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Kiel Institute for the World Economy, Düsternbrooker Weg 120, 24105 Kiel, Germany

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JEL classification: D85, L20, M14, M51

Thomas Lux
Kiel Institute for the World Economy
24100 Kiel, Germany
Phone: +49 431-8814 278
E-Mail: thomas.lux@ifw-kiel.de
E-Mail: lux@bwl.uni-kiel.de

The Small Core of the German Corporate Board Network*

MISHAEL MILAKOVIĆ
Department of Economics
University of Kiel

SIMONE ALFARANO
Department of Economics and
Center for Numerical Simulation
University of Kiel

THOMAS LUX
Department of Economics
University of Kiel, and
Kiel Institute for the World Economy

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Abstract

We consider the current bipartite graph of German corporate boards and identify a small core of directors who are highly central in the entire network while being densely connected among themselves. To identify the core, we compare the actual number of board memberships to a random benchmark, focusing on deviations from the benchmark that span several orders of magnitude. It seems that the board appointment decisions of largely capitalized companies are the driving force behind the existence of a core in Germany's board and director network. Conditional on being a board member, it is very improbable to obtain a second membership, but multiple board membership becomes increasingly likely once this initial barrier is overcome. We also present a simple model that describes board appointment decisions as a trade-off between social capital and monitoring ability.

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1 Introduction

The interlocks of corporate boards and their directors are receiving increasing interdisciplinary attention (see, e.g., Battiston and Catanzaro, 2004; Caldarelli and Catanzaro, 2004; Conyon and Muldon, 2006; Davis et al., 2003; Newman et al., 2001; Robins and Alexander, 2004), and current research in the field of management science and organization has already been actively addressing the impact of various corporate network structures on socio-economic outcomes, as witnessed by a number of recent review articles devoted to the subject (see, e.g., Brass et al., 2004; Borgatti and Foster, 2003; Galaskiewicz, 2007; Provan et al., 2007; Uzzi et al., 2007). It is uncontroversial that board and director networks are small worlds, i.e. they are highly clustered while exhibiting short average path lengths.

This paper addresses a somewhat different aspect of board and director networks by focusing on the *network core* of board and director interlocks. Mintz and Schwartz (1981) have argued that the degree of interest-group formation can be assessed by some core of board interlocks. Moreover, Alfarano and Milaković (2008) have argued theoretically that a network core is crucial for the propagation of opinion dynamics in a generic probabilistic herding model with a large number of agents, and several authors have suggested procedures to classify or identify a core of key players in complex networks (for a more recent take on the classic concept of core-periphery structures in networks see, e.g., Borgatti, 2006; Borgatti and Everett, 1999; Holme, 2005).

Here we suggest a simple procedure to detect the core of board and director interlocks by comparing the actual number of board memberships to a random benchmark given by a sequence of Bernoulli trials. The resulting binomial distribution and the empirically observed distribution display deviations over increasing orders of magnitude for multiple memberships. It turns out that directors with multiple board memberships are to a large extent connected among themselves, and exhibit high centrality in the overall network of director interlocks. Several directors with multiple membership are not connected to their peers, and our analysis suggests that board appointment decisions of largely capitalized firms are an important factor in observing a dense core of interlocked directors with high centrality. Thus we propose a simple model that accounts for the observed conditional probabilities of multiple board membership, based on the idea that board appointment represents a trade-off between the benefits of having a well-connected director on one's board, and the costs of increasingly binding time constraints arising from multiple board membership.

2 The network structure of German board and director interlocks

We collected board composition data for German publicly traded companies from their respective websites, focusing on companies which either have a market capitalization of more than one hundred million euro, or are included in one of the four *prime standard indices* of Deutsche Börse.[1] For the purpose of our study, the board of a German publicly traded company consists of management (*Vorstand*) and supervisory board (*Aufsichtsrat*). The resulting list is composed of $n = 3,383$ directors who work for $c = 284$ companies with a total market capitalization of 1.27 trillion euro as of May 31, 2008, accounting for roughly 95% of Deutsche Börse's overall market capitalization. We checked carefully that identical names refer to the same person, which was actually not always the case, and assigned a unique identifier to each director.

