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What makes a board director better connected? Evidence from graph theory

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Abstract. We are interested in quantifying and uncovering the relationships that form between the board directors of companies. Using these relationships we compute three network centrality measures for each director in the network and employ them in the analysis of connectedness of directors. Our focus in this study is on the attributes that make a board member better connected. The biological, educational and experiential attributes are used as independent variables to develop a regression model measuring the impact on the three connectivity measures (degree, betweenness and closeness). Our results show that "Age" has a direct significant impact on all connectedness measures of a board member. We also find that female directors have a higher measure of degree centrality and betweenness centrality, but lower closeness. The number of foreign degrees increases the degree centrality and betweenness centrality but not closeness. The three identified characteristics of "Age", "Gender", and "Education" are supporting the idea that a high level of social connection can in part be expected by the characteristics of individual board members and can explain up to 25% of the board member's connectivity.

Keywords: Board of director networks, Centrality Measures

1. Introduction

Abstractly speaking, a network is a set whose elements are linked in some way. Depending on the nature of elements and links we can often model social, economic, and political activities and phenomena using networks. Various networks have been objects of study of many researchers in the last half a century. From early studies in sociology to the latest economic analysis, it is evident that networks play an important role in our understanding of behaviour, influence, performance and information exchange of subjects or entities. The interest in networks is even more pronounced these days because of the tremendous amounts of data that are becoming available to researchers, and powerful computers that are being employed in the analysis of the data.

In business and finance research, especially in regards to corporate finance and corporate governance, we have seen a growing interest in the analysis of networks between company directors or between companies (Cohen et al., [6], El-Khatib et al. [8], Fogel et al. [13], Larcker and Wang [18], Larcker and Tayan [17], Renneboog and Zhao [21]. Networks of directors or companies can be equipped with numerous links. The most common linkage for directors is derived from their relationship through the same company (Fogel et al. [13], Larcker and Wang [18], Larcker and Tayan [17], Renneboog and Zhao [21]. Two directors will be connected in the network if and only if they sit on the board of the same company. Using affiliation as a starting relationship between directors one can see how interlocking directors [3] will immediately become links between companies. Beside the affiliation ties one may consider several other links, for example, two directors in a network are linked if and only if they have mutual alma mater, regional background or belong to the same social circle. These links are then used to measure director's or company's level of connectedness in the network.

To evaluate the level and specific notions of connectedness we use centrality measures. Network theorists have defined several distinct centrality measures that are correlated (Li et al. [19], Valente et al. [27].) An interlocking director will certainly be connected to more directors in the network than a director sitting on only one board. The number of connections of a director is measured by degree centrality. A director that is in the proximity of other directors can instantly communicate and exchange information with them. This type of connectedness is measured by closeness centrality. Lastly, a director that lies on the shortest path between two other directors will have power to control the flow of information or resources. This type of connectedness is measured by betweenness centrality. From the corporate governance point of view, a Director's Network plays an important role in the identification of relationships among board members and the overall effectiveness of the board.

Besides their regular responsibilities, directors on corporate boards are also expected to counsel and guide CEOs on major corporate strategic decisions. Directors' networks including educational, social, and professional relationships can have a positive impact on a director's advisory role. This is particularly important as firms with well-connected directors are known to outperform their peers and earn superior risk-adjusted stock returns as observed by Larcker, So and Wang [18]. We believe that with the increased impact of social media and accessibility of social networks, the flow of information can assist boards of directors in performing more effectively when their directors are well connected.

The study of connectedness through directors network seems to have significant implications for our understanding of the corporate governance as one of the most important areas of finance. This is particularly important at the present time as firms see broad demand and pressure from the public on understanding board members roles and responsibilities and the need for directors to be well connected to ensure global information exchange. In this regard, increasing the level of board's connectedness through the directors network is considered to be of great importance, and we would like to shed further light on this aspect through expected data-supported findings.

The paper is structured in the following manner. We start with the comprehensive review of the related literature in Section 2. Our main research question, "What attributes can be assigned to a director based on their centrality measures in the directors network",

[3] Directors that are members of more than one company board

and hypotheses are introduced in Section 3. Data used in the study and sample selections are described in Section 4. Details about modeling of networks using graph theory and centrality measures' statistics are discussed in Section 5. Finally, our empirical findings and conclusions are presented in Sections 6 and 7.

2. Literature Background

Various networks have been studied in the last few decades using mathematical tools. One of the most frequently used tools in network analysis is certainly graph theory (Proctor and Loomis [20], Sabidussi [22], Freeman [11], Borgatti and Everett [5], Schoch and Brandes [23]). It is now evident that a position of an individual or an entity in a network matters. Simply, individuals or entities that are at the center of the network, as opposed to the periphery, have more access to information and greater power to control the flow of information. Researchers have been predominantly using four network centrality measures (degree, closeness, betweenness and eigenvector centrality) to capture the position of an individual or an entity in a network. Although the four centrality measures are different in nature they are all functions of "nodal statistics" (a vector whose coordinates describe position of a node in a network) as noted recently by Bloch, Jackson and Tebaldi in [3]. They further show that all four centrality measures can be characterized by three axioms (monotonicity, symmetry and additivity), and argue that the centrality measures differ according to which nodal statistics they use, not the way in which the measure processes that information.

Taking advantage of the accessible data from various aspects of day to day life, researchers are trying to understand and explain behaviour of subjects in different social networks.

Fracassi and Tate [10] study the impact that CEOs may have on appointments of directors. They found that firms who have powerful CEOs are likely to appoint directors who have ties to the CEO. Furthermore, they suggest that network ties with the CEO lessens the efficacy of board governance and consumes corporate value.

Renneboog and Zhao investigated the relationship between director networks and takeovers [21]. They found that companies that are better connected are more effective bidders, and the presence of interlocking directorate between the bidder and target impacts the negotiations. They have also found that probability of a successful takeover transaction is higher and the negotiation time is shorter when two firms are directly connected through their directors.

