The Network Analysis of Interlocking Directors: The Case of Thailand's Listed Companies

Nattapong Puttanapong

Abstract

The network analysis has been applied to the dataset of interlocking directors of listed companies. All obtained indicators identify that the network of directors has the stable structure during 2012-2016. Also the computed Watts-Strogatz Statistics confirmed that the interlocking-director network has the small-world property, which is highly clustering pattern of affiliation. The computed Watts-Strogatz Statistics also identified the small-world feature in the case of the network of boards of listed companies, unveiling the new understanding of highly clustering linkages among listed firms. In order to examine the structure of these densely clustering networks, this study also used the computational technique of community detection. The outcomes revealed that the number of members in detected communities is not uniformly distributed. Instead, only a small number of communities constitute the majority of the network. These findings suggest the further studies examining the impacts of these characteristics on firms' performance.

บทคัดย่อ

งานวิจัยนี้ได้ประยุกต์วิธีวิเคราะห์แบบ Network Analysis กับข้อมูลกรรมการบริษัทในตลาดหลักทรัพย์แห่งประเทศไทย ผลการวิเคราะห์โดยใช้ดัชนีในหลายลักษณะได้แสดงให้เห็นว่าเครือข่ายของกลุ่มกรรมการซึ่งดำรงตำแหน่งในคณะกรรมการของหลายบริษัท (interlocking directors) มีคุณลักษณะของความสัมพันธ์ภายในเครือข่ายที่ไม่เปลี่ยนแปลงมากนักในช่วงปี พ.ศ. 2555-2559 ทั้งนี้ งานวิจัยนี้ได้วิเคราะห์คุณลักษณะของเครือข่ายโดยการคำนวณค่า Watts-Strogatz Statistics และพบว่าเครือข่ายของกลุ่มกรรมการซึ่งดำรงตำแหน่งในคณะกรรมการของหลายบริษัท มีลักษณะการกระจุกตัวตามรูปแบบของความสัมพันธ์แบบ small-world ซึ่งพบได้ในตลาดหลักทรัพย์ในหลายประเทศเช่นเดียวกัน นอกจากนี้เมื่อวิเคราะห์ความสัมพันธ์ระหว่างบริษัท ยังได้พบลักษณะของ small-world โดยเช่นเดียวกัน ซึ่งแสดงให้เห็นถึงการความสัมพันธ์ในลักษณะที่กระจุกตัวระหว่างบริษัทในตลาดหลักทรัพย์ที่เป็นผลมาจากการดำรงตำแหน่งในคณะกรรมการของหลายบริษัทของผ่านเครือข่ายกรรมการ โดยงานวิจัยนี้ได้การศึกษาในรายละเอียดของลักษณะความสัมพันธ์ดังกล่าว โดยใช้เทคนิคคำนวณที่เรียกว่า community detection เพื่อแยกกรรมการในเครือข่ายออกเป็นกลุ่มย่อย และผลลัพธ์แสดงให้เห็นว่าการกระจายตัวของจำนวนสมาชิกในกลุ่มย่อยเป็นไปแบบกระจุกตัว และเมื่อวิเคราะห์โดยใช้เทคนิคดังกล่าวกับบริษัททั้งหมด ก็ได้ผลลัพธ์ในลักษณะเดียวกัน ทั้งนี้ควรมีการศึกษาเพิ่มเติมเพื่อวิเคราะห์การส่งผลกระทบของคุณลักษณะของเครือข่ายดังกล่าวต่อผลประกอบการของบริษัทต่อไป

The Network Analysis of Interlocking Directors: The Case of Thailand's Listed Companies

Nattapong Puttanapong[1]

1. Introduction

The development of network analysis has been one of the most prominent fields of studies in the past 70 years. Barabási (2016) stated that when compared to other main areas of studies in science such as quantum and artificial intelligence, the network analysis has surpassed them in term of the number of citations and the frequency of use of the words in publications. Not only does the development of theories in network analysis provide the new foundation for physic, chemistry, biology and engineering, but it also broadens the knowledge in social science, economics, and even the counterintelligence investigation as documented by Lawton(2016).

The theoretical foundation of network analysis has been initiated by Erdős and Rényi (1959), introducing the mathematical framework describing the quantitative characteristics of network formulated by randomness (i.e. the random graph model). Specifically, this theory enables the prediction of key indicators of network's properties such as the numbers of linkages, the average length of all paths, and the diameter of the network.

Simultaneously, Ithiel de Sola Pool and Manfred Kochen initiated the mathematical framework in 1958, later published in de Sola Pooland and Kochen (1978), explaining the special characteristic of human's society. Particularly, their work proposes the idea that there is actually a short path linking any pair of persons in the world (i.e. the small world effect). Milgram(1967) documented the outcome of his actual experiment of small world effect using the technique of randomly distributed mails. His work, conducted in the US, has indicated that the median of intermediates is 5.2, implying that there are approximately the maximum of 5-6 links connecting any pair of persons in the society. Guare(1992) applied this finding as the fundamental of his famous Broadway play 'six degrees of separation', and this play's title has become the popular phrase.

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Scientifically, Watts and Strogatz(1998) solidified the concept of small world effect through their breakthrough work, providing the mathematical framework representing the formulation and quantitative characteristics of the small world phenomena.

In finance, the pattern of interlocking directorate has been observed for many decades, and it triggered attentions from regulators and researchers. In addition, the development of methods in network analysis quantitatively unveils two hidden networks, which are the affiliation among directors and the linkages among firms. Particularly many literatures have documented the empirical evidence of small-world pattern in stock markets the cases of both developed and developing countries. These revealed outcomes shed light on the new insight of the connection among listed companies, and they unveils the new dimension of networks that might extend the fundamental concept of symmetric risk through interlocking directorate.

With the evolving development of techniques in network analysis, this paper aims at examining the following characteristics of listed companies in Thailand using the data of 2012 - 2016.

(1) The quantitative characteristics of the network of directors and that of listed firms obtained from network analysis
(2) The existence of small world pattern
(3) The quantitative features of subgroups within the network of directors and that firms classified by network analysis

The analysis has been conducted in both cases of the network of directors and the network of boards of listed companies. Under this research's objective and scope, this paper has been organized as follows. The second section explores related literatures, and the third one describes data and quantitative methods employed in this study. The fourth session exhibits findings and discusses their implications. The last part concludes this paper and suggests main issues for future studies.

2. Literature review

As defined by Useem(1982) and Ljungqvist and Raff (2017), the "interlocking director" or "multiple director" has been synonymous with "busy director", identifying the individual who affiliates with more than one board. This section is organized based on three categories of related studies. The first is the related theories explaining factors influencing the pattern of cross-company directorate. The second is the international survey of research applying the network analysis to the data set of directors of listed companies. The last category is the related studies focusing on the case of Thailand.

2.1 Theories of interlocking directorates

The formation of cross-firm directors has been observed since the analysis of Berle and Means (1932). There are three theories describing this behavior, namely (1) the reciprocity theory, (2) the resource-based theory and (3) the class hegemony theory.

2.1.1 The reciprocity theory

Stearns and Mizruchi (1986) defined the case of reciprocity model as "the evidence of partially alliance between firms". Also Pfeffer and Salancik(1978) and Bazerman and Schoramn(1983) documented the mutual benefits among firms generated by interlocking directorate. Particularly it is shown that the interconnection of companies enabled the mitigation of external uncertainties, e.g. the risks caused by supplier and regulation, through the harmonized managerial activity across boards.

2.1.2 The resource-based theory

Mizruchi and Stearns (1988) identified that the obvious case of the resource-based formation is the connection between the financial firm and its borrowers. Likewise the similar connection is based on the supply chain relationship, interlocking the boards of supplier and purchaser. Richardson(1987) demonstrated that this relationship can lead to the higher performance of connected companies. Land and Lockhart(1990) confirmed the similar findings of mutual gains generated to interlocking firms. However, it is suggested that there is possibly the asymmetric benefits to all connected companies, especially the case of relationship designed for financial supervision and control as the case of France documented by Elouaer-Mrizak(2012).

2.1.3 The class hegemony theory

The class hegemony theory proposes the alternative perspective on the behavior of interlocking directors. As stated in Palmer(1983), the assignment of directors to corporates' boards is based on the social connection, particularly the dominant groups in the society. Caswell (1984) and Drago et al. (2015) identified that this pattern can formulate the specific social network which preserves the influence of the dominant groups and lessens their uncertainties during the economic fluctuations.

2.2 Network analysis of interlocking directorates

The network analysis has become one of main methods of examining the social structure of interlocking directorate. Furthermore, the small-world effect in interlocking directors and boards has been verified in many cases. Table 1 exhibits the list of countries and related literatures.

Table 1: The survey of literatures examining the small-world effect of interlocking directors

Counties	**Related literatures**
US	Battiston and Catanzaro(2004)
	Caldarelli and Catanzaro(2004)
	Davis et al.(2003)
	Strogatz(2001)
	Conyon and Muldon(2006)
	Caldarelli(2007)
	Robins and Alexander(2004)
	Kogut(2012)
UK	Conyon and Muldon(2006)
	Kogut(2012)
Australia	Robins and Alexander(2004)
Canada	Kogut(2012)
Italy	Battiston and Catanzaro(2004)
	Caldarelli and Catanzaro(2004)
	Caldarelli(2007)
	Kogut(2012)
Germany	Conyon and Muldon(2006)
	Kogut(2012)
The Netherlands and Switzerland	Kogut(2012)
	Heemskerk and Schnyder(2008)
Denmark, Norway and Sweden	Kogut(2012)
	Sinani et al.(2008)
South Africa	Durbach and Parker(2009)
South Korea	Kogut(2012)
	Nam and An(2017)
Poland	Sankowska and Siudak(2016)
Greek	Dimitrios and Vasileios(2015)
Spain, France, Brazil, Chile, Israel, Mexico and Taiwan	Kogut(2012)

Studies listed in Table 1 confirmed the similar findings of small-world effect in the case of listed companies. Especially, the small-world pattern has been verified in both networks of directors and the affiliation among firms sharing the directors. These findings have been confirmed for both cases of developed and developing economies.