In order to construct the current bipartite graph formed by German corporate boards, we consider the *incidence matrix* $\mathbf{M}$ of dimension $n \times c$, with $m_{ij} = 1$ if director i is on the board of company j and zero otherwise. The one-mode projection onto directors $\mathbf{D} = \mathbf{M}\mathbf{M}^{\mathbf{T}}$ is the weighted adjacency matrix of director interlocks. Its diagonal entries equal the total number of board memberships of director i, while non-zero entries off the diagonal of $\mathbf{D}$ represent the weight of a link, showing on how many boards two directors serve together.[2] Symmetrically, the one-mode projection onto boards $\mathbf{B} = \mathbf{M}^{\mathbf{T}}\mathbf{M}$ yields the weighted adjacency matrix of company interlocks, its diagonal entries correspond to the board size of company j, and off-diagonal non-zero elements indicate the number of directors that two companies have in common. In order to avoid self-loops, we always set the diagonal of adjacency matrices equal to zero. The resulting networks are displayed in Figure 1.

While the small-world properties of $\mathbf{D}$ have been documented before (see, e.g., Battiston and Catanzaro, 2004; Newman et al., 2001), several authors have pointed out that this might be a misleading way to approach the complexity of director interlocks. Conyon and Muldon (2006) argue that high clustering in director networks occurs by construction because

[1] The four prime standard indices are the DAX, the MDAX, the TecDAX, and the SDAX. The DAX is comprised of the top thirty companies ranked by market capitalization. The SDAX and MDAX refer to small cap and mid-cap companies, while the TecDAX consists of the thirty largest companies in the technology sector.

[2] Directors who form links with weight greater than unity are sometimes referred to as a *lobby*.