El-Khatib, Fogel and Jandik evaluated the impact of the CEOs network centrality measures to merger and acquisition outcomes in [8]. Their analysis shows that the CEOs with high network centrality easily access and control private information, influence other parties in the network and use these advantages for more frequent acquisition decisions. In spite of all these advantages, the merger and acquisition deals initiated by the CEOs with high network centrality are more likely to incur higher value losses to both the acquirer and the merged entity than the deals initiated by the low network centrality.

Cohen, Frazzini and Malloy investigated the connections between sell-side analysts and management of publicly listed companies [6]. Their focus is on connections through alumni networks. They argue that analysts with educational ties to the senior management

of companies benefit from exclusive information available to them and exceed on their stock recommendations.

Hwang and Kim add a social ties dimension to the conventional independence of boards [14] and find that social ties do matter. Directors are considered independent if they have no financial and familial ties to the CEO or to the company. They look into alumni links, same regional background, military service, academic discipline and type of industry as informal ties between the directors and CEOs. While 87% of boards from the dataset analyzed are categorized as conventionally independent, only 62% remain independent when a social component is added. They also argue that companies whose boards are both conventionally and socially independent compensate their directors at a lower rate and are more sensitive to performance-related pay.

Engelberg, Gao and Parsons consider CEOs personal connections ("rolodex [4]") with eminent individuals (executives, directors, senior management) of other companies in [7]. They found that CEOs with a hefty rolodex earn more than those with a narrow circle of personal connections. Moreover, they computed that on average an additional file on the CEOs rolodex is worth at least $\$17000$.

Kramarz and Thesmar study in [15] impact of social networks on board composition and governance of French corporations listed on Paris stock exchange between 1992 and 2003. They found a powerful relationship between the CEO's social network and the one of directors sitting on the board. They also argued that the governance of these companies is affected in a bad way by these social networks.

While most research related to social networks of directors focuses on the negative side of the inter-board-connections, Larcker and Tayan in [17] stress that these connections can contribute to the value of a company and its shareholders. Larcker, So, and Wang consider the network of boards of directors of U.S. corporations and define board's centrality as a measure of each board's well-connectedness in [18]. A position of a firm in the network is determined by using four standard centrality measures and the derived score from these measures called "N-score". By ranking the firms according to their board's centrality, they find that the firms whose boards are best-connected on average bring in significantly higher future surplus and stock price returns than the least-connected companies. They also observed that their findings are most evident among newly formed companies with a high growth potential. Overall, their conclusion is that the networks of boards of directors do have an "important and positive impact on the economic performance of a firm."

The relationship between specific attributes of directors on the boards of companies and companies performance, board independence, decision making, social responsibility etc., has been a theme of many research papers across various academic disciplines. Our focus in this study are "Biological attributes" such as age and gender; "Educational background" such as total number of degrees, number of degrees obtain in North America and number of foreign degrees; and "Corporate experience background" like number of years on boards of either quoted and/or private companies.

Sharma has looked into gender, age, ethnic and cultural diversity of corporate boards of U.S firms from 2000-2006 and its impact on innovation in [24]. While these diversity attributes can lead to conflicts between decision makers in general, they also can contribute to higher level of innovation.

[4] A Rolodex is a rotating file used to store business cards

Studying gender diversity in the corporate world has attracted attention of many researchers lately. There have been research showing how corporate world is male dominated and that female directors are not only under-represented but also often underpaid. Fortin, Bell and Bohm look into these observations in [9]. Based on the data from Canada, Sweden and United Kingdom, they found that women are in fact under-represented among top earners in these countries, and that explains a considerable part of a difference in gender pay. Lalanne and Seabright investigate the impact of the social network of directors on their salaries [16]. They found that in case of male directors the size of their networks (knowing influential individuals) is positively correlated to their earnings while that is not true for female directors. Their findings also apply to non-salaried compensation.

An interesting real world example of intervention to fix gender gap in corporate governance is the case of Norway. In 2003 the government passed the law requiring Norwegian firms to have a minimum of 40% women directors on their boards. At that time only 9% of directors were women. This particular law that regulated diversification of the boards of companies has been a topic of research in previous literature [28] and [1]. While Ahern and Dittmar [1] focus mostly on the negative impact of government's intervention on firms performance, Wang and Kelan argue [28] that mandatory gender quota has had a positive impact on the appointment of the female board chairs and CEOs.

3. Research Questions and Hypotheses

Our comprehensive review of the related literature shows that most studies that employ centrality measures, focus on one of the following scenarios:

I) The impact of centrality measures on the CEO's (or director's) decision making and governance skills. There is evidence for stronger centrality measures resulting in higher power to appoint new directors from their own networks [10], influencing merger and acquisitions decisions [8, 21], sharing information with analysts [6], receiving higher compensation [7, 14, 16],
II) The impact of centrality measures on individual company's performance and its corporate governance with no consensus: evidence for positive effects [17, 18], evidence for negative effects [15], the corporation's position in the corporate networks [18], impact on innovation [24],
III) The impact of various attributes (biological, educational, experiential) of BODs [5] on company's performance [1], board's diversity [1, 9, 24], company's innovation [24], board's decision making [24], company's hiring practices [14, 15], salaries of CEO's and directors based on gender [16].

To the best of our knowledge no study has been done that looks into the relationship between the centrality measures and attributes of directors. A simple question that we ask is what attributes can be assigned to a director based on their centrality measures in the directors network. Are directors' centrality measures related to certain age, gender, education, foreign descent, previous service on many boards? Do directors with high centrality come from certain age, specific gender, level of education, foreign education, or have they previously served on significant count of boards?

[5] Board of Directors

In our study, we look into three centrality measures individually (degree, closeness, and betweenness)[6] and have tested hypotheses that each centrality measure is related to, on the following attributes: Age, Gender, Number of boards to date (quoted and private), Average number of years on quoted boards, Number of domestic (North American) degrees, Number of foreign degrees. The definitions of these attributes can be found in Table 3 on page 364.

Our goal is to determine what drives the connectedness of the board members. What attributes make a board member better connected? For each director-year, we design three measures of connectedness. We investigate directors' network by estimating a panel regression with firm and year fixed effects and account for several attributes of the board members. In light of this observation, the findings of our study will shed light on these questions.

