0.683
Machinery	0.076	0.896
Passenger Transportation	0.076	0.860
Renewable Energy	0.070	0.820
Apparel and Textile Products	0.068	0.865
Health Care Facilities and Svcs	0.067	0.862
Construction Materials	0.066	0.882
Home & Office Products	0.054	0.906
Industrial Services	0.048	0.780
Semiconductors	0.045	0.791
Aerospace & Defense	0.045	0.912
Transportation Equipment	0.044	0.814
Consumer Services	0.041	0.916
Containers & Packaging	0.039	0.918
Recreation Facilities & Svcs	0.033	0.888
Manufactured Goods	0.031	0.902
Distributors - Discretionary	0.028	0.918
Forest & Paper Products	0.027	0.858
Waste & Environ Svcs & Equip	0.024	0.896
Distributors - Consumer Staples	0.017	0.871
Leisure Products	0.011	0.904
Design, Mfg & Distribution	0.008	0.839

The analysis of the role of sectors in the worldwide board network reveals some interesting features: First, the most central sectors are *Utilities*, *Banking* and *Oil, Gas & Coal*, with quite some difference of their eigenvector centrality to the bulk of remaining sectors. In terms of diversity of linkages, we find that most sectors are connected via board overlap to many other sectors. The pertinent entropy values are hovering around 0.8 – 0.9 in the wide majority of the cases. The only extreme outlier is *Utilities*, the sector with the highest eigenvector centrality whose entropy is a low 0.226. This is explained by the relatively small sector size compared to the large number of connections it has, both within and between sectors. The last two columns of table 5 show that the *Utilities* sector presents both the highest average board size and the highest average accumulation of positions by directors among all sectors. In addition, approximately 20% of all linkages in the network of sectors are within the *Utilities* sector (self-loops), followed by

Metals & Mining with 5% and *Oil, Gas & Coal* with 2%. *Utilities* also has the highest share of interlocks when self-loops are excluded (3.8%, followed by *Banking* and *Oil, Gas & Coal* with 3.1% each).

The central position of the *Banking* sector is, of course, as expected as the financial industry should have connections to all other sectors due to its service function. Note, however, that its entropy does not appear unusual which speaks against the popular perception that this sector operates as the tacit control center of modern capitalist economies. Drawing on 100 large US industrial corporations between 1969 and 1979, [7] hypothesize that interlocks with banks should be positively associated with corporate performance and debt/equity ratios. However, their findings revealed a negative association between bank interlocks and most measures of profitability. In this sense, [8] speak about financial hegemony: banks would play a central role in unifying the network of corporations linked through shared directors. In their view, the inner circle of directors with multiple and diverse affiliations, would maximize overall profits, rather than acting in the interest of particular companies. From a different perspective, [9] points out that no evidence of performance gains by interlocks with the financial sector has been found. Thus, it is argued that the financial institutions are not necessarily central, but different: banks are just special by their very nature in the sense they are holders and distributors of social capital.

4 The rich club phenomenon

In sec. 3 above, it has been documented that the frequencies of multiple board memberships are too high both at the international level and for single countries to be explained by random draws. Here we show that there also prevails a general tendency for those with many positions to be connected to others that have many positions, i.e. the existence of a core of highly connected directors that typically serve in multiple boards.

This is the so-called *rich club phenomenon*, i.e., some nodes are rich in network ties (they are the hubs) and highly interconnected to each other at the same time (they form a club). This feature is actually enhancing the robustness of a network in the presence of targeted attacks: given the high interconnectivity of the hubs, the removal of one or a few of them would not result in network fragmentation. The rich-gets-richer effect has been mentioned as an explanation for the existence of a very well connected core in the networks of interlocking directorates, as a natural consequence of adding nodes at random and attaching them to already well connected nodes [10]. However, models based on preferential attachment fail to explain the high

inter-connectivity present in the core of actual corporate networks.

It is worthwhile to stress that the rich club phenomenon does not necessarily have a one-to-one correspondence with a network's assortativity [6]. A positive (negative) degree assortative mixing implies nodes with high degrees tend to be connected to other nodes of high (low) degree. The fact that these two properties (degree assortativity and rich club) are not trivially related can be understood by considering a rich club formed by a clique of size four, in which each of the rich nodes is connected to nine other small nodes, as depicted in Fig. 6. This example exhibits the rich club phenomenon together with negative degree assortativity at the same time. Large nodes are more likely to connect to small nodes than to other large nodes (negative degree assortativity), while the inter-connectivity among the large nodes is higher than the connectivity among small nodes (rich club phenomenon).

