4 Degree and Strength Distribution Analysis

The study of the node degree refers to the distribution of the number of in-going and out-going relations. The number of outgoing links of a node corresponds to the number of firms in which a shareholder owns shares. It is a rough measure of the portfolio diversification. The in-degree corresponds to the number of shareholders owning shares in a given firm. It can be thought of as a proxy for control fragmentation. In the TNC network, the out-degree can be approximated by a power law distribution with the exponent -2.15 (see Fig. S5A). The majority of the economic actors points to few others resulting in a low out-degree. At the same time, there are a few nodes with a very high out-degree (the maximum number of companies owned by a single economic actor exceeds 5000 for some financial companies). On the other hand, the in-degree distribution, i.e., the number of shareholders of a company, behaves differently: the frequency of nodes with high in-degree decreases very fast. This is due to the fact that the database cannot provide all the shareholders of a company, especially those that hold only very small shares.

Next to the study of the node degree, we also investigate the strength which is defined as $\sum_j W_{ij}$, that is, the sum of all the weighed participations a company i has in other companies j (see Fig. S5B). It is a measure of the weight connectivity and gives information on how strong the ownership relationships of each node are.

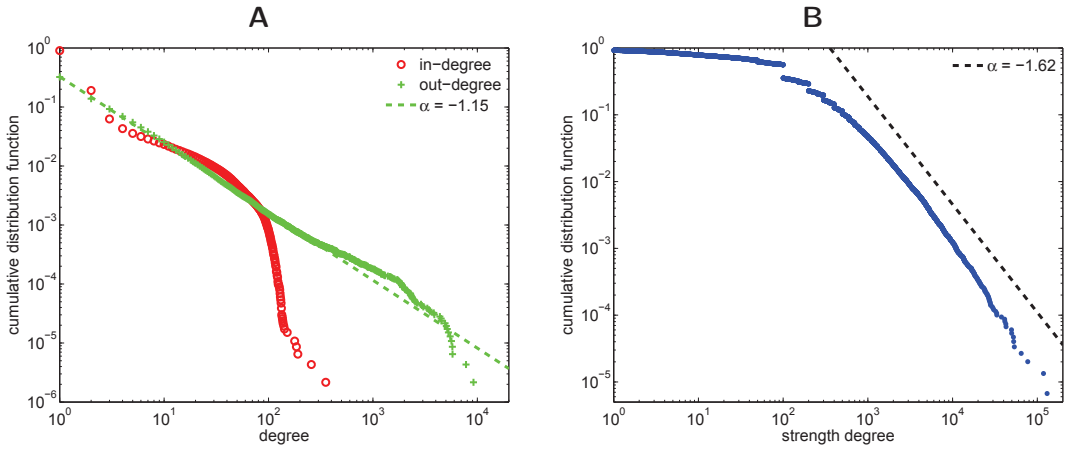

Figure S5: Various distribution functions. (**A**) Cumulative distribution function of the in- and out-degree of the nodes in the LCC (log-log scale). The power-law exponent for the corresponding probability density function of the out-degree is estimated to be -2.15. (**B**) Cumulative distribution function of the node strength in the LCC (log-log scale). As a reference, a power-law with an exponent of -1.62 is displayed.

5 Connected Component Analysis

Ownership relations between companies create formal ties among them. In a strongly connected component (SCC, see SI Sec. 7), all firms reach via an ownership pathway all other firms, thus owning each other indirectly to some extent. In contrast, in a weakly CC firms can reach each other only if one ignores the direction of the ownership links. This is still a situation of interest from an economic point of view because the flow of knowledge and information is not restricted by the direction of the link. The number and the size distribution of the CC provide a measure of the fragmentation of the market. We find that the TNC network consists of 23825 CC. A majority of the nodes (77%) belong to the LCC (largest connected component) with 463006 economic actors and 889601 relations. The remaining nodes belong to CCs with sizes at least 2000 times smaller. The second largest CC contains 230 nodes and 90% of the CC have less than 10 nodes (see Fig. S6).