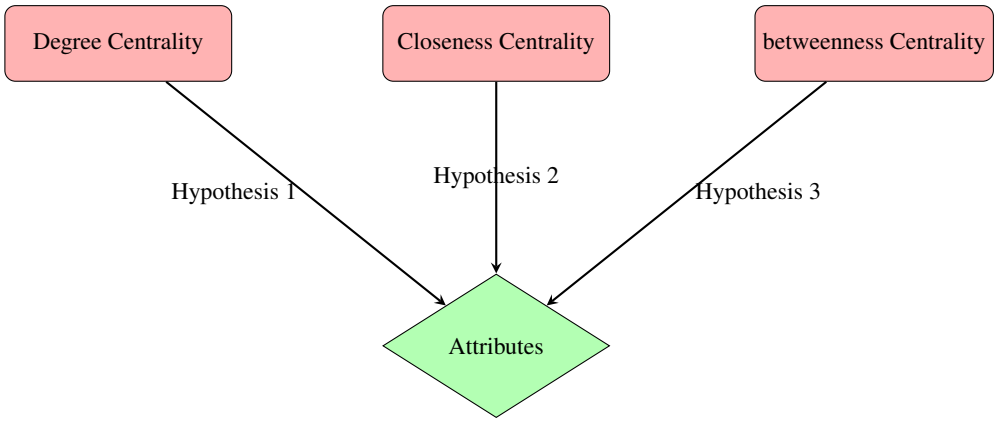

Fig. 1. Hypotheses

Null Hypothesis 1: *The directors with higher degree centrality*

a) have identifiable characteristics, and
b) will be an asset for the firm because of their direct access to many sources of communication and information exchange.

Null Hypothesis 2: *The directors with higher closeness centrality*

a) have identifiable characteristics, and
b) will be an asset for the firm because of their proximity to other directors and opportunity to communicate and influence them without having to go through many intermediaries.

[6] The three centrality measures were selected as historically the oldest and most commonly used centrality measures in the analysis of networks ([4], [12]). They also have very established interpretation in the directors network context

Null Hypothesis 3: *The directors with higher betweenness centrality*

a) have identifiable characteristics, and
b) will be an asset for the firm because they lie on numerous shortest paths between other directors in the network and often are vital brokers of information and resources exchange.

Our hypotheses are formulated in a compact way to include several attributes rather than listing them individually. For example, by testing age and degree centrality we expect to find that older directors will know more people in the network; female directors will have greater degree centrality, and directors with more education degrees will have greater degree centrality, as well as other measures.

4. Data Description and Sample Statistics

In order to conduct the empirical analysis, we used the data from the North American (United States and Canada) market for the period between 2005 and 2015. Our sample has been compiled using the BoardEx database [7] provided by Management Diagnostics Ltd. This database collects biographical information on corporate directors and top executives of publicly listed firms and large private firms in North America and around the world. It includes more than 400,000 individuals and over 14,500 companies.

Using the BoardEX database for North America we construct the graphs that describe the networks between directors on monthly basis and we compute metrics (centrality measures) on these graphs. The graphs are constructed and the measures are computed using Mathematica. Using the "Director Networks" files, that have information on connections between directors who were on the boards of the same company during a period of time, we have included the entries from Table 1 using the filters described in Table 2.

We considered only the new connections between directors that started in January 2005 or later. The connections that started prior to January 2005 and were still existing after January 2005 are not included in our analysis. We found that the total of 52352 directors were on the boards of 8270 companies during the decade 2005-2015. Out of 52352 directors approximately about 84% were NEDs and 16% were EDs.

Additionally, we have also included the information from the "Director Profile" files related to biological, educational and experiential attributes given in Table 3. The common characteristics such as age, gender, and nationality are defined in this table. In addition, the two variables "Quoted" and "Private" count the number of public and private company boards the director is sitting on respectively.[8]

Our data shows that boards of directors of public companies consist mostly of male directors. Only 12% of all directors are female. The information on nationality of directors is unknown for approximately 46.5% of all directors considered in our study. Out of remaining 53.5% of directors with known nationality, majority of them are American, almost 46.5%. Following are the directors with Canadian and British nationality who together comprise about 5%. The remaining 1.89% of directors are of 89 different nationalities.

[7] `http://corp.boardex.com`

[8] It is noteworthy to mention that total sum of Quoted and Private can be a measure of "Busyness" of each director.

Table 1. Director Profiles Characteristics

Characteristic	Definition
DirectorID*	A unique identifier assigned to each Director
Linked DirectorID*	Director ID of the individual linked to the starting Director
Connected CompanyID*	Company ID of the company through which the starting individual and the linked individual are connected
Connected Company Type	Type [a] of company through which the starting individual and the linked individual are connected
Date of overlap	Starting and ending dates through which the two individuals overlap at the given company or organization
Overlapping Person's Role Title	Role or title of the individual connected to the starting individual at the time of the overlap
Individual's Role Title	Role or title of the starting individual at the time of the overlap
ED/NED/SM	Executive Director, Non-Executive Director, or Senior Management Indicator

[a] Quoted - Publicly listed company, Private - Private company, University, Club etc.