2.3 Analysis of interlocking directorates in the case of Thailand

Peng et al. (2001) examined the Thailand-based multinational enterprises (MNEs) to validate the patterns of interlocking directorates. Following the resource dependence theory, their work concluded that MNEs were densely interlocking and mostly were among the central agents of the network. Sitthipongpanich and Polsiri (2013) applied the data of listed companies during 2001 – 2005 to their regression analysis and found that the diversity in age and study majors are positively related to Tobin's Q ratio, while diversity in educational levels leads to lower firm value.

3. Data and methods

3.1 Data

The data of directors of listed companies have been obtained from SETSmart, which is the on-line service provided by the Stock Exchange of Thailand. This data set covers the period of 2012-2016. Table 2 exhibits the description of interlocking directors, indicating that approximately 15.8 percent[2] of all directors was multiple directors and proportion were stable during 2012-2016. In this study, the data set of multiple directors was used in the network analysis, and all computations were conducted by using R with the installed 'igraph' package.

3.2 Methods

3.2.1 Main indicators of network's properties

The origin of network analysis was the graph theory, which is the mathematical principle focusing on relationships across nodes and paths. Therefore, the fundamental elements of network analysis are comprised of nodes and links[3].

Based on this foundation, the furthered mathematical concepts have been developed to examine the basic properties of network, which are the following indicators.

[2] The average of proportion during 2012-2016.

[3] Alternatively called vertices and edges in graph theory, respectively.

- **Degree:** One of main properties of each node is degree. The magnitude of degree indicates the number of links to other nodes. If we define k_i as the degree of the *i* node and *N* is the number of total nodes, the total number of links (*L*) is denoted as:

$$L = \frac{1}{2}\sum_{i=1}^{N} k_i$$

- **Average Degree:** One of key indicators of the network is the average degree, denoted as $<k>$. The formula for computing $<k>$ is defined as:

$$<k> = \frac{1}{N}\sum_{i=1}^{N} k_i = \frac{2L}{N}$$

- **Average Path Length:** The average distance between all pairs in a particular network is defined as the average path length, mathematically denoted as $<d>$.

$$<d> = \frac{1}{N(N-1)} \sum_{i,j=1 \; and \; i \neq j}^{N} d_{i,j}$$

- **Shortest Path:** The shortest path is the route between two nodes which has the minimum distance. Alternatively, it is called Geodesic Path.
- **Diameter:** The longest path between a pair of nodes in the network is defined as the diameter (d_{max}). This indicator represents the width of the network.
- **Density:** The density is the ratio of total number of links to the maximum number of potential links. For the network with N node, the maximum possible number of links is *N(N-1)/2*. Therefore, the density(*S*) of the network is mathematically denoted as:

$$S = \frac{2L}{N(N-1)}$$

In addition to the key indicators indicating the properties of the network listed above, the quantitative characteristics of network can be presented by using centrality indices, which are the following metrics.

- **Degree Centrality:** One of the most intuitive indicators representing the effect of a particular node on the overall network is the Degree Centrality. The Degree Centrality is the summation of all degrees of a particular node. This measure can also be standardized by its value with the maximum possible number of links.

- **Eigenvector Centrality:** Apart from the Degree Centrality, the Eigenvector Centrality has been developed by summing only linkages connected to important nodes. Mathematically speaking, the computation is based on the eigenvalue of the adjacency matrix, which is the tabulated representation of nodes and linkages.
- **Closeness Centrality:** The average of all distances originating from a particular node to all others in the network is defined as the Closeness Centrality. This metric represents the alternative measure of significance of a particular node to the network based on distances. It is noted that Closeness Centrality is the key indicator in the study of network's tolerance to failure. If the high Closeness Centrality node is attacked, the degree of negative consequence is substantial.
- **Betweenness Centrality:** In addition to the number of links or the distance to others, one of important properties of a particular node is its function of transmitting physical matter or information to other nodes. Based on this concept, the Betweenness Centrality is the metric quantifying the significance of each node as the key transmitter to the network. Mathematically, this measure is based on the computation of number of sets of shortest paths to other nodes. Therefore, the highest Betweenness Centrality node has the maximum numbers of shortest paths to other nodes, enabling it to minimize time to transmit a substance or the information to other nodes with the maximum network coverage.
- **Transitivity or Clustering Coefficient:** The transitivity is the metric defined as the sum of paths connecting neighbors to the maximum possible number of routes connecting all neighbors. Alternatively, transitivity is the number of pairs of mutual friends divided by the maximum possible numbers of pairs making all friends connected. In other words, the value of transitivity indicates the possibility that a randomly picked pair of neighbors of a particular node is connected. Transitivity or Clustering Coefficient is the key indicator in identifying the small-world case because its network has the highly clustering pattern.

3.2.2 Watts-Strogatz Statistics

All indicators introduced in the previous session are very important in quantifying the properties of a network. Specifically, these metrics are used as criteria in the classification of network. The first classification of network is the Random-Graph class or the Erdős–Rényi model. This model assumes that each pair of nodes is randomly connected. Therefore, this model is the hypothetical case. Furthermore, most of empirical evidences documented that the actual structure of human's society has a different property from that of Erdős–Rényi model. Particularly, it is conventionally found that the actual network has the substantially higher degree of transitivity (i.e. the high value of clustering coefficient). Following Humphries and Gurney (2008) and Sankowska and Siudak (2016), the Watts-Strogatz Statistics (S^{WS}) can be computed from the following equation.

$$S^{WS} = \frac{\gamma^{sw}}{\lambda} \ ,$$

where $\gamma^{sw} = \frac{Cluster\ Coefficient\ of\ Actual\ Data}{Cluster\ Coefficient\ of\ Random\ Graph}$ and $\lambda = \frac{Avg\ Shortest\ Path\ Length\ of\ Actual\ Data}{Avg\ Shortest\ Path\ Length\ of Random\ Graph}$

Based on the model develop by Watts and Strogatz (1998), it is expected that γ^{sw} >> 1.0 and $\lambda \approx$ 1.00, leading to the case of S^{WS} >> 1.00, which is the main indicator of the small-world case.

3.2.3 Community detection

In this study, in order to deeply examine the structure of network, the computational method of community detection was applied to the network of directors and the network of boards of listed companies. Specifically, the Walktrap algorithm was the method used. Developed by Pons and Latapy (2005), the Walktrap algorithm introduces the idea that for any network, the distance between two nodes can be measured based on the concept of random walk and probability. Mathematically, it is defined that P^t is the probability of randomly walking from a randomly picked node in the community C to reach node j within t steps, denoted as:

$$P^t(Cj) = \frac{1}{|C|} \cdot \sum_{i \in C} P^t_{i,j}$$

The distance between two communities, C_1 and C_2, of the network V is defined as r_t :

$$r_t(C_1, C_2) = \sqrt{\sum_{k=1}^{n} \frac{(P^t_{C_1 k} - P^t_{C_2 k})^2}{d(k)}}$$
$$C_1, C_2 \in V$$

Fundamentally, the Walktrap algorithm proposes the main idea that it is highly likely that the random walker can get "trapped" in the densely connected parts (i.e. the communities) of the network. Hence the network can be separated into communities based on this concept of distance measured in terms of P^t and r_t. Because most of social networks are highly clustered, the community detection can decompose the subtle affiliation and unveil the connection among sub-communities constituting the network.

4. Result

4.1 Properties of the director network and those of the board network

The discussions of computational results have been organized by based on the scopes of research questions listed in section 1. Since the data were organized in the format of table mapping the name of directors and their affiliation to each listed company, the first step of computation was the bipartie projection, generating the network of directors connected through the same board affiliation. Simultaneously this twin-domain projection generated the network of boards of listed companies, identifying the formation of linkages across firms via interlocking directors. The next step was the calculation of networks' main indicators. These matrices indicate the structural properties of the network of directors and that of boards. Following methods introduced in section 3.2, Table 3 and 4 exhibit that key characteristics of both networks were insignificantly fluctuating during 2012-2016. The stable values of diameters imply that the width of networks has been unchanged. The small variations of values of density, standardized average degree and average path length reveal that structural linkages of cross-firm directorate were hardly changed. Similarly all measures identifying the degree of centrality and clustering pattern, namely Eigen index, Closeness index and Transitivity index, quantitatively indicate the unwavering structure of both the network of directors and the affiliation among connected firms during 2012-216.

Figure 1 and 2 illustrate the graphical representations of both networks based on the data of 2016. Each node in Figure 1 represents an individual director, while the particular node in Figure 2 indicates the board of each listed company. The thickness of linkages of both plots is based on the magnitude of Betweenness indices. Figure 3 and 4 exhibit the diameter of each network. Specifically, the thick line running across the network of directors in Figure 3 illustrates the longest path connecting the pair of nodes, identifying the width of the network which is composed of 10 handshakes. In the similar vein, Figure 4 shows the diameter of the network of boards, which is the maximum number of 13 links connecting two listed companies.