From a geographical point of view, the LCC includes companies from 191 countries. Of these, 15491 are TNCs (about 36% of all TNCs but accounting for 94.2% of the total operating revenue) from 83 different countries. The firms that are PCs are much more numerous (399696) and are located in only 38 countries. Finally, there are 47819 SHs from 190 countries. This means that shareholders from all around the world hold shares in TNCs located in a more restricted number of countries, which, in turn, further concentrates their ownership shares of PCs in an even smaller number of countries, mainly Europe and the US.

In addition, a sector analysis of the LCC shows that the most represented industries are the

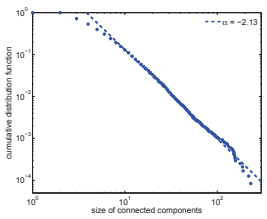

Figure S6: Cumulative distribution function of the size of the connected components. The data point representing the LCC is not shown, as it is three orders of magnitude larger than second largest (with 230 nodes) and completely offset. As a comparison, a power-law with exponent -3.13 ($= \alpha - 1$) is shown.

business activities sector, with 130587 companies, followed by the services sector with 99839 companies and the manufacturing sector with 66212 companies. On the other hand, surprisingly, the financial intermediaries sector counts only 46632 companies. However, if we distinguish between in-going and out-going relations, the financial intermediaries hold the largest number of shares (341363). Instead, the manufacturing and services sectors, with respectively 182699 and 170397 companies, have the companies with the most shareholders.

6 Bow-Tie Component Sizes

Does a bow-tie structure and the relative size of its IN, OUT and core result from specific economic mechanisms, or could it be explained by a random network formation process? For correlated networks, as in our case, there is no suitable theoretical prediction [11]. Heuristically, one could address the issue by performing a random reshuffling of links. However, this would violate economic constraints. For instance, exchanging a 10% ownership share in a small company with 10% in a big one requires the modification of the budget of the owner. In addition, the procedure is computationally cumbersome for large data sets.

7 Strongly Connected Component Analysis

Cross-shareholdings, or strongly connected components (SCCs) in graph theory, are sub-network structures where companies own each other directly or indirectly through a chain of links (see Fig. S7). Graphically speaking, this means that they form cycles and are all reachable by every other firm in the SCC.

In economics, this kind of ownership relation has raised the attention of different economic institutions, such as the antitrust regulators (which have to guarantee competition in the markets), as well as that of the companies themselves. They can set up cross-shareholdings for coping with possible takeovers, directly sharing information, monitoring and strategies reducing market competition.

In our sample we observe 2219 direct cross-shareholdings (4438 ownership relations), in which 2303 companies are involved and represent 0.44% of all the ownership relations (see Fig. S7A). These direct cross-shareholdings are divided among the different network actors as follow:

- 861 between TNCs;
- 563 between TNCs and PCs;
- 717 between PCs;
- 78 between SHs.

When there is a cross-shareholding involving three companies (see an example in Fig. S7B), many combinations of indirect paths are possible. In our network we observe the following ones:

- 829 of the type: $A \to B \to C \to A$;
- 4.395 of the type: $A \leftrightarrow B \to C \to A$;
- 8.963 of the type: $A \leftrightarrow B \leftrightarrow C \to A$;
- 3.129 of the type: $A \leftrightarrow B \leftrightarrow C \leftrightarrow A$.

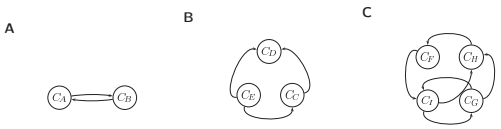

Figure S7: Examples of existing cross-shareholdings. (**A**) Mutual cross-shareholding. (**B**) Possible cross-shareholding with three nodes. (**C**) Cross-shareholding of higher degree.

Next to these simple examples, we also find many SCCs with bigger sizes. Note that smaller SCCs can be embedded in bigger ones. For instance, in the SCC in Fig. S7C there is also one cross-shareholding between the nodes C_I and C_G. In total there are 915 unique SCCs, of which almost all (83.7%) are located in the LCC. Focusing only on the LCC, there is one dominant SCC: it is comprised of 1318 companies in 26 countries. We define the bow-tie structure in the LCC by taking this SCC as its core (in the main text, we only refer to this SCC). The next smallest SCC contains 286 companies. This is a group of Taiwanese firms located in the OUT of the bow-tie. The remaining 99.7% of SCCs in the LCC have sizes between two and 21. The biggest SCC outside the LCC contains 19 firms.