Table 2. Filters applied to the Director Profiles Characteristics

Connected Company Type	Quoted
Date of overlap	January 2005 - December 2015
Overlapping Person's Role Title	ED, NED
Individual's Role Title	ED, NED

Table 3. Director Profiles Characteristics

Characteristic	Definition
Age	Director's Age either calculated from DOB [a] or known from disclosure
Gender	The Director's gender
Nationality	The Director's nationality
Education Country	The country in which director obtained education degree
Number of Degrees	Total number of director's education degrees
Number of Foreign Degrees	Total number of degrees obtained in the countries outside of North America
Number of Quoted Boards	Number of boards of publicly listed companies the director has sat on over his career
Number of Private Boards	Number of boards of private companies the director has sat on over his career

[a] Date of birth

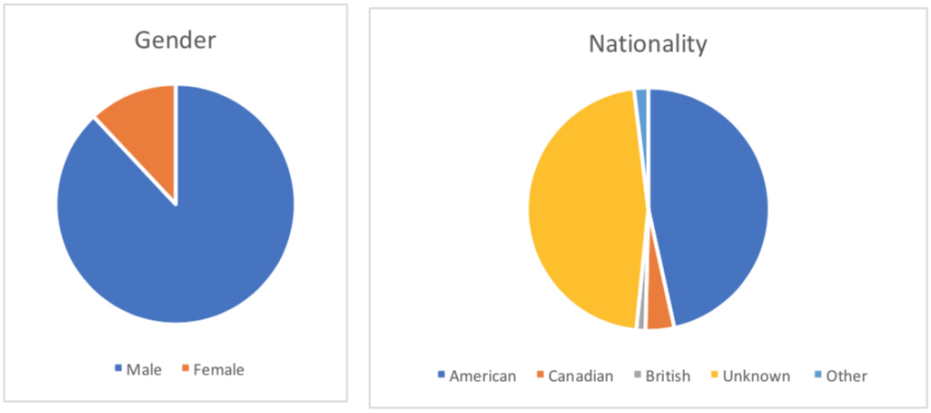

Fig. 2. Pie Charts of Director Attributes

5. Methodology

We consider the network of directors a graph. The individual directors are the vertices of the graphs and the edges represent relationships of connectivity. We then apply graph theory to detect, using a quantitative method, some of the characteristics of the board of directors' connectedness.

The directors attributes (age, gender, nationality, education, number of quoted boards to date) will be exogenous variables to the model of centrality measures. In order to measure the strength of the relationship, we use the three centrality measures (degree, closeness and betweenness) as the observed dependent variables. In other words, we expect to find that the following relationships hold

$$\text{Degree Centrality} = f_1(\text{Attributes})$$

$$\text{Closeness Centrality} = f_2(\text{Attributes})$$

$$\text{betweenness Centrality} = f_3(\text{Attributes})$$

5.1. Modeling Director Network Using Graphs

A graph is an ordered pair $G = (V(G), E(G))$, where $V(G)$ is a nonempty set of vertices and $E(G)$ is the set of edges. Vertices are elements of a nonempty set. A set can be finite or infinite. Edges are links between 2 vertices and can be oriented if needed.

Given a set of directors $D_1, D_2, \ldots, D_n$ from a network we define the set of vertices to be $V = \{D_1, D_2, \ldots, D_n\}$. Edges represent relationships that may exist between directors. We studied the edges defined by the following relation

1. there is an edge between two directors if and only if they were on a board of a company at the same time,

but various other types of edges can be defined on the set of directors. For example,

2. there is an edge between two directors if and only if they attended the same university,
3. there is an edge between two directors if and only if they share the same regional background.

For each month between January 2005 and December 2015 we constructed a graph whose vertices are directors (only NED and ED), and there is an edge between two directors if and only if they were on a board of a company during a particular month period. We used three centrality metrics (degree, betweenness, and closeness) to explain how director's connections are related to their professional and personal characteristics.

5.2. Director and Edge Count

The chart in Figure 3 presents the average number of directors and edges per year from 2005-2015. As mentioned earlier, this only includes directors who started serving on boards of companies from January 2005. We see that 22684 directors (identified by their unique IDs) joined boards of various companies during the year 2005. This number grew over a decade to 50392. The growth has plateaued after 2008 to approximately 49000 directors per year. In spite of this, the number of edges (ED and NED connections through boards of companies) has continued to grow steadily. In 2005 there were 39213 edges, but by the end of 2015 this number almost quintupled to 191911 edges. Considering that the number of directors became more or less constant after 2008, this suggests a very significant increase of interlocking directors.

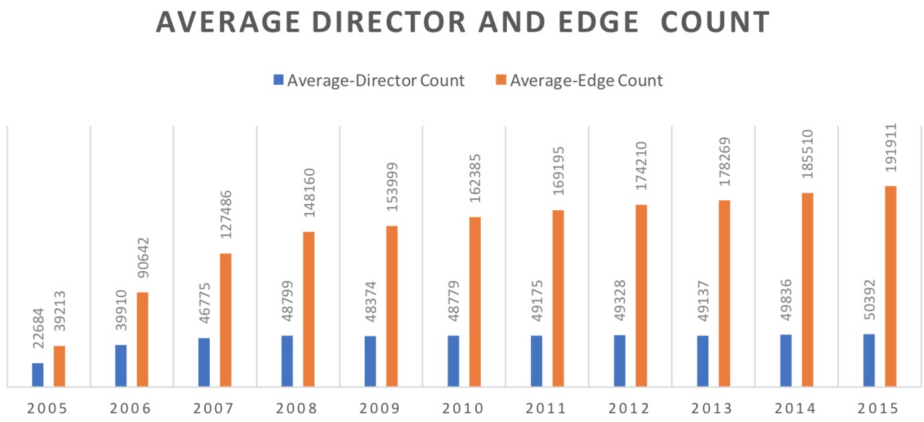

Fig. 3. Average Director and Edge Count

The average number of directors per year indicates the approximate size of an average monthly graph. These monthly graphs were not connected. A usual monthly scenario would be a few big connected subgraphs and many small isolated connected subgraphs that represent companies with no interlocking directorate. The centrality measures were computed on the connected components.

5.3. Centrality Measures

Centrality as a concept was first introduced in social network analysis as a tool to identify influential individuals in the network and to explain how networks of individuals or organizations behave. The most commonly used centrality measures include degree, closeness, betweenness, eigenvector, clustering coefficient, page rank centrality etc. As previously mentioned, we considered only the first three measures. In this section we first define these measures using graph theory language and afterwards we interpret their meaning in relation to the networks of directors constructed using BoardEx database.

Degree Centrality An important vertex in a graph is involved in large number of interactions. The degree of a vertex in a graph measures the amount of direct links between that vertex and other vertices.