Table 2: Proportion of interlocking directors

Year	Total Directors	Interlocking Directors	(% of total)	Single-Board Director	(% of total)	Avg. Directors per Board
2012	6,516	1,030	*15.81%*	5,486	*84.19%*	10.13
2013	6,725	1,072	*15.94%*	5,653	*84.06%*	10.27
2014	6,804	1,047	*15.39%*	5,757	*84.61%*	10.39
2015	6,896	1,089	*15.79%*	5,807	*84.21%*	10.28
2016	6,991	1,123	*16.06%*	5,868	*83.94%*	10.49

Table 3: Summary of key indicators of network's properties (the network of directors)

Year	Type of Network	Density	Standardized average degree	Closeness index	Eigen index	Diameter	Transitivity index	Average shortest path length
2012	Director Network	0.0082	0.0335	0.0017	0.9683	10.0000	0.6413	4.1056
2013	Director Network	0.0121	0.0395	0.0058	0.9364	9.0000	0.6001	3.8134
2014	Director Network	0.0119	0.0428	0.0061	0.9464	9.0000	0.5907	3.8469
2015	Director Network	0.0101	0.0404	0.0043	0.9368	11.0000	0.6385	3.9284
2016	Director Network	0.0117	0.0423	0.0049	0.9343	10.0000	0.6130	4.0310

Table 4: Summary of key indicators of network's properties (the network of boards of listed companies)

Year	Type of Network	Density	Standardized average degree	Closeness index	Eigen index	Diameter	Transitivity index	Average shortest path length
2012	Board Network	0.0081	0.0355	0.0026	0.9199	15.0000	0.3878	4.2342
2013	Board Network	0.0094	0.0349	0.0027	0.8993	15.0000	0.3835	3.9568
2014	Board Network	0.0094	0.0350	0.0028	0.9043	12.0000	0.3999	4.0182
2015	Board Network	0.0093	0.0340	0.0027	0.9061	11.0000	0.3950	3.9478
2016	Board Network	0.0083	0.0413	0.0026	0.9340	13.0000	0.3984	4.1595

Figure 1: Network of directors (computationally formulated based on Betweenness index of data of directors of 2016)

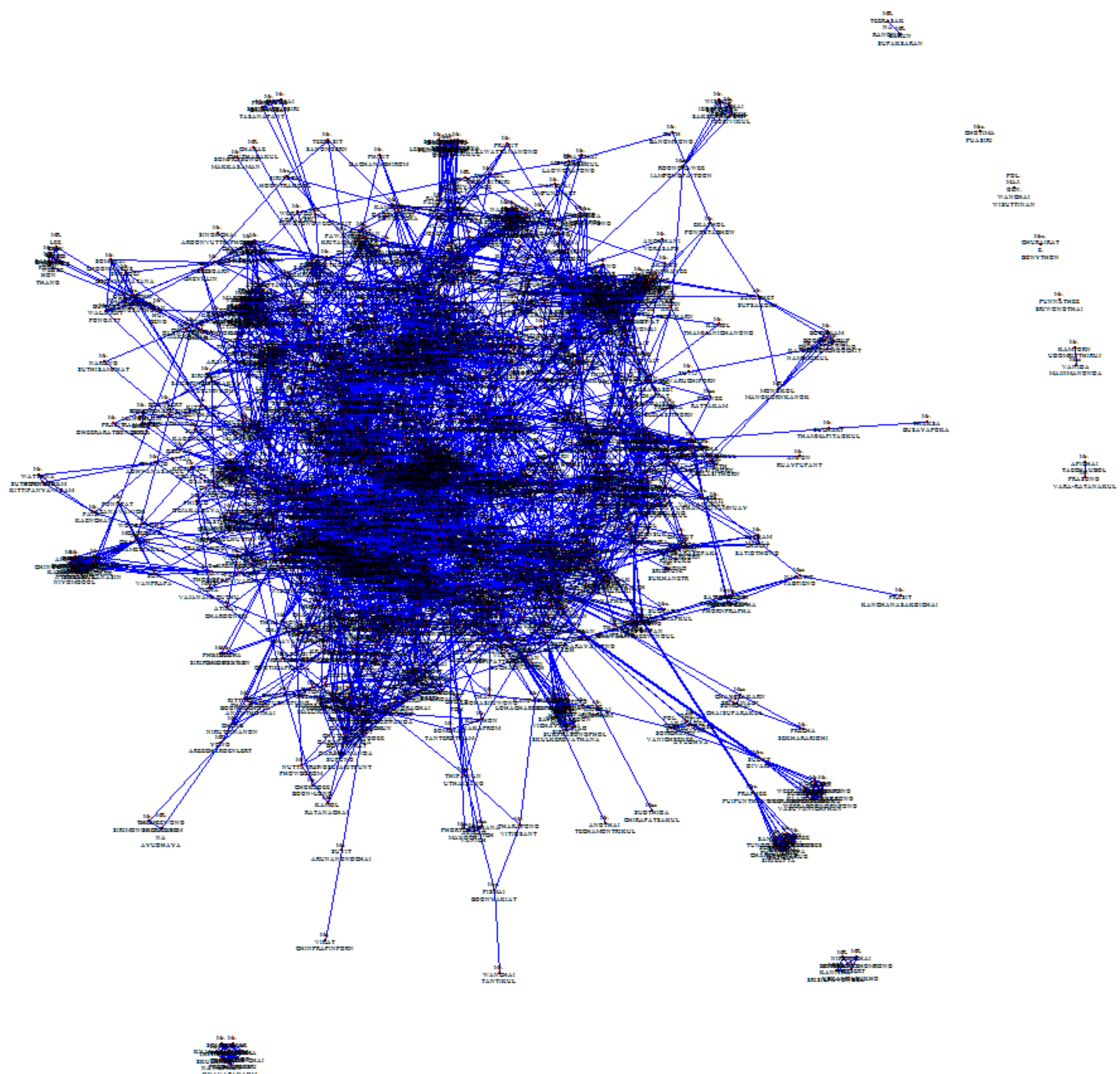


Figure 2: Diameter of network of directors (computationally formulated based on Betweenness index of directors in 2016)

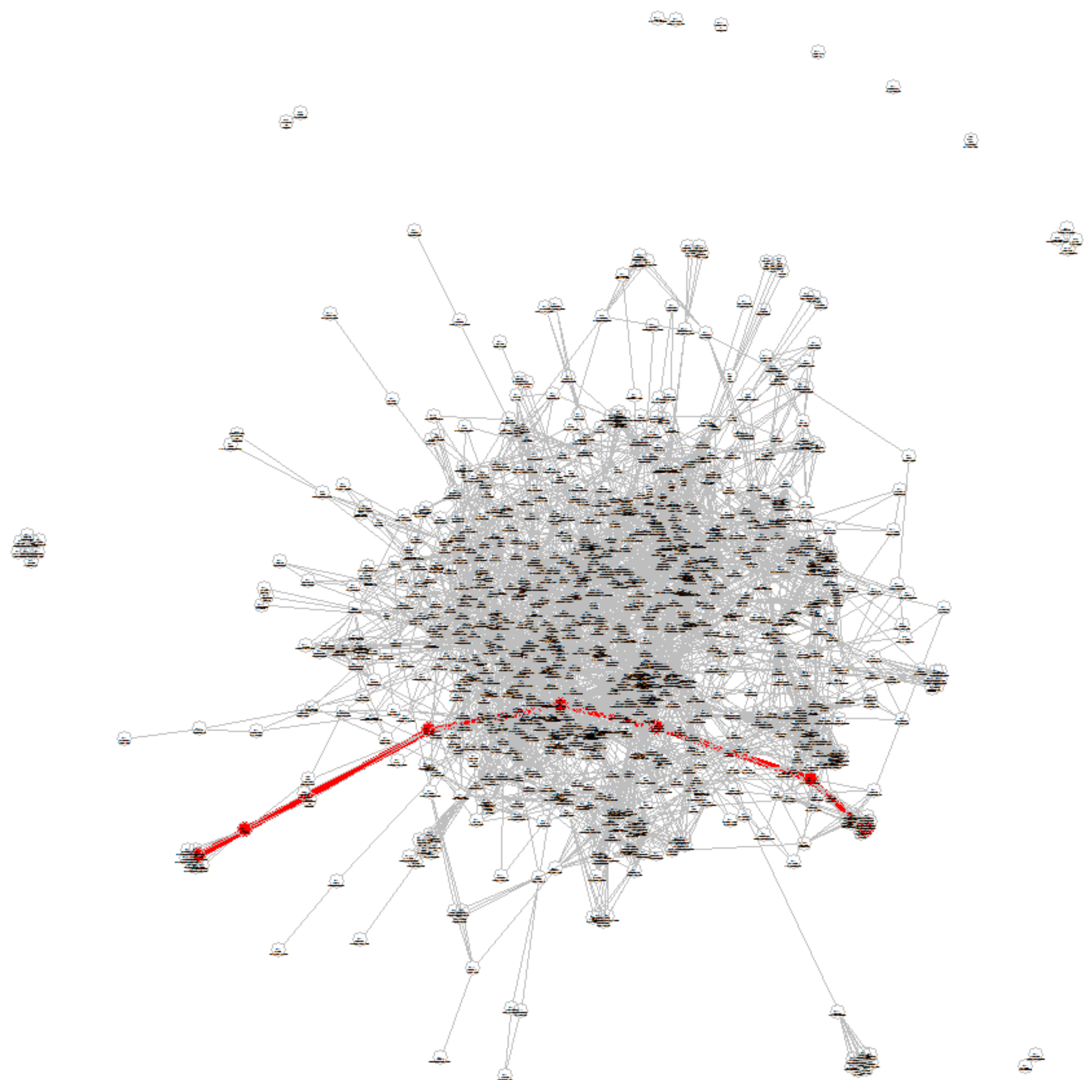


Figure 3: Network of boards of listed companies (computationally formulated based on Betweenness index of all boards in 2016)