8 Network Control Concentration

8.1 Control of Financial Institutions

One meaning of control in the corporate finance literature is the frequency by which a shareholder is able to influence the firm' strategic decision during the official voting [12]. Differently, in this work, by control we mean how much economic value of companies a shareholder is able to influence. Moreover, we did not limit our focus on the control of a shareholder of a single firm. Instead, we look at the control each shareholder has over its whole portfolio of directly and indirectly owned firms. As a result, the shareholders with a high level of control are those potentially able to impose their decision on many high-value firms. The higher a shareholder's control is, the higher its power to influence the final decision. In this sense, our notion of control can be related to Weber's definition of "power", i.e. the probability of an individual to be able to impose their will despite the opposition of the others [13].

In the literature on corporate control there is a debate on weather financial institutions really exert the control associated with their ownership shares. On the one hand, they are not supposed to seek an active involvement in the companies' strategies. However, some works argue that institutional investors, including banks and mutual funds, do exert control to some extent [14, 15, 16, 17]. In particular, the outcome of votes can be influenced by means of informal discussions, in which pro-management votes are used as a bargaining chip (e.g., in exchange of business related "favors" or in negotiating the extension of credit)[§]. On the contrary, [18] and [19] find that mutual funds, which typically hold large blocks of shares, vote against the management (i.e., in favor of corporate governance proposals) only 33% of the times (in the case of Fidelity Fund). However, they do so in more than 60%, on average, in other 11 cases analysed. These results are suggested to originate mainly from a conflict of interest, where the benefits of providing pension plan management to client corporations outweighs the possible benefits gained from increased shareholder value. However, while some mutual funds are reticent to exercise their power during voting mainly in the US, an activist stance is observed for some smaller funds and when operating outside the US [19]. In any case, in our study US mutual funds represent only a small fraction of all global financial institutions. In general, 49 mutual funds, identified by the NACE code 6714, are among the 737 top power-holders (see main text, Sec. Concentration of Control).

[§]For example, a mutual fund owning some percent of a large corporation may try to impose job cuts because of a weak economic situation. This can happen: (i) without voting and (ii) although the fund does not plan to keep these shares for many years. In this case, the influence of the mutual fund has a direct impact on the company and its employees. Furthermore, mutual funds with shares in many corporations may try to pursue similar strategies across their entire portfolio.

8.2 Relation to the Rich Club Phenomenon

The so-called rich club phenomenon [20, 21] refers to the fact that in some complex networks the nodes with the highest degree tend to be connected among each other. Being based solely on node degree, rich club indices are not suitable for ownership networks, in which *indirect* and *weighted* paths matter. Moreover, in order to benchmark the resulting value of rich club indices, it is usually necessary to reshuffle the links in the network. This would be a problem in our network because it would lead to economically unviable ownership networks. Notice, however, that the core of the TNC network could be seen as a generalization of the rich club phenomenon with control in the role of degree. Thus, future work should look into this issue more in depth.

8.3 Top Control-Holders Ranking

This is the first time a ranking of economic actors by global control is presented. Notice that many actors belong to the financial sector (NACE codes starting with 65,66,67) and many of the names are well-known global players. The interest of this ranking is not that it exposes unsuspected powerful players. Instead, it shows that many of the top actors belong to the core. This means that they do not carry out their business in isolation but, on the contrary, they are tied together in an extremely entangled web of control. This finding is extremely important since there was no prior economic theory or empirical evidence regarding whether and how top players are connected. Finally, it should be noted that governments and natural persons are only featured further down in the list.

Table S1: Top 50 control-holders. Shareholders are ranked by network control (according to the threshold model, TM). Column indicate country, NACE industrial sector code, actor's position in the bow-tie sections, cumulative network control. Notice that NACE code starting with 65,66,67 belong to the financial sector.