Let $G = (V(G), E(G))$ be a graph with n vertices and let $x \in V(G)$ be a vertex. Degree centrality of a vertex x, denoted by $d_G(x)$, is defined by

$$d_G(x) = \text{the number of edges connecting x with other vertices.}$$

In order to compare networks of different sizes we normalize the degree centrality of a vertex. The normalised degree centrality of a vertex x, denoted by $Nd_G(x)$, is defined by

$$Nd_G(x) = \frac{d_G(x)}{n-1}$$

($n-1$ is the maximum possible degree of a vertex in an undirected graph). It can be expressed either as a proportion or percentage.

In relation to the graphs constructed using BoardEx database, where vertices are directors, the higher degree of a vertex (director) implies better connectedness of that director in the network (graph). A director with high degree will have immediate access to more information, resources, and communication channels through his direct connections. As we can see from the summary Table 4 of degree centrality statistics, the minimal degree was 1. This may look like an anomaly on the first sight, implying that we have a company whose board has only 2 directors. The reason for this is the fact that some North American directors also serve on the boards of international companies and not all details of those boards were accessible to us. For example, if North American directors A, B in a given month were only sitting on a board of a British company, their connection will be listed in BoardEx data but there will be no additional information of the other board members of the British company unless they were also North American. This allows for a minimum degree to be 1. We were not aware of this fact until recently.

Maximum degrees range between 44 and 110 approximately. High degree like these implies that a director was sitting on several large boards of companies. Mean degree is more realistic number of direct connections of a typical director. The column Mean DC of Table 4 shows a 125% increase of the number of direct connections of a typical director over the period 2005-2015. The polygon line given in Figure 4 indicates that although the mean degree grew continuously it did not go above 8. This suggests that an average director was likely sitting on the board of only one company over the decade 2005-2015.

Table 4. Degree Centrality Statistics

Degree Centrality: DC	Min DC	Max DC	Mean DC
2005	1.00	43.75	3.33
2006	1.00	87.25	4.51
2007	1.00	104.00	5.45
2008	1.00	110.00	6.07
2009	1.00	106.64	6.37
2010	1.00	109.27	6.66
2011	1.00	104.36	6.88
2012	1.00	98.27	7.06
2013	1.00	90.91	7.26
2014	1.00	89.82	7.44
2015	1.00	85.73	7.62

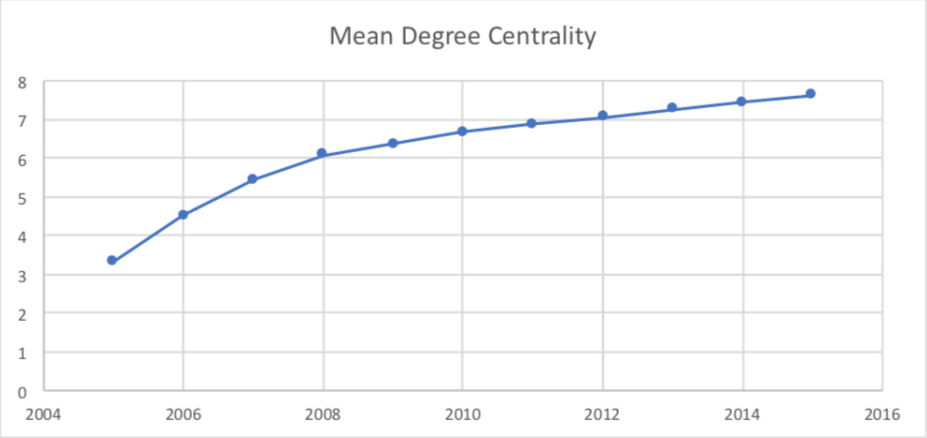

Fig. 4. Polygon line of Mean Degree Centrality

Closeness Centrality Closeness measures proximity of a vertex in a graph to other vertices. Let $G = (V(G), E(G))$ be a connected graph with n vertices $V = \{x_1, x_2, \ldots, x_n\}$ and let $x_i \in V(G)$ be a vertex. Geodesic distance (also known as the shortest path) between vertices x_i and x_j is denoted by $d(x_i, x_j)$. Closeness centrality of a vertex x_i, denoted by $C_G(x_i)$, is defined by

$$C_G(x_i) = \frac{n-1}{\Sigma_{j=1}^{n} d(x_i, x_j)}$$

$C_G(x_i)$ is the inverse of the average of all shortest paths between the vertex x_i and any other vertex x_j.

Closeness of a vertex is always between 0 and 1. A vertex will have closeness centrality 1 if it has direct access (the path of length 1) to all other vertices. The smaller the average of all shortest paths between the vertex x_i and any other vertex x_j, the larger the

closeness centrality of the vertex x_i. In relation to the graphs constructed using BoardEx database, where vertices are directors, the larger closeness centrality means that a director can quickly reach other directors in a network without having to go through several intermediaries. Closeness is often referred to as a measure of influence rather than information flow.

Table 5. Closeness Centrality Statistics

Closeness Centrality: CC	Min CC	Max CC	Mean CC
2005	0.04	1.00	0.31
2006	0.06	1.00	0.26
2007	0.07	1.00	0.25
2008	0.07	1.00	0.26
2009	0.06	1.00	0.26
2010	0.06	1.00	0.26
2011	0.06	1.00	0.26
2012	0.08	1.00	0.26
2013	0.07	1.00	0.26
2014	0.07	1.00	0.26
2015	0.06	1.00	0.26