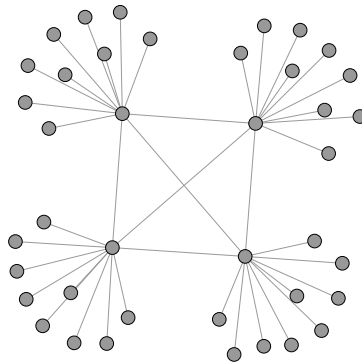


Figure 6: This network combines the rich club phenomena with negative degree assortativity. Large nodes are more likely to connect to small nodes than to other large nodes (negative degree assortativity), while the inter-connectivity among the large nodes is higher than the connectivity among small nodes (rich club phenomena).

The rich club phenomenon refers to the tendency of the dominant elements of the system to form tightly interconnected communities and it is one of the most important properties with respect to the formation of dominant communities in the social sciences [11]. Considering the core of corporate networks, the existence of the rich club phenomenon might indicate the presence of a unique group of mutually connected and powerful individuals (or a locus for the interconnection of smaller subgroups), while its absence could

suggest the existence of several virtually disconnected (perhaps competing) corporate elites.

The rich club coefficient in networks can be defined as, for a given degree k , the tendency of nodes with degree higher than k to be more densely connected to themselves than to nodes with degree lower than k [12]. It implies that the nodes with degree larger than some k tend to be more densely connected among themselves than the nodes with degree smaller than k , for any significant range of degrees in the network.

Formally, it is described as follows: consider a graph G with N nodes and M edges representing a complex network. Let N_k be the number of nodes with degree larger than k , and M_k be the number of edges between such nodes. The so-called rich club coefficient $\phi(k)$ for a given degree k is given by

$$\phi(k) = \frac{2|M|_{>k}}{|N|_{>k}(|N|_{>k} - 1)} \quad (3)$$

Here again, the statistical significance of possible values of $\phi(k)$ is an issue: Even in the absence of any systematic rich club tendency, we would expect positivity of $\phi(k)$ simply because nodes with higher degrees are naturally more likely to be more interconnected as they have more incident edges [11]. Indeed, even in the case of the *ER* graph an increasing rich club coefficient with k can be found. This implies that the increase of k is a natural consequence of the fact that nodes with large degree have a larger probability of sharing edges than low degree vertices. This feature is therefore imposed by construction and does not represent a signature of any particular organizing principle or structure, as it is clear for the *ER* case. The simple inspection of the k trend is therefore potentially misleading in the discrimination of the rich club phenomenon [11].

The rich club coefficient, therefore, needs to be normalized by its corresponding value in a random graph which follows the same (probably highly skewed) degree distribution. Such a random graph can be generated, for example, by the following procedure described in [13]: take two edges of the empirical network and switch one of their endpoints randomly. If sufficient iterations of this process are carried out, this procedure reshuffles the edge structure of the network but conserves its degree structure. Then the rich club coefficient is computed for the resulting maximally random network, $\phi_{ran}(k)$, and it is used to find the normalized rich club coefficient as follows

$$\rho(k) = \frac{\phi(k)}{\phi_{ran}(k)} \quad (4)$$

While $\phi(k)$ gives the rich club coefficient with respect to an ideal uncorrelated graph, $\rho(k)$ is a realistic normalized measure that takes into account the structure and finiteness of the network. Figure 7 presents the normalized version of the rich club coefficient described in [12] for the *LCC* (largest connected component) of C (red circles) and for the *LCC* of D_2 (network formed by board members holding at least two board positions, blue crosses). We indeed find strong indication of the rich club phenomenon over the entire range of k .

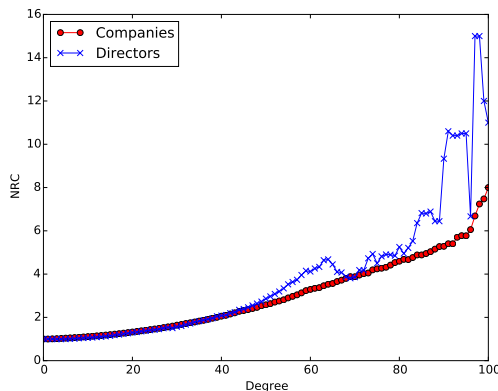


Figure 7: Normalized Rich Club Coefficients for varying degrees for the *LCC* of C (red circles) and D_2 (blue crosses)

5 Conclusion

We have established a number of stylized facts for a large dataset extracted from Bloomberg’s archive of company profiles that should cover to a large extent the segment of large and medium-sized companies of all countries that are integrated sufficiently into the global economy. Our findings confirm previous evidence for national board networks that find a closely connected core around a small set of board members with a relatively large number of positions. Practically the same deviation from a random benchmark is observed for a variety of countries as well as for the entire aggregated network. This supports the view of [3] of a particular type of *self-organization* of the board network into a distinctly non-random structure. Since we have confined ourselves to a data-analytical study here, we cannot provide an explanation of this seemingly very robust phenomenon. Given the strong evidence

that exists by now on the formation of a closely connected core in board network structures, the analysis of potential generating mechanisms for this emergent feature should be an important task for future research.

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