Rank	Economic actor name	Country	NACE code	Network position	Cumul. network control (TM, %)
1	BARCLAYS PLC	GB	6512	SCC	4.05
2	CAPITAL GROUP COMPANIES INC, THE	US	6713	IN	6.66
3	FMR CORP	US	6713	IN	8.94
4	AXA	FR	6712	SCC	11.21
5	STATE STREET CORPORATION	US	6713	SCC	13.02
6	JPMORGAN CHASE & CO.	US	6512	SCC	14.55
7	LEGAL & GENERAL GROUP PLC	GB	6603	SCC	16.02
8	VANGUARD GROUP, INC., THE	US	7415	IN	17.25
9	UBS AG	CH	6512	SCC	18.46
10	MERRILL LYNCH & CO., INC.	US	6712	SCC	19.45
11	WELLINGTON MANAGEMENT CO. L.L.P.	US	6713	IN	20.33
12	DEUTSCHE BANK AG	DE	6512	SCC	21.17
13	FRANKLIN RESOURCES, INC.	US	6512	SCC	21.99
14	CREDIT SUISSE GROUP	CH	6512	SCC	22.81
15	WALTON ENTERPRISES LLC	US	2923	T&T	23.56
16	BANK OF NEW YORK MELLON CORP.	US	6512	IN	24.28
17	NATIXIS	FR	6512	SCC	24.98
18	GOLDMAN SACHS GROUP, INC., THE	US	6712	SCC	25.64
19	T. ROWE PRICE GROUP, INC.	US	6713	SCC	26.29
20	LEGG MASON, INC.	US	6712	SCC	26.92
21	MORGAN STANLEY	US	6712	SCC	27.56
22	MITSUBISHI UFJ FINANCIAL GROUP, INC.	JP	6512	SCC	28.16
23	NORTHERN TRUST CORPORATION	US	6512	SCC	28.72
24	SOCIÉTÉ GÉNÉRALE	FR	6512	SCC	29.26
25	BANK OF AMERICA CORPORATION	US	6512	SCC	29.79
26	LLOYDS TSB GROUP PLC	GB	6512	SCC	30.30
27	INVESCO PLC	GB	6523	SCC	30.82
28	ALLIANZ SE	DE	7415	SCC	31.32
29	TIAA	US	6601	IN	32.24
30	OLD MUTUAL PUBLIC LIMITED COMPANY	GB	6601	SCC	32.69
31	AVIVA PLC	GB	6601	SCC	33.14
32	SCHRODERS PLC	GB	6712	SCC	33.57
33	DODGE & COX	US	7415	IN	34.00
34	LEHMAN BROTHERS HOLDINGS, INC.	US	6712	SCC	34.43
35	SUN LIFE FINANCIAL, INC.	CA	6601	SCC	34.82
36	STANDARD LIFE PLC	GB	6601	SCC	35.2
37	CNCE	FR	6512	SCC	35.57
38	NOMURA HOLDINGS, INC.	JP	6512	SCC	35.92
39	THE DEPOSITORY TRUST COMPANY	US	6512	IN	36.28
40	MASSACHUSETTS MUTUAL LIFE INSUR.	US	6601	IN	36.63
41	ING GROEP N.V.	NL	6603	SCC	36.96
42	BRANDES INVESTMENT PARTNERS, L.P.	US	6713	IN	37.29
43	UNICREDITO ITALIANO SPA	IT	6512	SCC	37.61
44	DEPOSIT INSURANCE CORPORATION OF JP	JP	6511	IN	37.93
45	VERENIGING AEGON	NL	6512	IN	38.25
46	BNP PARIBAS	FR	6512	SCC	38.56
47	AFFILIATED MANAGERS GROUP, INC.	US	6713	SCC	38.88
48	RESONA HOLDINGS, INC.	JP	6512	SCC	39.18
49	CAPITAL GROUP INTERNATIONAL, INC.	US	7414	IN	39.48
50	CHINA PETROCHEMICAL GROUP CO.	CN	6511	T&T	39.78

9 Additional Tables

Table S2: Number of top control-holders (TCHs) located in the SCC and being members of the financial sector (FS). Various intersections thereof. The columns refer to the three models of network control and the TM of network value.

	c^{net} (LM, #)	c^{net} (TM, #)	c^{net} (RM, #)	v^{net} (TM, #)
TCH	763	737	648	1791
TCH∩TNC	308	298	259	1241
TCH∩TNC∩SCC	151	147	122	211
TCH∩SCC∩FS	116	115	92	140