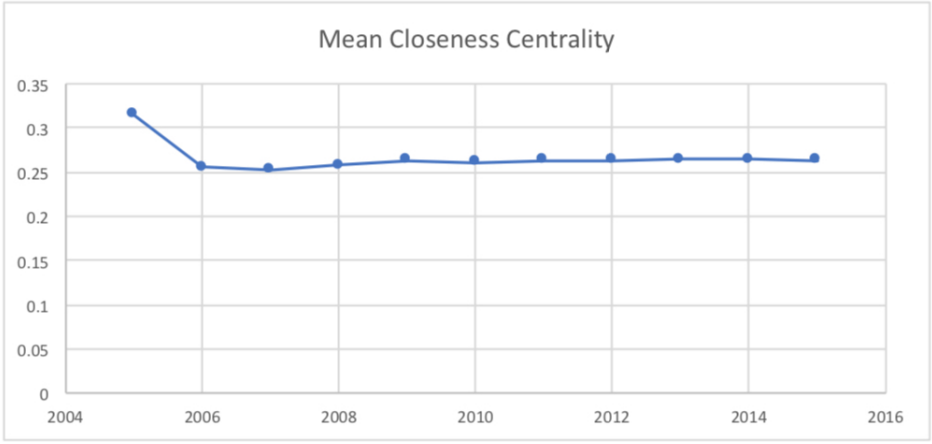

Fig. 5. Polygon line of Mean Closeness Centrality

Table 5 shows the closeness centrality statistics. We see that the closeness centrality ranges between 0.04 and 1.The maximum closeness of 1 is attributed to the above-mentioned directors with degree of 1, or to directors of an isolated company with no interlocking directorate. We can ignore these because no director who is a part of a bigger

subnetwork (connected subgraph) will have centrality score of 1. The minimum closeness is between 0.04 and 0.08 approximately. These would be the scores of the most remote directors in a bigger subnetwork. The polygon line of the mean closeness, given in Figure 5, was constantly around 0.26 except for the year 2005. This implies that during the decade 2005-2015, the average of all shortest paths between a typical director and any other director in the connected subnetwork was around 4.

Betweenness Centrality A vertex that is often in the shortest path (geodesic) between two other vertices has a central role in the network. Such a vertex is essential in the information transfer between other vertices. Let $G = (V(G), E(G))$ be a connected graph with n vertices $V = \{x_1, x_2, \ldots, x_n\}$ and let $x_i \in V(G)$ be a vertex. $\sigma(x_i, x_j)$ denotes the total number of shortest paths from the vertex x_i to the vertex x_j and $\sigma_k(x_i, x_j)$ is the number of those paths that pass through the vertex x_k. Betweenness centrality of a vertex x_k, denoted by $B_G(x_k)$, is defined by

$$B_G(x_k) = \Sigma_{i \neq j \neq k} \frac{\sigma_k(x_i, x_j)}{\sigma(x_i, x_j)}.$$

$B_G(x_k)$ is the sum of the shortest paths between all vertices x_i and x_j that pass through the vertex x_k, scaled by the total number of shortest paths between the vertices x_i and x_j. Normalizing the betweenness centrality is done by rescaling $B_G(x_k)$ by $\frac{(n-1)(n-2)}{2}$, which is the largest possible betweenness metric in a connected graph with n vertices. Our betweenness centrality measure is not normalized.

Table 6. betweenness Centrality Statistics

betweenness Centrality: BC	Min BC	Max BC	Mean BC
2005	0.00	4388166.40	46558.70
2006	0.00	9466666.67	90428.00
2007	0.00	8503636.36	103280.84
2008	0.00	9489090.91	103055.71
2009	0.00	8703636.36	99524.35
2010	0.00	9955454.55	100807.40
2011	0.00	9423636.36	100757.29
2012	0.00	9482727.27	101169.78
2013	0.00	7861818.18	100558.75
2014	0.00	8582727.27	101971.89
2015	0.00	8409090.91	103332.10

Table 6 shows the betweenness centrality statistics. Peripheral directors in a network, and directors of boards of isolated companies with no interlocking directorate will have betweenness 0. As the size and the number of edges of the monthly graphs grew, some directors took up a between position on many more geodesics connecting other directors in a network. The maximal values come from directors who were part of subnetworks that had between 4000 and 4500 connected directors. Directors with high betweenness

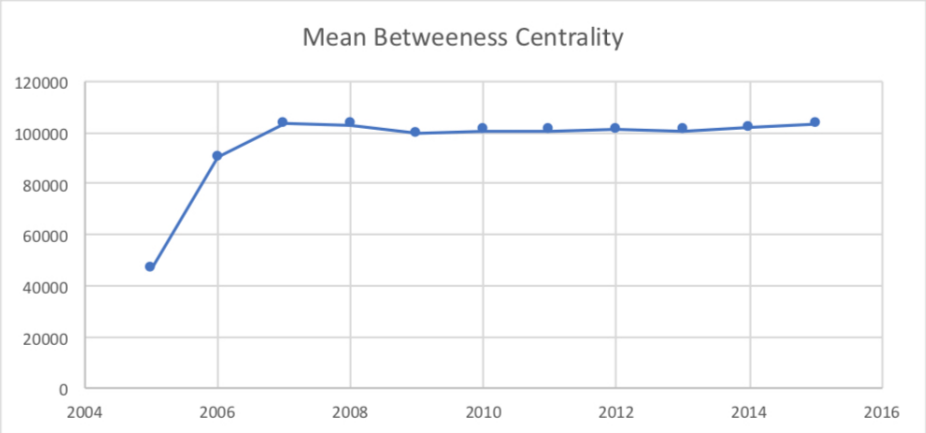

Fig. 6. Polygon line of Mean Betweenness Centrality

are exposed to a lot of information being exchanged among other directors and as such have power to influence other directors and collect information faster. As indicated on the polygon line given in Figure 6, the mean betweenness has plateaued after 2007. This suggests that the number of shortest communication channels between directors, that a typical director was a part of, stayed relatively constant for the most part of the decade 2005-2015.

6. Empirical Results

The calculated measures of connectivity provide an important input into the empirical analysis of our research. In this section we explain the results from the statistical and econometrics findings.

By employing 2,407,752 firm-year-board observations of 52,352 unique board members from 8270 companies in North America from 2005 to 2015, we create a pooled panel dataset that includes the three connectivity measures as the key dependent variables of the study. The sample shows some interesting findings which supports our hypotheses.

We conduct a series of multiple regression analyses that reveal a significantly positive relationship between board connectivity and key characteristics of the board members. The empirical results confirm that such individual characteristics increase the network connectivity of each board member and hence facilitate corporate governance and consequently promote a better connected board. Our results can also be interpreted that a good institutional environment may benefit from the effect of board members' social connectedness facilitated by diverse characteristics of the board members.