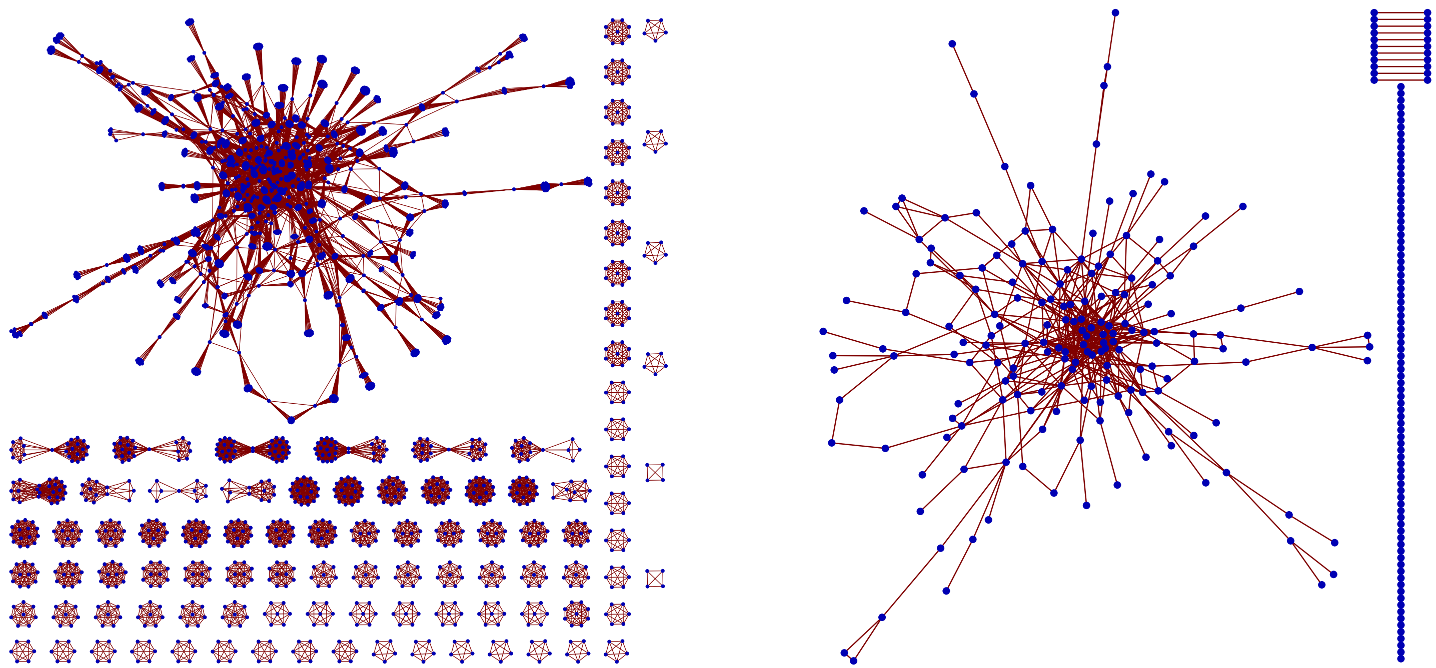

Figure 1: The network of German director interlocks (left panel) is composed of 3,383 nodes and 29,820 links. The large connected component contains 2,411 (71.3% of all) nodes and 24,895 (83.5% of all) links. The corresponding board network (right panel) consists of 284 nodes and 549 links, and its connected component contains 176 (62% of all) nodes and 528 (96.2% of all) links. The average director serves on 1.12 boards (1.15 in the large component), and the average board contains 13.3 seats (15.8 in the large component). The large connected components of the one-mode projections account for roughly 90% of the overall market capitalization of publicly traded companies in Germany. Graphical inspection suggests that the large connected components of both graphs have a "core."

directors who serve on the same board form a complete graph. They show that a constrained random graph, which accounts for the number of complete subgraphs, is in line with the observed graph of director interlocks, implying that boards of directors are no more clubby than would be expected in a chance experiment. But they do find that positive degree correlation (or assortativity) is an unexpected characteristic among interlocking directors who serve on many boards; or as Newman et al. (2001) slangly put it, "bigshots run with other bigshots." Similarly, Robins and Alexander (2004) investigate deviations of what they term 'infrastructures' from a constrained random benchmark, where infrastructures account for the fact that every company (in the large connected component) has at least one interlocker, and that each interlocker is at least on two boards. They conclude as well that more boards than expected choose a high number of directors with external linkages. Our approach is quite similar in spirit to those of Conyon and Muldon (2006) and Robins and Alexander (2004) because we also focus on deviations from a random benchmark after realizing that the vast majority of directors serves on a single board.

In contrast to their approaches, we do not start from the immediate topological features of the bipartite graph or its respective one-mode projections. Instead we begin by realizing that nearly 92% of directors (3,102 out of 3,383) serve on a single board, which we henceforth label as the "one-director-one-seat" principle.[3] The sample consists of a total of 3,773 board positions, which leaves 390 positions to be filled with multiple board memberships from the pool of 3,383 directors. To establish a random benchmark of multiple board membership, we assume that all directors in the sample are unconditionally indistinguishable among themselves after accounting for the 1-director-1-seat principle. Then we can determine the probability of observing multiple board membership as a sequence of $k = 390$ independent Bernoulli trials, resulting in a binomial distribution

[3]Notice that 89% of directors in the large connected component conform with the 1-director-1-seat principle. For the purpose of identifying deviations in orders of magnitude, the difference in the relative frequency of single board membership between the entire network and the large connected component does not matter.

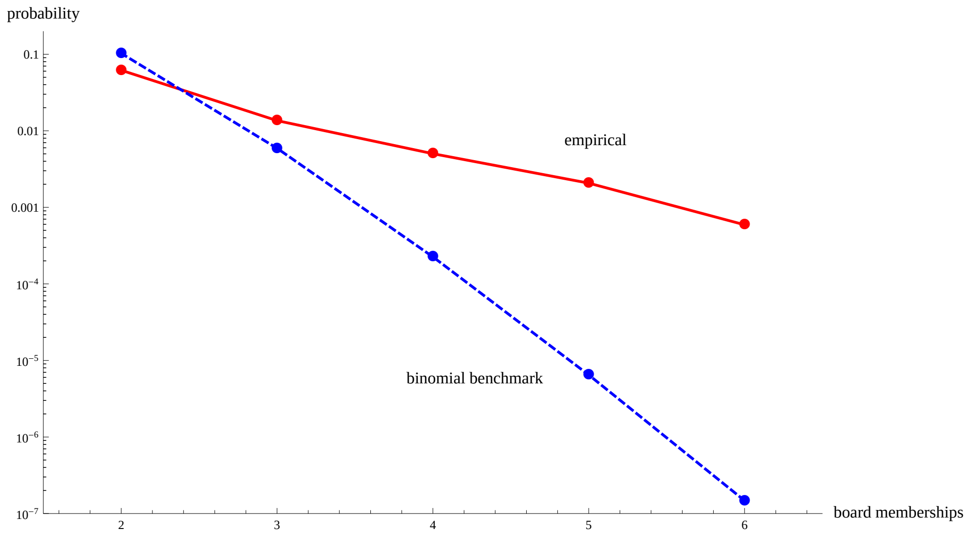

Figure 2: The solid curve shows the relative frequency of multiple board membership, while the dashed curve illustrates the binomial probability of observing multiple board membership in an independent sequence of $k = 390$ Bernoulli trials with probability $p = 1/3383$ of success. The semi-log scale reveals deviations on increasing orders of magnitude for $b > 3$.