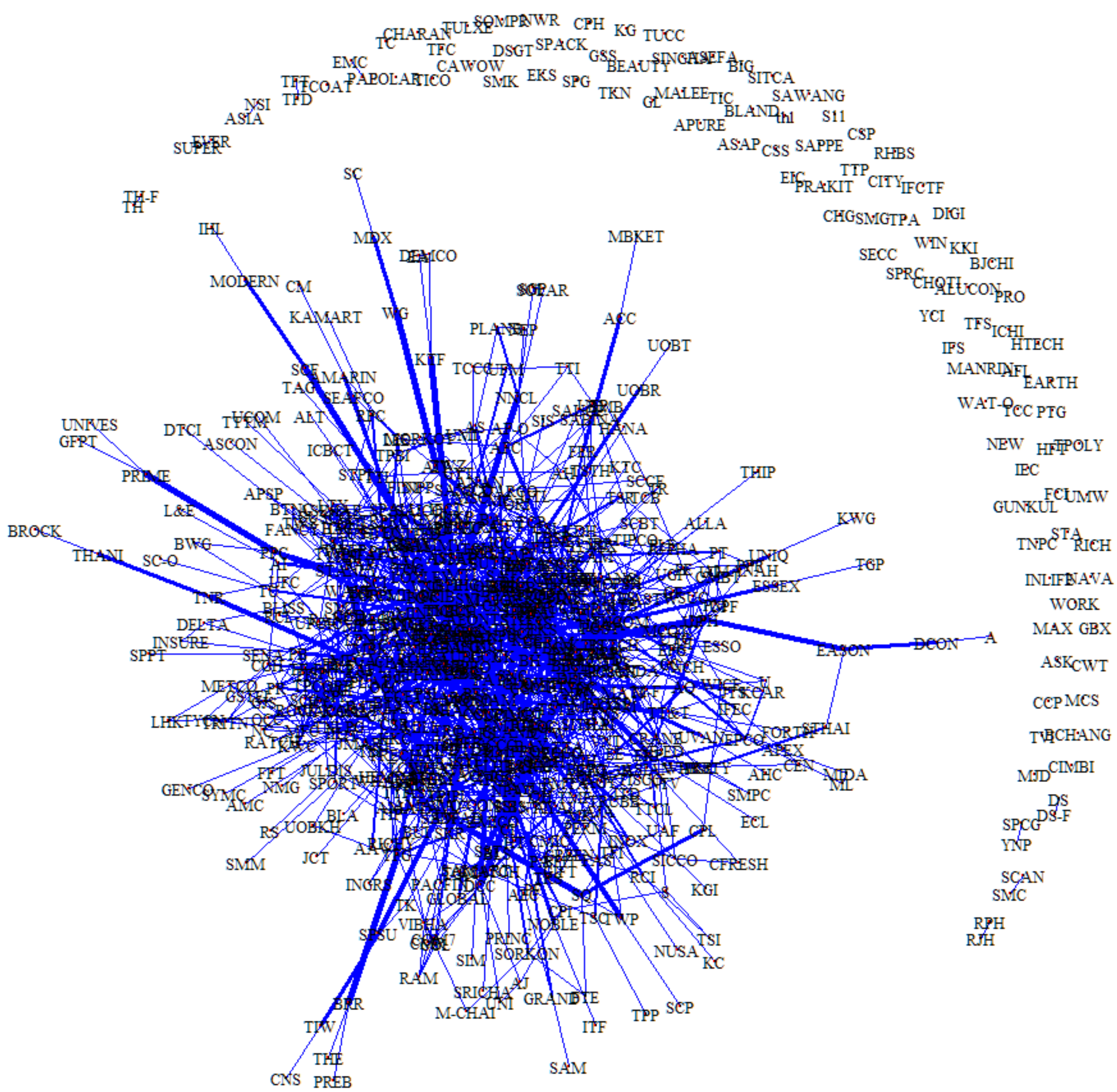


Figure 4: Diameter of network of boards of listed companies (computationally formulated based on Betweenness index of boards in 2016)

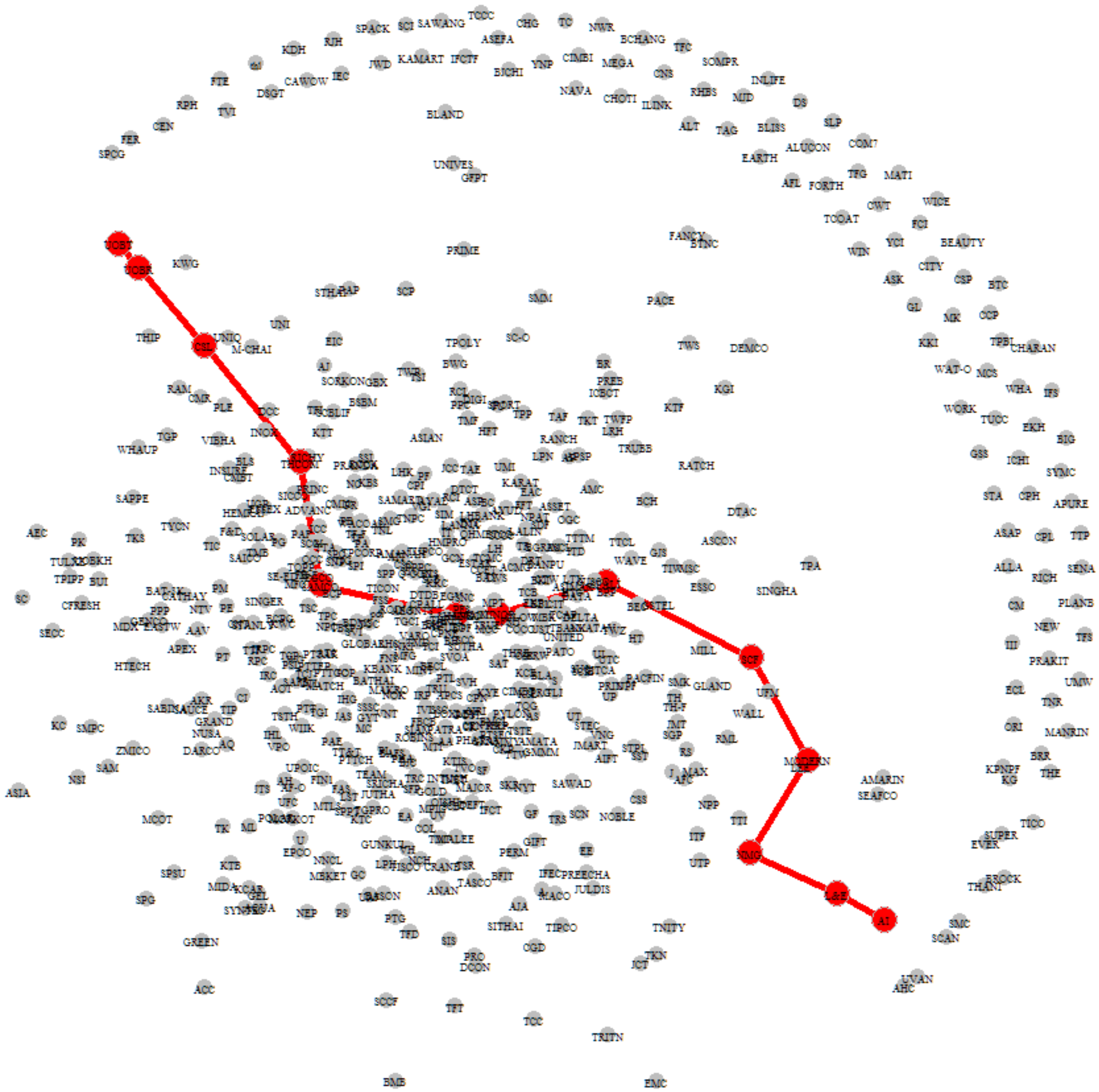


Table 5 – 10 exhibit the outcomes of applying the calculation of centrality indices to the individual level. The obtained results follow the previous finding of stable structure of both networks as shown in Table 3 -5. Specifically all values of the standardized average degree, Betweenness index and Pagerank index indicate the similar outcomes throughout the period of 2012-2016, confirming the invariant structure of both networks.

Based on these findings, one of interesting properties of these networks is the high degree of Transitivity index (i.e. the clustering coefficient). This empirical evidence suggests the further examination of the small-world effect verification, which is discussed in the following section.

4.2 Watts-Strogatz Statistics

As earlier introduced in section 2.2, there are a number of studies confirming the property of interlocking-director network as the classification of small-world case. Following theoretical foundation and computational method as stated in section 3.2, the verification can be conducted by comparing the ratio obtained from the random-graph model and that of the actual data. In the case of small-world network, the magnitude of Transitivity (i.e. the clustering coefficient) is substantially larger than that of the random-graph model. However, the value of average shortest paths of both small-world and random-graph networks are within the same range. This property resembles the actual social structure, which is highly clustering.

Obtained from the computation, the results shown in Table 11 clearly identify that the network of interlocking directors of listed companies in Thailand has the small-world property. Strictly following the theoretical concept of Watts-Strogatz statistics, the magnitude of Transitivity of the actual network is much larger than that obtained from simulation's outcome of the random-graph model. Also the values of average length of shortest paths of both are very close. Therefore, the interlocking-director network among Thai listed companies is similar to cases of other countries as listed in Table 1.

In addition, Table 12 exhibits the results of similar verification method. Particularly, the listed companies are interlocked with the small-world property via the affiliation of their boards. In this case, the values of Watts-Strogatz statistics are high because the actual network has the larger magnitude of Transitivity index than that of the simulation result of random-graph case. This finding sheds light on the new perspective of relationship among listed companies, and the new understanding of connection allowing risk and information propagating among them. Also the insight on systematic risk in Thailand's stock exchange has to be extended to include this affiliation among listed companies.