6.1. Correlation analysis

Table 7 shows the correlation between the variables under study. Based on the correlation results, we find that Age, Number of degrees, Number of foreign degrees, and gender,

are correlated with our connectivity measures. This supports conducting the regression analysis later. We can then test our hypotheses by running a linear regression on these characteristics against the key dependent variables.

Table 7. Correlation Analysis.
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	DC	CC	BC	Age	Qtd	Pvt	Fem	AvgYr	NumDeg	NumFDeg
DC	1									
CC	-0.1389	1								
BC	0.7522	-0.1328	1							
Age	0.0659	-0.0047	0.071	1						
Quoted	0.4651	-0.1798	0.4683	0.1581	1					
Private	0.195	-0.1205	0.1865	0.0689	0.4629	1				
Female	0.0634	-0.0278	0.0407	-0.0545	-0.0213	-0.0706	1			
Average years on board	-0.1467	0.0059	-0.0621	0.2955	-0.0088	0.0224	-0.0544	1		
Number of degrees	0.053	-0.0567	0.0566	0.0789	0.0709	0.0696	0.0585	-0.0063	1	
Number of Foreign Degrees	0.0901	-0.0457	0.0876	-0.0419	0.0823	0.088	-0.0248	-0.0586	0.2181	1

6.2. Regression analysis

In this section we run three key regressions to test our hypotheses. We test whether directors with higher number of connections have any identifiable characteristics. This as a result will be an asset for the firm because of the facilitation and speed of information exchange in the global market.

For each director-year, we have designed and calculated three measures of connectedness. These three measures act as dependent variables in each regression model. Tables 8, 9, and 10 display the results of the regression analysis. We also control the analytic tests by estimating a panel regression with firm and year fixed effects. We account for several characteristics of the board members.

The results show that "Age" has a direct significant impact on all connectedness measures of the board member. This is intuitive, given the longer the experience of the board member, the more individuals they would know. Our next finding is on role of gender: Female directors have a higher measure of degree centrality and betweenness centrality, but lower closeness.

Expanding on this result, there are implications for directors as well as board composition: nominating committee will be more likely to support that additional female directors will be added to the board. Having a higher degree of betweenness for female directors can also motivate policy makers to encourage inclusion of female directors which will impact board effectiveness as well as more diverse board decisions. See Bernilea, Bhagwal, and Yonker [2] and Sila, Gonzales, and Hagendorff [26].

Finally, the number of degrees and foreign degrees both increase the connectedness degree and betweenness centrality but not closeness. The results support the value of global education and the resulting network of such experience for a board member.

The three identified characteristics of "Age", "Gender", and "Education" are supporting the idea that a high level of social connection can in part be expected by the describing characteristics of individual board members. These characteristics can explain up to 25% of the board member's connectivity (based on the average R-squared values). [9]

Table 8. Degree Centrality Regression.
Regression results showing the relationship between independent variables (described in Table 3) Age, Quoted, Private, Gender, Average Years on Board, Number of Degrees, Number of Foreign Degrees and the dependent variable Degree Centrality

Dependent Variable: DC	Coefficient	Standard Error	*t*
Age	0.0247	0.0004	69.2300
Quoted	1.1764	0.0017	712.2200
Private	-0.0219	0.0009	-23.9000
Female	1.7203	0.0138	124.4300
Average Years on Board	-0.1535	0.0006	-241.8400
Number of Degrees	0.0234	0.0046	5.0600
Number of Foreign Degrees	0.7132	0.0078	91.6100
Intercept	5.1521	0.0217	237.2500
R-squared	24.10%		

Table 9. Closeness Centrality Regression. Regression results showing the relationship between independent variables (described in Table 3) Age, Quoted, Private, Gender, Average Years on Board, Number of Degrees, Number of Foreign Degrees and the dependent variable Closeness Centrality

Dependent Variable: CC	Coefficient	Standard Error	*t*
Age	0.0006	0.0000	37.3200
Quoted	-0.0162	0.0001	-232.3000
Private	-0.0023	0.0000	-58.9500
Female	-0.0201	0.0006	-34.4500
Average Years on Board	-0.0006	0.0000	-23.2100
Number of Degrees	-0.0122	0.0002	-62.4200
Number of Foreign Degrees	-0.0106	0.0003	-32.3100
Intercept	0.3134	0.0009	341.4900
R-squared	4.04%		

[9] In panel data analysis, it is customary to rely more on individual significance and overall significance of the model instead of R^2 or adjusted R^2. In our panel data due to large number of directors and heterogeneity of cross sections, R^2 is not too high.

Table 10. Betweenness Centrality Regression. Regression results showing the relationship between independent variables (described in Table 3) Age, Quoted, Private, Gender, Average Years on Board, Number of Degrees, Number of Foreign Degrees and the dependent variable Betweenness Centrality

Dependent Variable: BC	Coefficient	Standard Error	*t*
Age	683.9481	23.33007	29.32
Quoted	78699.05	107.9423	729.08
Private	-3118.249	59.85688	-52.1
Female	79559.59	903.524	88.05
Average Years on Board	-4032.804	41.48484	-97.21
Number of Degrees	5636.232	302.2457	18.65
Number of Foreign Degrees	46183.41	508.7785	90.77
Intercept	-71865.91	1419.166	-50.64
R-squared	22.64%		

Table 11. Log of Betweenness Centrality Regression. Regression results showing the relationship between independent variables (described in Table 3) Age, Quoted, Private, Gender, Average Years on Board, Number of Degrees, Number of Foreign Degrees and the Log of dependent variable Betweenness Centrality. Since the betweenness centrality scores used are inherently large values, this table provides a robustness test for Table 10 results.