for observing $B = b$ additional board memberships,

$$Pr[B = b] = \binom{k}{b} p^b (1-p)^{k-b},$$

where $p = 1/n \approx 3 \times 10^{-4}$ is the probability of success, i.e. of obtaining an additional board membership. Figure 2 illustrates the result and compares it to the empirically observed relative frequencies of multiple board membership.

At least for $b \geq 4$, the incidence of multiple board membership is several orders of magnitude higher than we would expect in a sequence of independent Bernoulli trials. If the network of director interlocks is indeed assortative, then focusing on directors that serve on an unexpectedly large number of boards should conveniently identify a core of key players. Figure 3 displays the network structure among directors with $B \geq b$ board memberships, and already visually confirms that the resulting subgraphs, which we label as B-cores, are to a very large extent connected.[4] The density of the (unweighted version of) graph $\mathbf{D}$ is given by the ratio of the existing number of links $|L|$ to the number of links in a complete graph of the same size, denoted $|N|$,

$$\text{density}_D = 2|L|/|N|(|N|-1),$$

which is by construction confined to the interval $[0, 1]$. Table 1 illustrates that the density of B-core subgraphs increases with b, so core directors are more densely connected among their core peers compared to the average director in the network.

Let $\mathbf{C}$ denote the adjacency matrix of the large connected component of $\mathbf{D}$, and let V denote the set of directors contained in C. A shortest path between two directors $u, v \in V$ is known as a graph *geodesic*, which is not necessarily unique, and the length of the geodesic $d_C(u, v)$ is known as the graph *distance* between the pair (u, v). The *eccentricity* of node u is the maximum graph distance between u and any other node v. The maximum eccentricity is the graph *diameter*, and the minimum graph eccentricity is the graph *radius*. We can see from Table 1 that the radius and diameter of B-cores decrease with b, as one intuitively desires in the definition of a core. We also compute two simple measures of centrality in order to investigate whether directors in the increasing sequence of B-cores show an increasing centrality in the entire network $\mathbf{C}$. The simplest measure of the centrality of node u is *degree centrality*, constructed by summing the number of links that each node has, $\text{degree}_u = \sum_{v \in V} \mathbf{C}_{uv}$. Intuitively, directors who have many links compared to their peers are in an advantageous position if they are able to influence many of their peers, or if they have better access to resources through their many links. But degree centrality only takes immediate ties of directors into account, and lacks information about the distance to directors that are not immediate neighbors. Moreover, directors with many board memberships have a relatively large de-

[4]Notice that our notion of B-cores is different from the concept of k-cores, which are constructed using a node's minimum degree (see, e.g., Seidman, 1983).