Table 5: Ranking of standardized average degree (network of directors)[4]

Std. Avg. Degree 2012		Std. Avg. Degree 2013		Std. Avg. Degree 2014		Std. Avg. Degree 2015		Std. Avg. Degree 2016	
Mr. SUCHIN WANGLEE	0.042	Mr. SUCHIN WANGLEE	0.051	Mr. SUCHIN WANGLEE	0.054	Mr. SUCHIN WANGLEE	0.050	Mr. ARSA SARASIN	0.054
Mr. BOONSITHI CHOKWATANA	0.035	Mr. PRASERT BUNSUMPUN	0.049	Mr. PRASERT BUNSUMPUN	0.048	Mr. PRASERT BUNSUMPUN	0.046	Mr. SUCHIN WANGLEE	0.051
Mr. WEERAWONG CHITTMITTRAPAP	0.034	Miss POTJANEE THANAVARANIT	0.044	Mr. MANU LEOPAIROTE	0.043	Mr. ARSA SARASIN	0.042	Mr. PRASERT BUNSUMPUN	0.051
Mr. APIPORN PASAWAT	0.034	Mr. MANU LEOPAIROTE	0.042	Mr. CHATCHAVAL JIARAVANON	0.042	Mr. MANU LEOPAIROTE	0.040	Mr. RAWAT CHAMCHALERM	0.046
Mr. BOONCHAI CHOKWATANA	0.033	Mr. BOONCHAI CHOKWATANA	0.041	Miss POTJANEE THANAVARANIT	0.040	Mr. WEERAWONG CHITTMITTRAPAP	0.038	Mr. MANU LEOPAIROTE	0.044
Mr. CHACKCHAI PANICHAPAT	0.033	Mr. CHATCHAVAL JIARAVANON	0.038	Mr. ARSA SARASIN	0.038	Miss POTJANEE THANAVARANIT	0.037	Mr. SITHICHAI CHAIKRIANGKRAI	0.042
Mr. PRAJYA PHINYAWAT	0.033	Mr. BOONSITHI CHOKWATANA	0.038	Mr. BOONSITHI CHOKWATANA	0.038	Mr. CHATCHAVAL JIARAVANON	0.036	Mr. WEERAWONG CHITTMITTRAPAP	0.038
Mr. CHATCHAVAL JIARAVANON	0.032	Mr. ARSA SARASIN	0.037	Mr. AVIRUTH WONGBUDDHAPITAK	0.037	Mr. CHOKCHAI AKSARANAN	0.036	Mr. THAPANA SIRIVADHANABHAKDI	0.038
Mr. MANU LEOPAIROTE	0.031	Mr. AVIRUTH WONGBUDDHAPITAK	0.037	Mrs. KULPATRA SIRODOM	0.037	Mrs. KULPATRA SIRODOM	0.035	Mr. BOONSITHI CHOKWATANA	0.036
Mr. WISSANU KREA - NGAM	0.031	Mr. PRAJYA PHINYAWAT	0.037	Mr. JOTI BHOKAVANIJ	0.037	Mr. BOONSITHI CHOKWATANA	0.034	Mr. CHATCHAVAL JIARAVANON	0.035

Table 6: Ranking of standardized average degree (network of boards of listed companies)

Std. Avg. Degree 2012		Std. Avg. Degree 2013		Std. Avg. Degree 2014		Std. Avg. Degree 2015		Std. Avg. Degree 2016	
SSC	0.043	ERW	0.044	ERW	0.044	THRE	0.043	SSC	0.049
ERW	0.042	SSC	0.044	THRE	0.042	ERW	0.041	SCC	0.037
HIPRO	0.040	HIPRO	0.042	HIPRO	0.041	HIPRO	0.040	TRUE	0.037
TRUE	0.037	THRE	0.041	SSC	0.041	TRUE	0.040	DTC	0.036
SPI	0.035	TRUE	0.041	TRUE	0.041	SCC	0.038	HIPRO	0.036
SCC	0.034	MINOR	0.036	SCB	0.038	SSC	0.038	TOC	0.036
MINOR	0.032	SCB	0.036	MINOR	0.036	DTC	0.037	ERW	0.034
MPT	0.032	LOXLEY	0.035	SCC	0.035	SCB	0.037	MINOR	0.033
TOC	0.031	TOC	0.035	DRT	0.032	TOC	0.037	LOXLEY	0.031
DRT	0.029	DRT	0.032	MPT	0.032	MINOR	0.035	SPI	0.028

[4] This is an outcome of scientific computation. With all best regards, the author has no intention of creating any negative consequences to all directors listed in this table.

Table 7: Ranking of Betweenness index (network of directors)[5]

Betweenness index 2012		Betweenness index 2013		Betweenness index 2014		Betweenness index 2015		Betweenness index 2016	
Mr. CHACKCHAI PANICHAPAT	0.039	Mr. MANU LEOPAIROTE	0.045	Mr. CHATCHAVAL JIARAVANON	0.050	Mr. MANU LEOPAIROTE	0.046	Mr. MANU LEOPAIROTE	0.064
Mr. PRAKIT PRADIPASEN	0.037	Miss POTJANEE THANAVARANIT	0.036	Mr. MANU LEOPAIROTE	0.041	Mr. SUCHIN WANGLEE	0.043	Mr. PRASERT BUNSUMPUN	0.049
Mrs. CHANTRA PURNARIKSHA	0.033	Mr. SUCHIN WANGLEE	0.036	Mr. SUCHIN WANGLEE	0.040	Miss POTJANEE THANAVARANIT	0.037	Mr. SUCHIN WANGLEE	0.040
Mr. SUCHIN WANGLEE	0.032	Mr. CHATCHAVAL JIARAVANON	0.036	Miss POTJANEE THANAVARANIT	0.037	Mr. CHATCHAVAL JIARAVANON	0.036	Mr. ARSA SARASIN	0.038
Mr. WEERAWONG CHITTMITTRAPAP	0.031	Mr. PRASERT BUNSUMPUN	0.033	Mr. PRAKIT PRADIPASEN	0.032	Mr. PRAKIT PRADIPASEN	0.034	Mr. PRAKIT PRADIPASEN	0.036
Mr. MANU LEOPAIROTE	0.030	Mr. WISSANU KREA - NGAM	0.028	Mr. PRASERT BUNSUMPUN	0.031	Mr. WEERAWONG CHITTMITTRAPAP	0.033	Mr. RAWAT CHAMCHALERM	0.032
Mr. WISSANU KREA - NGAM	0.030	Mrs. NUALPHAN LAMSAM	0.028	Mr. SUVARN VALAISATHIEN	0.028	Mr. PRASERT BUNSUMPUN	0.032	Mr. VIRACH APHIMETEETAMRONG	0.031
MR. PONG SARASIN	0.029	Mr. PRAKIT PRADIPASEN	0.028	Mr. SIRI GANJARERNDEE	0.026	Mr. SIRIPOL YODMUANGCHAROEN	0.027	Mr. SUVARN VALAISATHIEN	0.030
Mr. CHAI SOPHONPANICH	0.025	Mr. JOTI BHOKAVANIJ	0.025	Mr. SATIT CHANJAVANAKUL	0.024	Mr. ARSA SARASIN	0.026	Mr. CHAINOI PUANKOSOOM	0.026
Mr. CHATCHAVAL JIARAVANON	0.025	Mrs. KULPATRA SIRODOM	0.025	Mr. CHAI SOPHONPANICH	0.023	Mr. CHAI SOPHONPANICH	0.024	Mr. CHATCHAVAL JIARAVANON	0.026

Table 8: Ranking of Betweenness index (network of boards of listed companies)

Betweenness index 2012		Betweenness index 2013		Betweenness index 2014		Betweenness index 2015		Betweenness index 2016	
SSC	0.036	SCB	0.033	TRUE	0.031	TOC	0.032	SSC	0.044
SCC	0.032	MFC	0.030	THRE	0.029	DTC	0.032	DTC	0.043
KBANK	0.032	SCC	0.028	ERW	0.029	SCC	0.031	TOC	0.036
BH	0.030	LOXLEY	0.027	FBCB	0.028	SCB	0.029	MINOR	0.032
SAMCO	0.026	FBCB	0.027	SCB	0.027	ERW	0.029	SCC	0.031
LOXLEY	0.026	TRUE	0.026	LOXLEY	0.026	THRE	0.028	ERW	0.027
FBCB	0.025	BKI	0.024	SCC	0.025	TRUE	0.028	SPALI	0.027
ERW	0.025	THAI	0.024	TOC	0.024	BKI	0.025	TRUE	0.025
TRUE	0.025	THRE	0.023	DTC	0.023	MFC	0.024	MTI	0.025
CSC	0.024	TOC	0.022	MC	0.023	BAY	0.024	BH	0.024

[5] This is an outcome of scientific computation. With all best regards, the author has no intention of creating any negative consequences to all directors listed in this table.

Table 9: Ranking of Pagerank index (network of directors)[6]

Pagerank index 2012		Pagerank index 2013		Pagerank index 2014		Pagerank index 2015		Pagerank index 2016	
Mr. SUCHIN WANGLEE	0.004	Mr. SUCHIN WANGLEE	0.004	Mr. SUCHIN WANGLEE	0.004	Mr. SUCHIN WANGLEE	0.004	Mr. PRASERT BUNSUMPUN	0.004
Mr. BOONSITHI CHOKWATANA	0.003	Mr. PRASERT BUNSUMPUN	0.003	Mr. PRASERT BUNSUMPUN	0.004	Mr. PRASERT BUNSUMPUN	0.003	Mr. ARSA SARASIN	0.003
Mr. PRAJYA PHINYAWAT	0.003	Mr. BOONSITHI CHOKWATANA	0.003	Mr. BOONSITHI CHOKWATANA	0.003	Mr. ARSA SARASIN	0.003	Mr. SITHICHAI CHAIKRIANGKRAI	0.003
Mr. SITHICHAI CHAIKRIANGKRAI	0.003	Mr. PRAJYA PHINYAWAT	0.003	Mr. MANU LEOPAIROTE	0.003	Mr. BANYONG PONGPANICH	0.003	Mr. SUCHIN WANGLEE	0.003
Mr. APIPORN PASAWAT	0.003	Mr. BOONCHAI CHOKWATANA	0.003	Mr. BANYONG PONGPANICH	0.003	Mr. BOONSITHI CHOKWATANA	0.003	Mr. WEERAWONG CHITTMITTRAPAP	0.003
Mr. PRAKIT PRADIPASEN	0.003	Miss POTJANEE THANAVARANIT	0.003	Mr. CHATCHAVAL JIARAVANON	0.003	Mr. CHATCHAVAL JIARAVANON	0.003	Mr. PRAJYA PHINYAWAT	0.003
Mr. BOONCHAI CHOKWATANA	0.003	Mr. SITHICHAI CHAIKRIANGKRAI	0.003	Mr. PRAKIT PRADIPASEN	0.003	Mr. CHUMPOL NALAMLIENG	0.003	Mr. THAPANA SIRIVADHANABHAKDI	0.003
Mr. WISSANU KREA - NGAM	0.003	Mr. THAPANA SIRIVADHANABHAKDI	0.003	Mr. SIRI GANJARERNDEE	0.003	Mr. MANU LEOPAIROTE	0.003	Mr. BOONSITHI CHOKWATANA	0.003
Mr. CHATCHAVAL JIARAVANON	0.003	Mr. MANU LEOPAIROTE	0.003	Miss POTJANEE THANAVARANIT	0.003	Miss POTJANEE THANAVARANIT	0.003	Mr. MANU LEOPAIROTE	0.003
Mr. THAPANA SIRIVADHANABHAKDI	0.003	Mr. CHATCHAVAL JIARAVANON	0.003	Mr. CHUMPOL NALAMLIENG	0.003	Mr. SIRI GANJARERNDEE	0.002	Mr. VUDHIPHOL SURIYABHIVADH	0.003