Dependent Variable: LogBC	Coefficient	Standard Error	*t*
Age	0.0112	0.0004	29.0900
Quoted	0.6228	0.0015	425.6900
Private	-0.0081	0.0008	-9.7400
Female	0.6008	0.0134	44.8700
Average Years on Board	-0.0286	0.0007	-41.0200
Number of Degrees	0.2027	0.0046	44.0600
Number of foreign degrees	0.3150	0.0072	43.6500
Intercept	6.2436	0.0233	267.7600
R-squared	17.22%		

7. Conclusion

In the context of the directors network and the impact of the directors attributes (age, gender, education) to the centrality measures we found that "Age" has a direct significant impact on all connectedness measures of a board member. This suggests that older directors are likely to get to know or meet many directors in their long tenure and career lifetime, and use these connections to channel swiftly the information exchange either directly or through liaisons.

Another important finding is the multi-dimensional role of gender: Female directors have a higher measure of degree and betweenness centrality, but lower closeness. This indicates that female directors despite having more direct connections and being on the

shortest paths between many directors in the network, are less influential than male directors. Our study is unique in quantifying such important aspect.

In addition, the number of degrees and foreign degrees increase the degree and betweenness centrality measures but not closeness. The directors who obtained one or more education degrees in North America (or internationally), have potentially met some directors outside of business world. So, they are likely to have more connections in general and to be intermediaries for the information exchange, but they are not necessarily more influential individuals in their current business network.

While this research explores multiple attributes of board members and makes key contributions on the role of connectivity, our future research is directed towards measuring the numerical impact of these attributes on firms' performance. Analyzing firm's return and boards turnover is another interesting expansion that will be further studied.

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References

1. Ahern, K. R, Dittmar, A., K., 2012. The changing of the boards: the impact on firm valuation of mandated female board representation. The Quarterly Journal of Economics 127, 137–197. doi:10.1093/qje/qjr049.
2. Bernilea, G., Bhagwat, V., Yonker, S., 2018. Board diversity, firm risk, and corporate policies. Journal of Financial Economics Vol. 127 Issue 3, 588–612.
3. Bloch, F., Jackson, M. O., Tebaldi, P., 2017. Centrality Measures in Networks. Available at SSRN: http://dx.doi.org/10.2139/ssrn.2749124
4. Boldi, P., Vigna S., 2014. Axioms for centrality. Internet Mathematics 10, 222–262.
5. Borgatti, P., Everett, G., 2006. A graph-theoretic perspective on centrality. Social Networks, 28, 466–484.
6. Cohen, L., Frazzini, A., Malloy C., 2010. Sell-Side School Ties. The Journal of Finance 65.4, 1409–1437.
7. Engelberg, J., Gao, P., Parsons, C., 2013. The price of a CEO's rolodex. Review of Financial Studies 26, 79–114.
8. El-Khatib, R., Fogel, K., Jandik, T., 2015. CEO network centrality and merger performance. Journal of Financial Economics 116, 349–382.
9. Fortin, M. N., Bell, B., Bohm B., 2017. Top earnings inequality and the gender pay gap: Canada, Sweden, and the United Kingdom. Labour Economics Vol. 47, 107–123.
10. Fracassi, C., Tate, G., 2012. External Networking and Internal Firm Governance. The Journal of Finance Vol LXVII, No 1, 153–194.
11. Freeman, L.C., 1977. A set of measures of centrality based on betweenness. Sociometry 40, 35–41.
12. Freeman L., 1979. Centrality in social networks: Conceptual clarification. Social Networks 1, 212–239.
13. Fogel, K., Ma. L, and Morck, R., 2014. Powerful Independent Directors. European Corporate Governance Institute (ECGI) - Finance Working Paper No. 404/2014. Available at http://dx.doi.org/10.2139/ssrn.2377106
14. Hwang, B., Kim, S., 2011. It pays to have friends. Journal of Financial Economics 100, 382–401.

15. Kramarz, F., Thesmar, D., 2013. Social networks in the boardroom. J. Eur. Econ. Assoc. 11, 780–807.
16. Lalanne, M., Seabright, P., 2011. The Old Boy Network: Gender Differences in the Impact of Social Networks on Remuneration in Top Executive Jobs. CEPR Discussion Paper No. DP8623. Available at https://ssrn.com/abstract=1952484
17. Larcker, D.F., Tayan B., 2010. Director Networks: Good for the Director, Good for Shareholders. Rock Center for Corporate Governance at Stanford University Closer Look Series: Topics, Issues and Controversies in Corporate Governance No. CGRP-08
18. Larcker, D.F., So E.C., Wang C.C., 2013. Boardroom centrality and firm performance. Journal of Accounting and Economics 55.2, 225–250.
19. Li, C., Li, Q., Van Mieghem, P. et al., 2015. Correlation between centrality metrics and their application to the opinion model. Eur. Phys. J. B 88: 65. https://doi.org/10.1140/epjb/e2015-50671-y
20. Proctor, C., Loomis, C., 1951. Analysis of sociometric data. In: Holland, P., Leinhardt, S. (Eds.), Research Methods in Social Relations. Dryden Press, New York, NY.
21. Renneboog, L., Zhao, Y., 2014. Director networks and takeovers. Journal of Corporate Finance 28, 218–234.
22. Sabidussi, G., 1966. The centrality index of a graph. Psychometrika 31, 581–603.
23. Schoch, D., Brandes, U. 2016. Re-conceptualizing centrality in social networks. European Journal of Applied Mathematics, 27(6), 971–985. doi:10.1017/S0956792516000401
24. Sharma, Z. 2016. Board Composition and Innovation. Applied Finance Letters, Vol 05, Issue 02.
25. Shahgholian, A., Theodoulidis, B., Diaz, D., 2015. Social Network Metrics: The BoardEx case study, http://ssrn.com/abstract=2613156
26. Sila, V., Gonzalez, A., Hagendorff, J., 2016. Women on board: Does boardroom gender diversity affect firm risk? Journal of Corporate Finance 36, 26–53.
27. Valente T.W. et al., 2008. How Correlated Are Network Centrality Measures? Connect (Tor)., 28(1), 16–26. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2875682/.
28. Wang, M., Kelan, E., 2013. The Gender Quota and Female Leadership: Effects of the Norwegian Gender Quota on Board Chairs and CEOs. Journal of Business Ethics Vol. 117, Issue 3, 449–466.

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