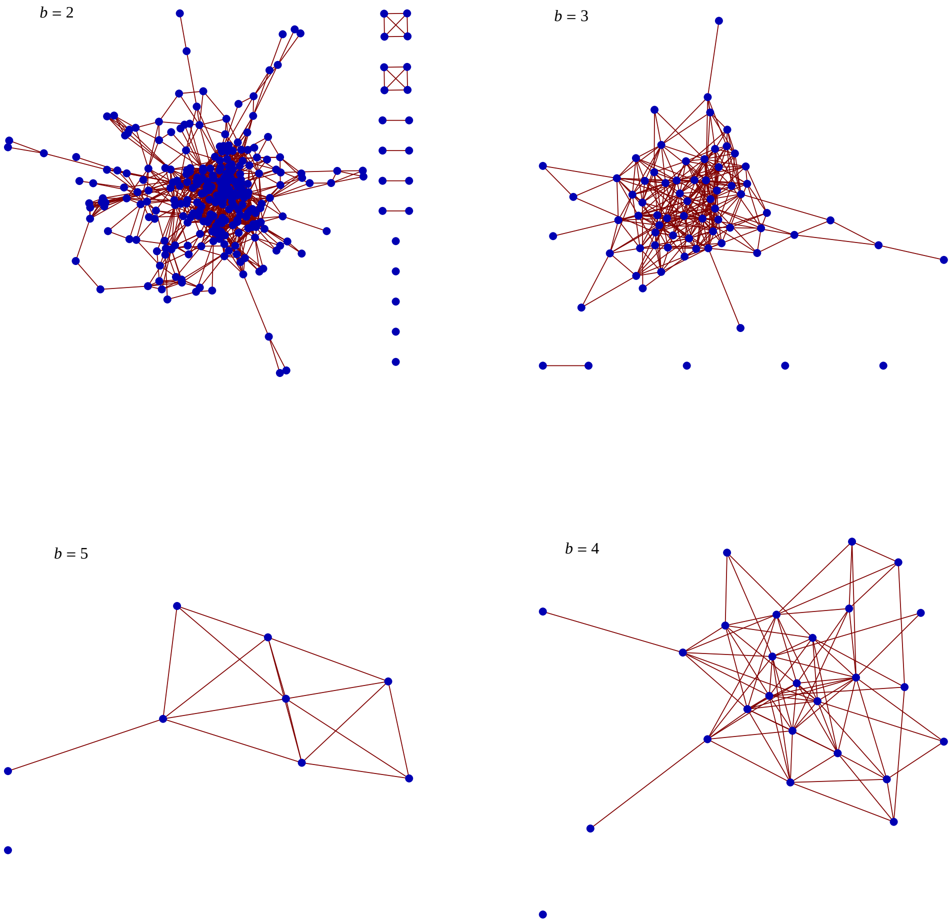

Figure 3: Network structures formed by considering directors with an increasing threshold of board memberships $B \geq b$. The fractions of directors that are not part of the respective connected components are (clockwise from top left) 7.5%, 6.9%, 3.9%, and 11.1%. The B-6 core forms a complete graph of size two. Notice that for $b \geq 3$ all directors are in the large connected component of $\mathbf{D}$ shown in the left panel of Figure 1.

gree by construction since the board size distribution has a characteristic scale that is well captured by its mean. *Closeness centrality*, on the other hand, aims at measuring the distance of a node to all other nodes in the network, and is typically defined as the reciprocal of the sum of geodesics to all other nodes in the network,

$$\text{closeness}_u = 1/\sum_{v \in V} d_C(u,v)\,.$$

To normalize the closeness measure, we divide by the closeness score of the director with maximal closeness centrality. Directors who are more central in this sense should in principle be better able to reach out into the entire network or be faster in doing so. Third, we also compute the eigenvector centrality (see, e.g., Bonacich, 1972) for all nodes in V. *Eigenvector centrality* assigns scores of relative importance to directors in the network, based on the principle that connections to high-scoring directors contribute more to a director's score than equal connections to low-scoring peers. Hence the idea behind eigenvector centrality is that the quality of links is important, because directors who are connected to many influential peers can be expected to be important themselves. Suppose the eigenvector centrality score of node u, denoted e_u, is proportional to the centrality score of its neighbors,

$$e_u = \frac{1}{\lambda} \sum_{v \in V} C_{uv}\, e_v\,,$$

where λ is a constant. Then we can write the vector of centrality scores in matrix notation as $\lambda \mathbf{e} = \mathbf{C} \cdot \mathbf{e}$, which shows that $\mathbf{e}$ is an eigenvector of $\mathbf{C}$ with corresponding eigenvalue λ. It is convenient to consider the eigenvector corresponding to the largest eigenvalue of $\mathbf{C}$ since its elements are all non-negative according to the Perron-Frobenius theorem. As in the case of closeness centrality, we divided all scores by the maximum score. Table 1 shows that core directors are not only densely connected among themselves, but that they are also increasingly central in the entire network, which is another characteristic that one intuitively expects in the

Table 1: Various characteristics of B-cores and their respective directors. The notation $b = 1$ refers to all directors in the large connected component $\mathbf{C}$.