Table 10: Ranking of Pagerank index (network of boards of listed companies)

Pagerank index 2012		Pagerank index 2013		Pagerank index 2014		Pagerank index 2015		Pagerank index 2016	
SPI	0.006	SSC	0.005	TRUE	0.005	TRUE	0.005	SSC	0.006
SSC	0.005	TRUE	0.005	ERW	0.005	TOC	0.005	BJC	0.005
BJC	0.005	SPI	0.005	SPI	0.005	THRE	0.004	BMCL	0.005
SFP	0.005	TF	0.005	SSC	0.005	SPI	0.004	BTC	0.005
ERW	0.005	BJC	0.005	THRE	0.004	ERW	0.004	SPI	0.005
TF	0.005	ERW	0.005	TF	0.004	TF	0.004	TOC	0.005
TRUE	0.005	TOC	0.004	CPN	0.004	SSC	0.004	TRUE	0.005
TOC	0.005	SFP	0.004	BJC	0.004	KSL	0.004	KSL	0.004
NPC	0.004	THRE	0.004	KSL	0.004	BJC	0.004	ERW	0.004
HIPRO	0.004	HIPRO	0.004	SCB	0.004	HIPRO	0.004	MINOR	0.004

[6] This is an outcome of scientific computation. With all best regards, the author has no intention of creating any negative consequences to all directors listed in this table.

Table 11: Result of Watts-Strogatz Statistics (network of directors)

2012				2013				2014				2015				2016			
Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density
Random-graph model	0.008	3.488	0.008	random-graph model	0.011	3.097	0.011	random-graph model	0.011	3.114	0.011	random-graph model	0.009	3.183	0.011	random-graph model	0.011	3.103	0.012
Actual data	0.641	4.105	0.008	actual data	0.600	3.813	0.012	actual data	0.590	3.846	0.011	actual data	0.638	3.9283	0.011	actual data	0.613	4.031	0.012
γ^{sw}= 80.125 , λ= 1.176 , S^{ws} = 68.081				γ^{sw}= 54.545 , λ= 1.231 , S^{ws} = 44.303				γ^{sw}= 53.636 , λ= 1.235 , S^{ws} = 43.427				γ^{sw}= 70.888 , λ= 1.234 , S^{ws} = 57.439				γ^{sw}= 55.727 , λ= 1.299 , S^{ws} = 42.897			

Table 12: Result of Watts-Strogatz Statistics (network of boards of listed companies)

2012				2013				2014				2015				2016			
Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density	Model	Transitivity	Avg. path length	Density
Random-graph model	0.006	4.146	0.008	Random-graph model	0.007	3.796	0.009	Random-graph model	0.008	3.813	0.009	Random-graph model	0.010	3.833	0.009	Random-graph model	0.013	4.103	0.008
Actual data	0.388	4.234	0.008	Actual data	0.383	3.957	0.009	Actual data	0.400	4.018	0.009	Actual data	0.395	3.948	0.009	Actual data	0.398	4.159	0.008
γ^{sw}= 64.666 , λ= 1.021 , S^{ws} = 63.322				γ^{sw}= 54.714 , λ= 1.042 , S^{ws} = 52.448				γ^{sw}= 50.000 , λ= 1.053 , S^{ws} = 47.448				γ^{sw}= 39.500 , λ= 1.030 , S^{ws} = 38.349				γ^{sw}= 30.615 , λ= 1.013 , S^{ws} = 30.203			

4.3 Results from applying the community detection method

In order to examine the highly clustering relationship, the computational technique of subgroup decomposition was applied to the data set of both director and board networks. Similar to the conventional structure of human's society composed of multiple sub-communities, the mathematical method of the modularity and community detection was conducted, unveiling all subgroups of directors within the network. Likewise, applying the same computation to the network of boards of listed companies generated all details of subgroups and their members, enabling the deeper understanding of composition of affiliation among listed firms.

Figure 5 illustrates the outcome of conducting the community detection to the interlocking-directors network of 2016. Table 13 exhibits the general characteristics of results obtained from implementing the community detection to the director networks of 2012-2016. For each year, the director network was comprised of many subgroups. However, as shown in Table 15, the number of members in each subgroup is not uniformly distributed. Instead, the majority of directors were members of a smaller number of subgroups. As listed in the last column of Table 15, a large proportion of directors are members of 10 percent of subgroups.

Figure 6 and Table 14 show the identical characteristics found in the case of networks of boards of listed firms. For all data of 2012 to 2016, the affiliation among companies can be partitioned into many subgroups, implying the structural composition similar to the case of director network. As listed in Table 16, the distribution of members of subgroups is not uniform for all board networks of 2012-2016. Besides, as exhibited in the last column of Table 14, the majority of listed companies are members of merely 10 percent of sub communities. Technically speaking, these patterns are very similar to the case of Power Law probability distribution as previously founded in Guimerà et al.(2003), Newman(2004) and Palla(2005), and it is an interesting issue for the further study.

5. Conclusion

This study applied the dataset of interlocking directors of listed companies in Thailand to the method of network analysis. The outcomes show that the structural properties of both director network and that of boards of listed companies were stable during 2012-2016. The analysis also confirmed the case of small-world networks of locking boards based on the computed Watts-Strogatz Statistics, which was analogous to most of international empirical evidences. Similarly, the computed Watts-Strogatz Statistics affirmed that the affiliations of boards of listed firms during 2012-2016 were the classification of small-world network as well. These results reveal the new perspective on the linkages among listed companies, which are very clustering through the interlocking directorate. In addition, the community detection was conducted to thoroughly examine the structure of the highly clustering networks. The outcomes indicate that for both networks of directors and boards, there are only a small number of subgroups constituting the majority of the network. These unveiled properties of highly clustering and unequal distribution of subgroups' members suggest the furfure studies examining the consequences of these features on the performance of listed companies.

Figure 5: Subgroups of network of directors (data of 2016)

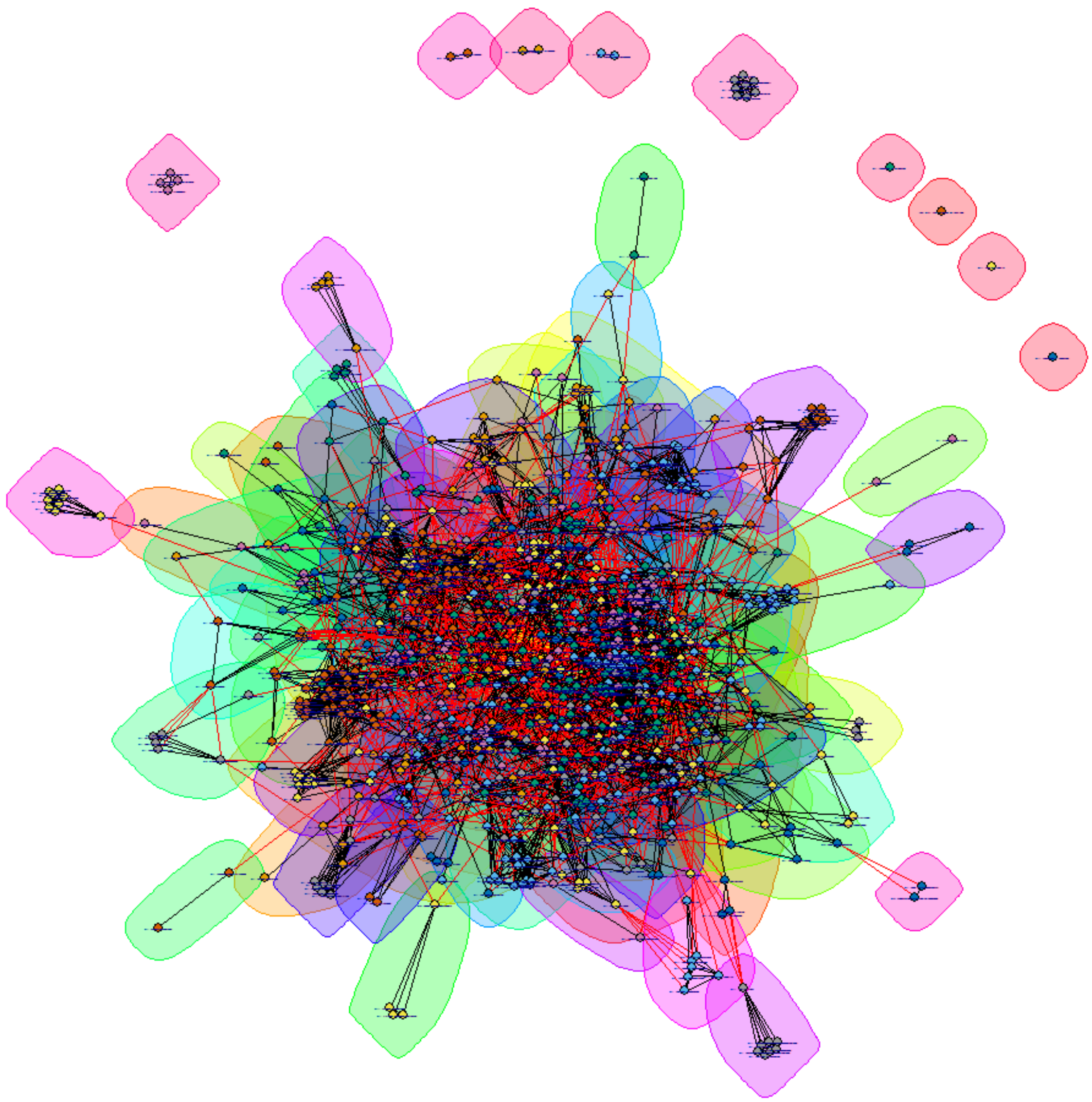


Figure 6: Subgroups of network of boards of listed companies (data of 2016)