Table S3: Concentration of 80% of network control (LM, TM, RM) and network value (TM). The percentages refer to the network controlvalue held by the TCHs according to their location in the SCC and their possible belonging to the FS, and various intersections thereof.

	c^{net} (LM, %)	c^{net} (TM, %)	c^{net} (RM)	v^{net} (TM, %)
TCH∩TNC	54.87	54.63	52.94	63.34
TCH∩TNC∩SCC	39.54	38.37	37.29	30.37
TCH∩SCC∩FS	36.58	35.37	34.90	24.36

Table S4: Probability that a randomly chosen economic actor (TNC or SH) belongs to the group of top control-holders with respect to its position in the network structure. The first column refers to all top control-holders (TCHs), the second column to the first 50 TCH.

	All TCH	First 50 TCH
IN	6.233%	0.273%
SCC	49.831%	11.525%
OUT	0.432%	0%
T&T	0.413%	0.002%
OCC	0.016%	0%

References

1. OECD (2000) *The OECD Guidelins for Multinational Enterprises* (www.oecd.org).

2. Goergen, M, Martynova, M, Renneboog, L (2005) Corporate governance convergence: evidence from takeover regulation reforms in Europe. *Oxford Rev. Econ.Pol.* 21:243–268.

3. The Deminor Group (2005) Application of the one share - one vote principle in europe., (http://www.abi.org.uk/Bookshop/), Technical report.

4. La Porta, R, de Silanes, FL, Shleifer, A (1999) Corporate ownership around the world. *J. Finance* 54:471–517.

5. Glattfelder, JB, Battiston, S (2009) Backbone of complex networks of corporations: The flow of control. *Phys. Rev. E* 80.

6. Brioschi, F, Buzzacchi, L, Colombo, M (1989) Risk capital financing and the separation of ownership and control in business groups. *J. Bank. Financ.* 13:747–772.

7. Bonacich, P (1987) Power and centrality: A family of measures. *Amer. J. Sociol.* pp 1170–1182.

8. Ballester, C, Calvo-Armengol, A, Zenou, Y (2006) Who's who in networks. wanted: the key player. *Econometrica* pp 1403–1417.

9. Hubbell, C (1965) An input-output approach to clique identification. *Sociometry* pp 377–399.

10. Baldone, S, Brioschi, F, Paleari, S (1998) Ownership Measures Among Firms Connected by Cross-Shareholdings and a Further Analogy with Input-Output Theory. *4th JAFEE International Conference on Investment and Derivatives.*

11. Dorogovtsev, S, Mendes, J, Samukhin, A (2001) Giant strongly connected component of directed networks. *Phys. Rev. E* 64:25101.

12. Davis, G (2008) A new finance capitalism? Mutual funds and ownership re-concentration in the United States. *Europ. Manage. Rev.* 5:11–21.

13. Weber, M (1922) Wirtschaft und Gesellschaft, Tübingen. *Max Weber im Kontext. InfoSoftWare Karsten Worm, Berlin* 2.

14. Santos, J, Rumble, A (2006) The American keiretsu and universal banks: Investing, voting and sitting on nonfinancials' corporate boards. *J. Finan. Econ.* 80:419–454.

15. Becht, M, Bolton, P, Röell, A, Roosevelt, A (2005) Corporate governance and control. *NBER.*

16. Gillan, S, Starks, L (2000) Corporate governance proposals and shareholder activism: The role of institutional investors. *J. Finan. Econ.* 57:275–305.

17. Davis, G, Thompson, T (1994) A social movement perspective on corporate control. *Admin. Sci. Quart.* 39:141–173.

18. Davis, G, Kim, E (2007) Business ties and proxy voting by mutual funds. *J. Finan. Econ.* 85:552–570.

19. Davis, G (2008) A new finance capitalism? Mutual funds and ownership re-concentration in the United States. *Euro. Manage. Rev.* 5:11–21.

20. Colizza, V, Flammini, A, Serrano, M, Vespignani, A (2006) Detecting rich-club ordering in complex networks. *Nat. Phy.* 2:110–115.

21. Fagiolo, G, Reyes, J, Schiavo, S (2009) World-trade web: Topological properties, dynamics, and evolution. *Phys. Rev. E* 79:36115.