	$b = 1$	$b = 2$	$b = 3$	$b = 4$	$b = 5$	$b = 6$
B-core statistics:						
Diameter	11	9	6	4	3	1
Radius	6	5	3	2	2	1
Density	.005	.037	.126	.255	.444	1
Centrality averages:						
Degree centrality	20.6	42.5	68.3	91.4	110.6	131
Closeness centrality	0.68	0.79	0.87	0.93	0.97	0.99
Eigenvector centrality	0.06	0.17	0.33	0.49	0.70	0.75
MarketCap averages:						
Entire B-core	525	4,322	14,875	35,929	77,564	144,910
B-core isolates	N/A	871	1,785	4,594	8,070	N/A

definition of a network core.

It is also informative to look at the B-core directors that are not connected with their peers in the respective B-cores. As it turns out, the average market capitalization per director is about one order of magnitude higher for directors that are connected in the respective B-cores. Moreover, the isolated directors in the respective cores typically serve on the boards of companies that are sectorally close in terms of their two-digit SIC classification, which is generally not the case for connected core directors. Consider for instance Fritz Vahrenholt and Robert J. Koehler, who are the isolated directors in the B-4 and B-5 cores: Vahrenholt works for Norddeutsche Affinerie (33), ErSol Solar Energy (36), REpower Systems (35), and Vereinigte BioEnergie Veribo (28), where the numbers in parentheses correspond to the two-digit SIC classification of their primary activities. The company names readily reveal a focus on energy production from renewable resources.[5] Similarly, Koehler works for Demag Cranes (35), Heidelberger Druckmaschinen (35), Lanxess (28), Pfleiderer (32), and SGL Carbon (36), which focus on the production of chemically, electronically, or mechanically complex manufacturing goods. Very similar pictures of sectoral or industry specificity in board membership arise for the isolated directors in lower B-cores.

3 Modeling multiple board membership

So far we have argued that the unconditional probability of observing a given number of board memberships provides a convenient way to detect core structures in the network of German director interlocks. The network features and the level of market capitalization in the B-core sequence indicate some hierarchical principle of organization in the network structure of board and director interlocks. A simple approach to multiple board membership is to consider it as the outcome of hiring or appointment decisions concerning new board members. Hence one would like to understand the rationale underlying board appointment decisions that are mirrored in the degree of board membership.

In a first approximation, we start by considering the conditional probability $P(b|b-1)$ of serving on b boards, calculated as the fraction of directors who remain in the increasing sequence of B-cores (Figure 4). One could also think of these conditional probabilities as reflections of a director's chances to climb up in the hierarchy of the director network, but from a causal viewpoint we prefer to conceptualize the conditional probabilities as the outcome of a recruitment process for new board members. The conditional probabilities in Figure 4 display a parabolic shape that is concave to the origin. The parabolic shape of $P(b|b-1)$ suggests a trade-off between benefits and increasingly prohibitive costs that establish a clear limit on the potential number of board memberships. Interestingly, this

[5] To be precise, the name Norddeutsche Affinerie does not readily imply a focus on alternative resources, but their main line of business concerns the copper value chain, which is a crucial resource in the production of renewable energy technologies.

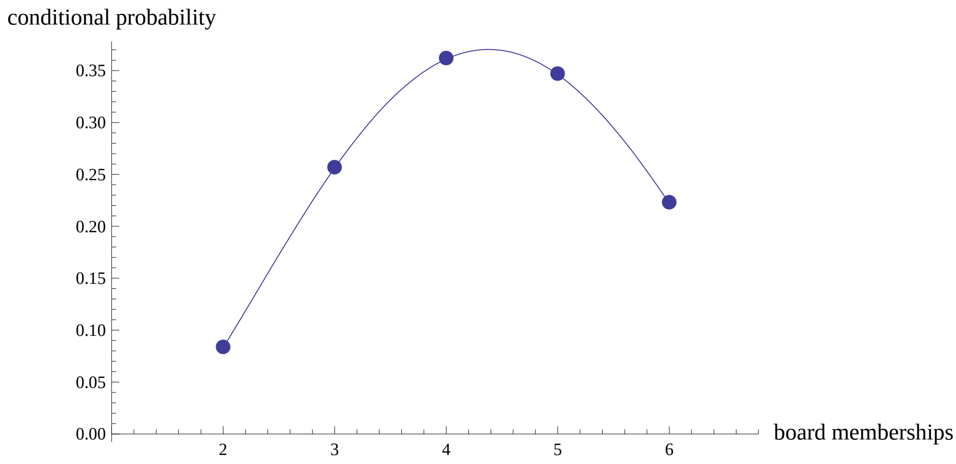

Figure 4: The conditional probability $P(b|b-1)$ of board membership is calculated from the ratio of successive B-core sizes; for instance, 72 of the 281 directors in the B-2 core form the B-3 core, and the conditional probability $P(3|2)$ of observing $b = 3$ memberships is 72/281 = 25.6%. While the conditional probability of board membership increases at first, the fitted parabolic shape indicates that the number of board appointments per director is obviously limited.