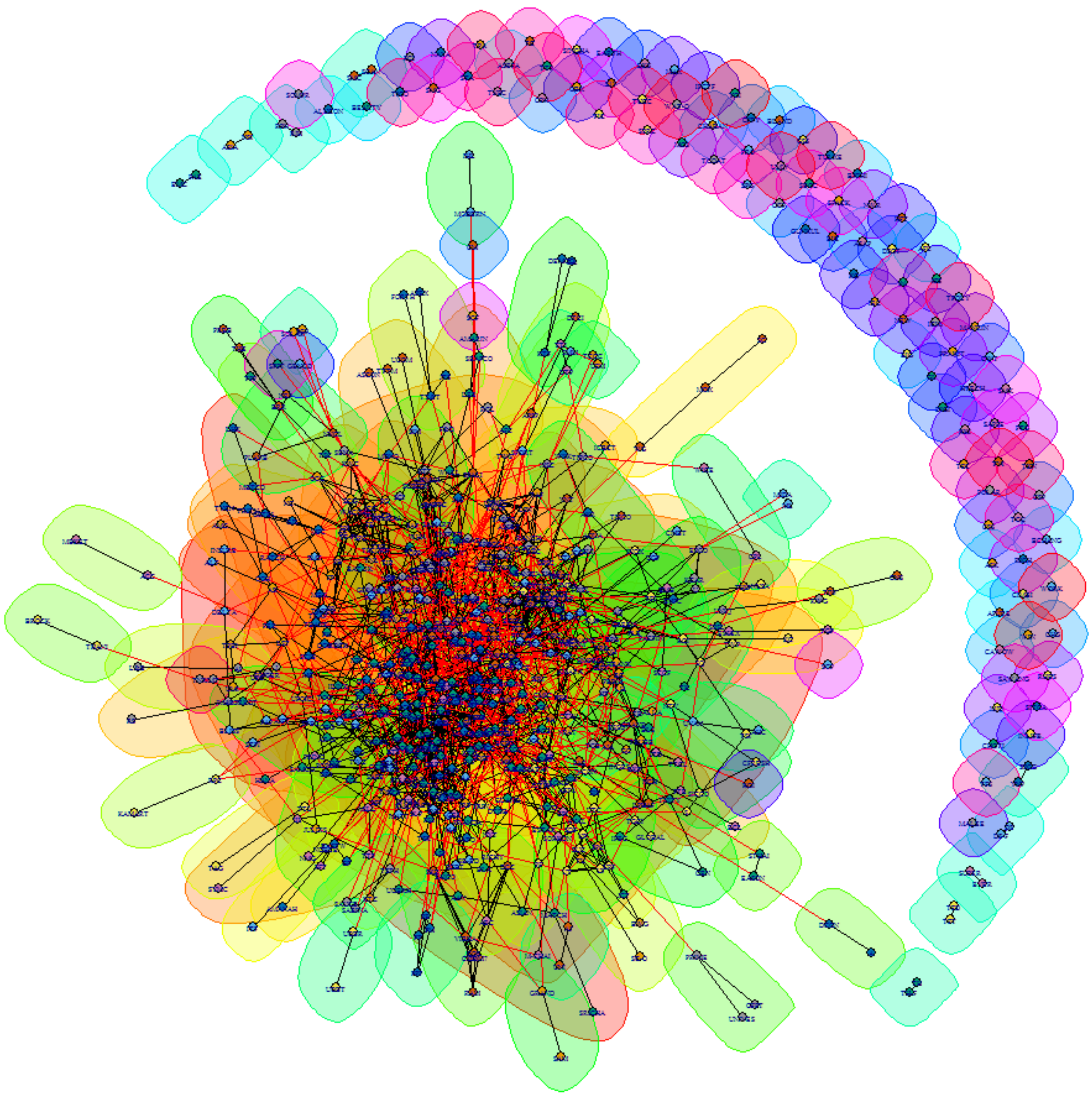


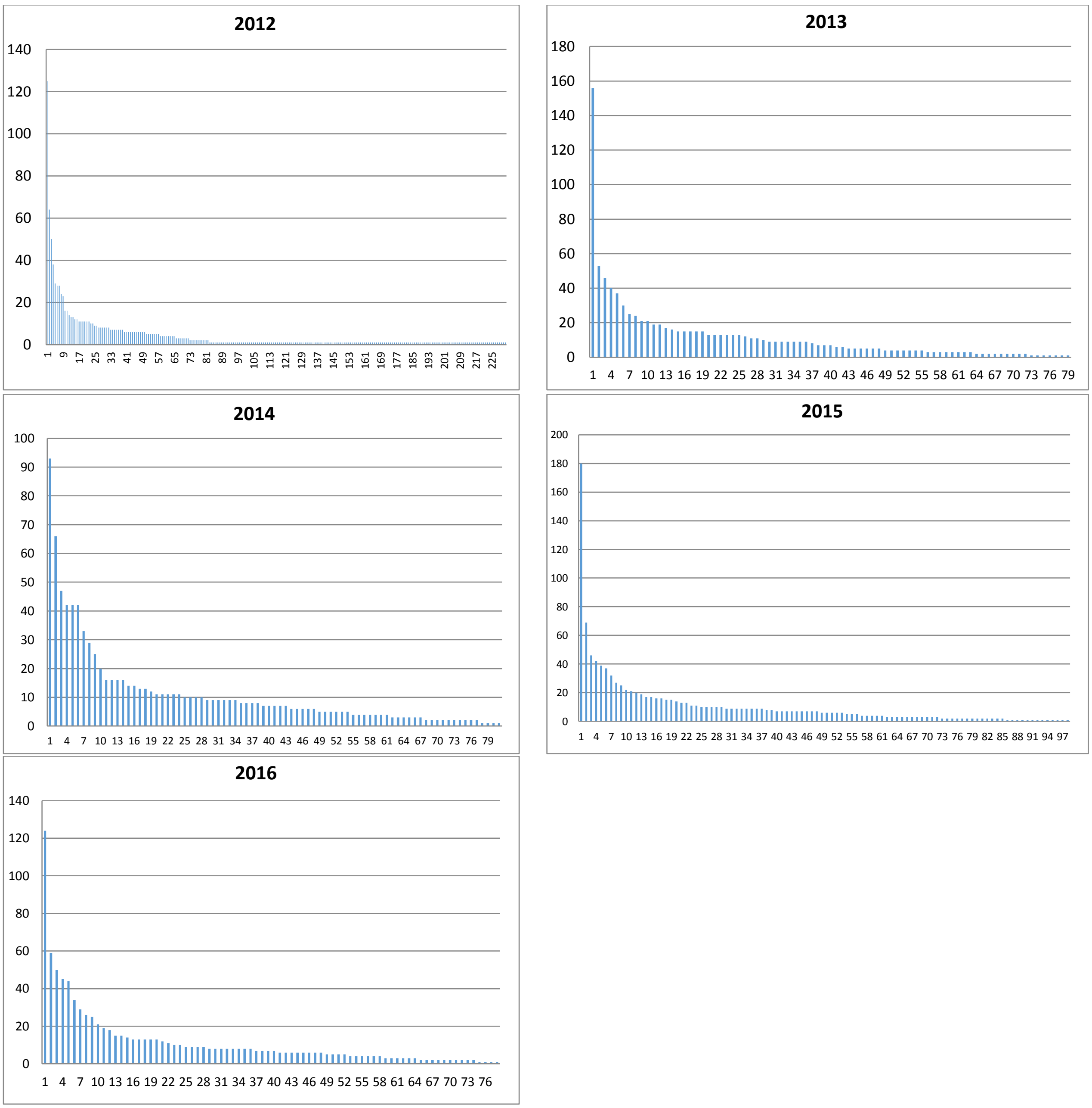
Table 13: Characteristics of subgroups of directors

	Number. of interlocking directors	Number. of subgroups	Number. of subgroups having more than 2 directors	Number o. of subgroups having only one director	Total directors in top 10% of subgroups
2012	1,030	232	82	150	581
2013	1,072	79	72	7	411
2014	1,047	81	77	4	394
2015	1,089	99	85	14	472
2016	1,123	78	73	5	385