limit is markedly below the recently introduced legal limit on board memberships. According to German law (§ 100(2) of *Aktiengesetz*), a director cannot serve on more than ten boards in Germany. In fact, the actual legal limit is even higher, because up to five board memberships in conglomerates or parent companies are excluded from the maximum rule of ten, showing that the observed maximum number of memberships is clearly below the legally permitted one. We take the position that existing multiple membership represents an important factor in the appointment decision. On one hand, the number of existing memberships serves as a proxy for the social capital of a prospective candidate, and speaks in favor of the candidate being appropriately skilled and equipped for taking on the responsibility of board membership. On the other hand, multiple board membership also implies that the prospective candidate faces serious time constraints that we interpret as a cost in the hiring committee's decision, since directors who serve on multiple boards will find increasingly less

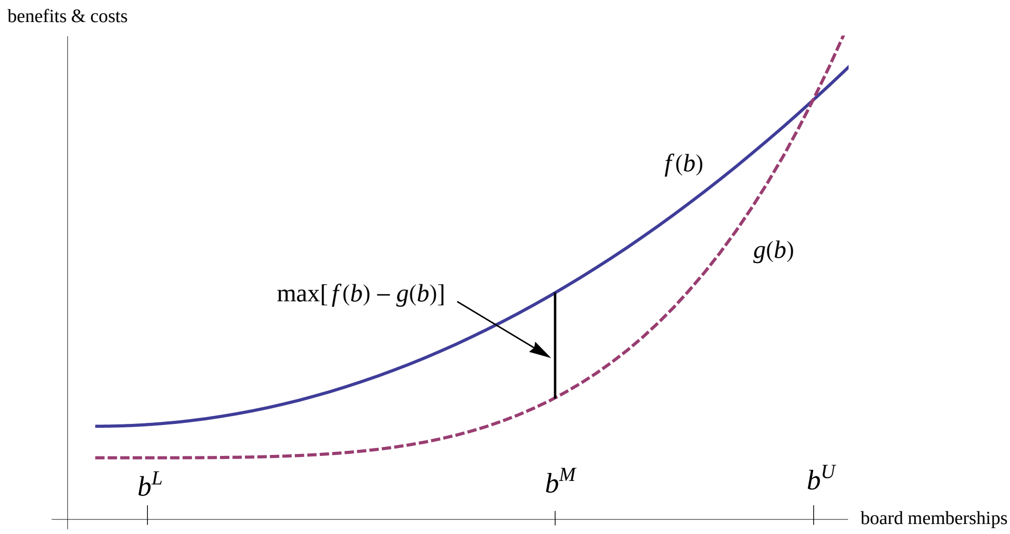

Figure 5: The costs and benefits of existing board membership in director appointment decisions.

time to competently carry out their services and duties.

Suppose that the conditional probability of multiple board membership is such that it depends on the costs and benefits of existing membership in the following fashion,

$$P(b+1|b) = p_0 + \alpha \left[f(b) - g(b) \right] ,$$

where p_0, α are normalization parameters, while $f(b) > 0$ and $g(b) > 0$ respectively denote the benefits and costs associated with appointing a board member who already serves on b boards. Provided that f and g are everywhere differentiable in the interval $b \in [b^L, b^U]$, it seems reasonable to assume that both benefits and costs are monotonically increasing in b, and that there exists a point b^M at which the marginal benefit equals the marginal cost of appointing a director with b^M memberships, $\mathrm{d}f(b^M)/\mathrm{d}b = \mathrm{d}g(b^M)/\mathrm{d}b$. At low b the benefits of appointing a well-connected director outweigh the costs, and $\mathrm{d}f(b)/\mathrm{d}b > \mathrm{d}g(b)/\mathrm{d}b$ for all $b^L \leq b \leq b^M$, but due to time constraints the costs become increasingly prohibitive as b gets larger such that $\mathrm{d}g/\mathrm{d}b \to \infty$ for $b > b^U$, while

$\mathrm{d}f/\mathrm{d}b < \infty$ for $b > b^U$, hence $\mathrm{d}f(b)/\mathrm{d}b \ll \mathrm{d}g(b)/\mathrm{d}b$ for all $b^M < b \leq b^U$. A graphical representation of this simple argument is illustrated in Figure 5.

There are, of course, other potential mechanisms underlying the existence of benefits and costs in board appointment decisions. A recent strand of research emphasizes the interplay between the hiring of executives or directors and the agency problems among different stakeholders like managers, employees, shareholders, etc. (see, e.g., Hermalin and Weisbach, 2003; Pagano and Volpin, 2005; Tirole, 2001). Inside directors could have an incentive to resist employee lay-offs, but also to keep on ineffective managers against the interests of shareholders or institutional investors. Abe and Shimizutani (2007), for instance, find that board composition between inside and outside directors has a significant influence on the willingness of boards to remove excess employment. Similarly, Lindbeck and Snower (2001) have argued from a macroeconomic perspective that insiders have an incentive to protect incumbent employees at the expense of outside interests. Naturally, directors with multiple board membership are outsiders,[6] and our simple cost-benefit approach could be adapted to an agency view by considering f as the benefit to shareholder interests stemming from the appointment of increasingly "reputable" outside directors, and g as the increasingly prohibitive opposition of insiders against the appointment of outside directors.

After all, and irrespective of a particular mechanism, the unexpected finding is that the limit on observed board membership is well below the legally binding limit, which speaks in favor of the hypothesis that economic constraints are of crucial importance in board appointment decisions. Research into the exact nature of these constraints is probably a worthwhile task in organization theory.

[6] According to Germany's co-determination laws (*Mitbestimmungsgesetz*), half of the directors on large corporate boards are elected employee representatives or trade union members. However, trade union guidelines limit board membership to two positions per union representative, thus it is fairly safe to assume that directors with three or more memberships represent "outsiders."

4 Conclusion

We tend to agree with Conyon and Muldon (2006) that the routinely used comparison of clustering coefficients and average path lengths versus a random graph benchmark is not overly useful in the context of board and director interlocks, which exhibit a high degree of clustering by construction. Starting from a random benchmark of multiple board membership, we were able to identify a small core in the network of director interlocks. Core agents turn out to be densely connected among themselves, to be highly central in the entire network, and to work for companies with a relatively large market capitalization. Therefore it seems reasonable to assume that these directors, in spite of their small number relative to the overall network size, exert a disproportionate degree of influence in the network. The hierarchical nature of the director network is also important from the viewpoint of probabilistic herding models, such as the one studied by Alfarano and Milaković (2008), because the hierarchical structure of the network can generate system-wide conformity in agents' opinions irrespective of the size of the network, including the possibility that the social interaction of core agents leads to the propagation of "animal spirits" across an entire system that is several orders of magnitude larger than the size of the core.

While it is probably true that core actors have considerable influence in the shaping of economic policy, and society in general, we would like to point out that one does not need a mighty conspirator who intentionally organizes the network of director interlocks into a hierarchical core-periphery structure. Initial positive feedbacks in our simple cost-benefit approach to board appointment decisions would explain the observed conditional probabilities of multiple board membership, which appear as an important force behind the existence of a small network core in director interlocks. In our opinion, it would be interesting to simulate the evolution of director interlocks under the assumption that the probability of board appointment, i.e. the linking probability, is proportional to the director-associated market capitalization. If such a procedure indeed replicates the core feature of director interlocks, one obtains a hierarchical structure without intentional design.

Finally, the fact that the overwhelming majority of directors who serve on many boards do so at largely capitalized companies is potentially useful information for researchers subscribing to an agency point of view. Moreover, policy makers and legislators might want to reconsider the limit on the number of legally permitted board memberships because, for one, it appears that economic constraints limit empirically observed board membership well below the legal limit anyway, while on the other hand, the multiple memberships that we do observe all coincide at companies with large market capitalization. After all, fifteen board memberships at companies with low market capitalization probably create much less pressure group influence than five memberships at the very largest companies, particularly if fellow directors at these companies in turn also serve on several other largely capitalized companies, as we observe in our sample.

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