Table 14: Characteristics of subgroups of boards of listed companies

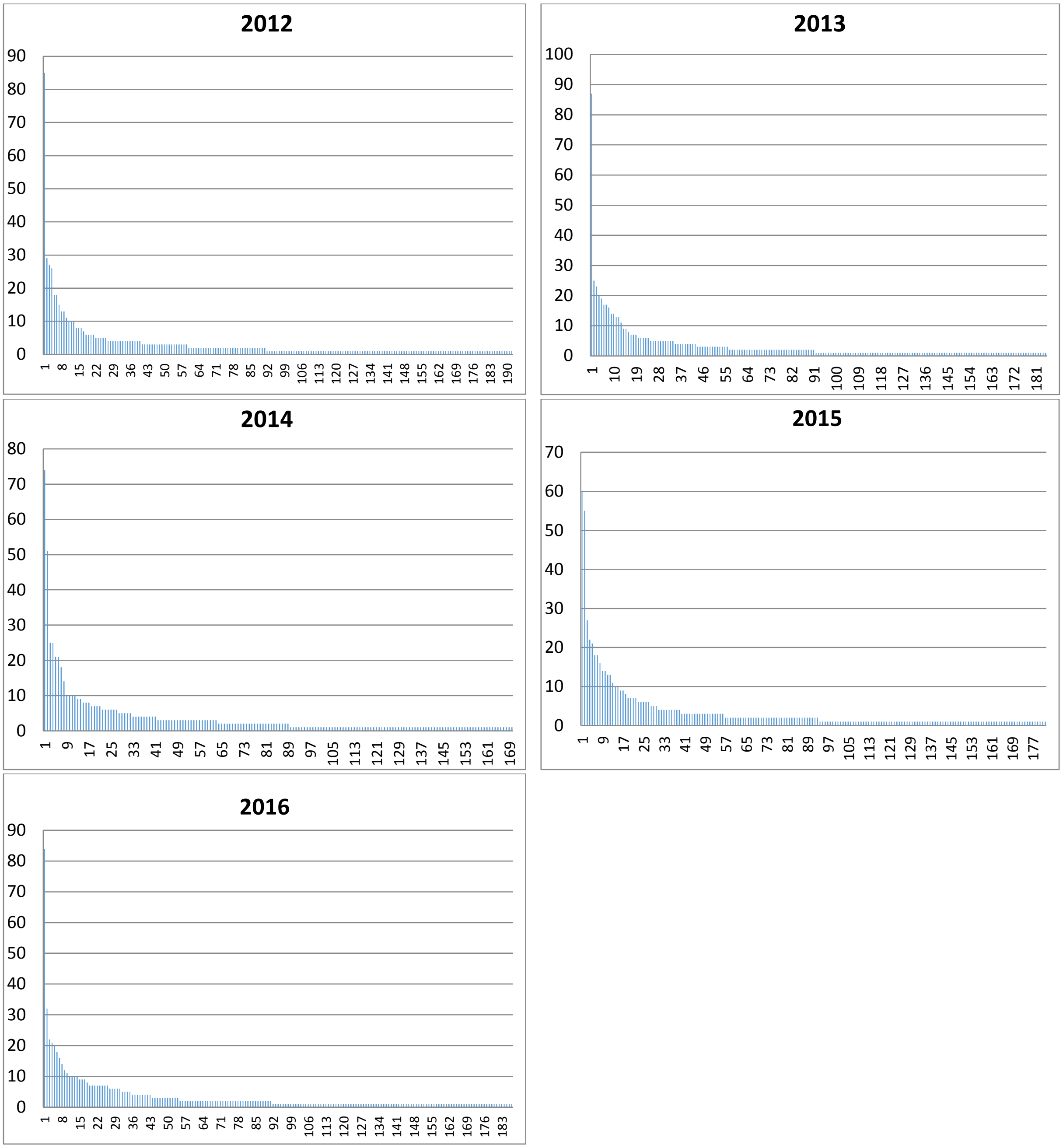
	Total firms	Number. of subgroups	Number. of subgroups having more than 2 firms	Number. of subgroups having only one firm	Total firms in top 10% of subgroups
2012	643	192	91	101	328
2013	655	185	91	94	238
2014	655	170	89	81	249
2015	671	182	89	93	221
2016	666	187	92	95	239

Table 15: Distributions of members of director subgroups (2012-2016)



Note: the value on vertical axis is the number of members in each subgroup. The horizontal axis lists the identification number of each subgroup.

Table 16: Distributions of members of board subgroups (2012-2016)



Note: the value on vertical axis is the number of members in each subgroup. The horizontal axis lists the identification number of each subgroup.

Reference

Barabási. A.L. (2016). Network Science. Cambridge University Press.

Battiston, S. & Catanzaro, M. (2004). Statistical properties of corporate board and director networks, *The European Physical Journal B*, 38(2), 345-352.

Bazerman, M. & Schoramn, F. (1983). "A Limited Rationality Model of Interlocking Directorates*," Academy of Management and Review*, 8(2), 206-217.

Berle, A. A., & Means, G. C. (1932). The modern corporation and private property. New York: Macmillan.

Caldarelli, G. & Catanzaro, M. (2004). The corporate boards networks, *Physica A*, 338, 98–106.

Caldarelli, G. (2007). Scale-Free Networks. Complex Webs in Nature and Technology, Oxford University Press.

Caswell, J. A. (1984). An institutional perspective on corporate control and the network of interlocking directorates. *Journal of Economic Issues*, 18(2), 619-626.

Conyon, M. & Muldon, M. (2006). The small world of corporate boards, *Journal of Business and Finance Account*, 33(9–10), 1321–1343.

Davis, G.F., Yoo, M. & Baker, W.E. (2003). The small world of the American corporate elite, 1982–2001, *Strategic Organization*, 301–326.

de Sola Pool, I. & Kochen, M. (1978). Contacts and influence, *Social Networks*, 1, 5-51.

Drago, C., Millo, F. , Ricciuti, R., & Santella, P. (2015). Corporate governance reforms, interlocking directorship and company performance in Italy. *International Review of Law and Economics*, 41(1), 38-49.

Dimirtrios, K. & Vasileios, O. (2015). A network analysis of the Greek stock market, *Procedia Economics and Finance*, 33, 340-349.

Durbach, I. & Parker, H. (2009). An analysis of corporate board networks in South Africa, *South African Journal of Business Management*, 40(2), 15–26.

Elouaer-Mrizak, S. (2012). A social network analysis of interlocking directorates in French firms. *Conference Proceeding, 2012 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM).* doi=10.1109/ASONAM.2012.177

Erdős, P.and Rényi, A. (1959). On random graphs, *Publicationes Mathematicae*, 6, 290–297.

Guimerà, R., Danon, L., Díaz-Guilera, A., Giralt, F. & Arenas, A. (2003). Self-similar community structure in a network of human interactions. *PHYSICAL REVIEW E*, 68(6), 65-103. doi=10.1103/PhysRevE.68.065103.

Heemskerk, E. & Schnyder, G. (2008). Small states, international pressures, and interlocking directorates: the cases of Switzerland and the Netherlands, *European Management Review*, 5(1), 41–54. doi=10.1057/emr.2008.3

Kogut B.(Ed.) (2012). The Small Worlds of Corporate Governance, MIT Press, Cambridge.

Humphries, M.D. & Gurney, K. (2008). Network 'Small-World-Ness': a quantitative method for determining canonical network equivalence, PLoS One, 3(4), 1-10. doi = https://doi.org/10.1371/journal.pone.0002051

Lang, J. & Lockhart, D. (1990). Increased environmental uncertainty and changes in board linkage patterns, *Academy of Management Journal*, 33, 106–128.

Lawton, J. (2016). Intelligence Planning and Methods Employed: Operation Red Dawn - The Capture of Saddam Hussein, *Small Wars Journal*.

Ljungqvist, A. and Raff, K. (2017). Busy directors: strategic interaction and monitoring synergies, NBER Working Paper No. 23889.

Milgram, S. (1967). The small world problem, *Psychology Today*, 2, 60-67.

Mizruchi, M. & Stearns, L. (1988). A longitudinal study of the formation of interlocking directorates,

Administrative Science Quarterly, 33, 194–210.

Nam, H.J. & An Y. (2017). The effect of interlocking directors network on firm value and performance: evidence from Korea-listed firms, *Global Economic Review*, 46(3), 1-23. doi=10.1080/1226508X.2017.1374197

Newman, M., Strogatz, S., & Watts D. (2001). Random graphs with arbitrary degree distributions and their applications, *Physical Review E*, 64(2 Pt 2):026118.

Newman, M.E.J. (2004). Detecting community structure in networks. *The European Physical Journal B*, 38(2), 321-330. doi=https://doi.org/10.1140/epjb/e2004-00124-y

Palla, G., Derenyi, I., Farkas, I. & Vicsek, I. (2005). Uncovering the overlapping community structure of complex networks in nature and Society, *Nature*, 435, 814-818. doi=10.1038/nature03607

Peng, M.W., Au, K.Y. and Wang, D.Y.L. (2001). Interlocking Directorates as Corporate Governance in Third World Multinationals: Theory and Evidence from Thailand, *Asia Pacific Journal of Management*, 18, 161–18.

Pfeffer, J. & Salancik, G. (1978). The External Control of Organizations (New York: Harper and Row).

Pons, P. & Latapy, M. (2005). Computing communities in large networks using random walks. *Journal of Graph Algorithms and Applications*, 10(2), 191–218.

Richardson, J. (1987). Directorship interlocks and firm profitability, *Administrative Science Quarterly*, 32, 367–386.

Robins, G., & Alexander, M. (2004). Small worlds among interlocking directorates: network structure and distance in bipartite graphs, *Computational & Mathematical Organization Theory*, 10(1), 69–94.

Sankowska, A. & Siudak, D. (2016). The small world phenomenon and assertive mixing in Polish corporate board and director networks, *Physica A*, 443, 309-315.

Sinani, E., Stafsudd, A., Thomsen, S., Edling, C. and Randoy, T. (2008). Corporate governance in Scandinavia: comparing networks and formal institutions, *European Management Review*, 5(1), 27–40.

Sitthipongpanich, T. and Polsiri, P. (2013). Who’s on board? Influence of diversity and network of Thai boards of directors on firm value, *The Journal of Applied Business Research*, 29(6), 1763-1779.

Strogatz, S.H. (2001). Exploring complex networks, *Nature*, 410, 268–276.

Useem, M. (1982). Classwide rationality in the politics of managers and directors of large corporations in the United States and Great Britain, *Administrative Science Quarterly*, 27, 199-226.

Watts, D.J. & Strogatz, S.H. (1998). Collective dynamics of 'small-world' networks, *Nature*, 393, 440-442. doi=10.1038/30918