Complex Networks Analysis of Indian Corporate Networks

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Outline

Our Contribution

1. We have analyzed the Indian corporate network using complex network analysis.
2. We modelled the director boards network.
3. We modelled the directors network.
4. We have studied the relationship between degree centrality and financial performance
5. We have done a modualrity maximization based community analysis and linked it to financial performance.

Complex Networks : An Introduction

What are Complex Networks?

Many physical, social, biological, and technological systems display substantilal non trivial topological features, i.e. the patterns of connections between these elements are neither completely regular nor fully random. The graph theoretic characterisation and statisitical analysis of these systems is the study of complex networks.

Graphs

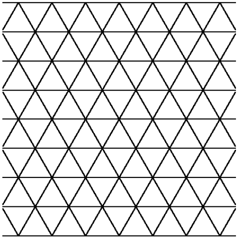


Figure 1

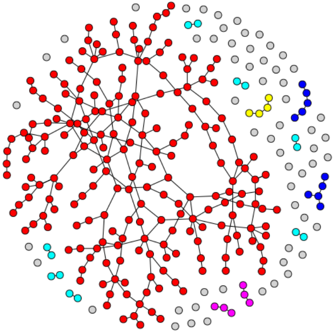


Figure 2

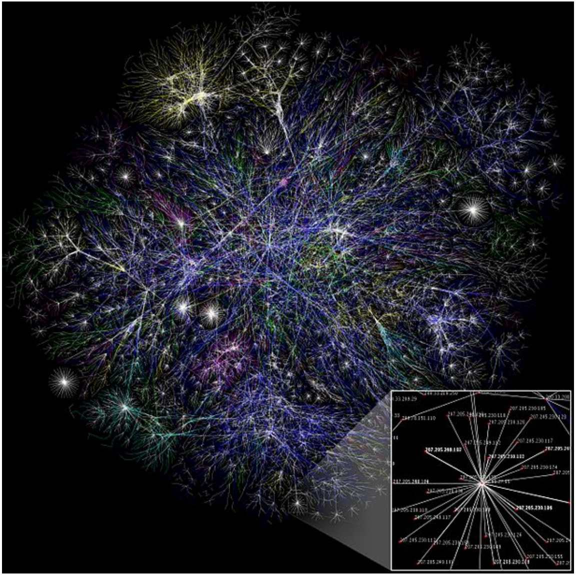


Figure 3: Graph of the Internet on January 15, 2005

Graphical Representation

The first step in analyzing a complex system is representing the system in graph theoretic framework. In this methodology a node is the fundamental anchor of the system whereas an edge is the connection between such anchors.

An edge can be

- Weighted: Here the weight of an edge represents the intensity of connections between the nodes
- Directed: A directed edge signifies that the connection between the nodes exist only in one direction.

Graphical Representation

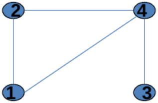


Figure 4: Undirected Graph

$$g = \begin{pmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

Figure 5: Undirected Graph Adjacency Matrix

Graphical Representation

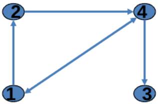


Figure 6: Directed Graph

$$g = \begin{pmatrix} 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 \end{pmatrix}$$

Figure 7: Directed Graph Adjacency Matrix

Graphical Representation

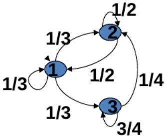


Figure 8: Weighted Directed Graph

$$g=\begin{pmatrix} 1/3 & 1/3 & 1/3 \\ 1/2 & 1/2 & 0 \\ 0 & 1/4 & 3/4 \end{pmatrix}$$

Figure 9: Weighted Directed Graph Adjacency Matrix

Centrality

Complex network metrics provide a statistical characterisation of the network. Here, centrality is a generic term which measures the relative position of a node in the network from different perspectives:

1. Degree Centrality
2. Closeness Centrality
3. Betweeness Centrality
4. Eigenvector Centrality

Degree Centrality

Degree centrality (DC) is defined as the sum of edge weights connected to a node.
For a complex network graph with N nodes, DC of node i in a network is defined as

$$DC(i) = \sum_{j} w_{ij}; \quad i, j \in \{1, 2, \dots, N\}$$

Closeness Centrality

Closeness centrality measures how close a node is to other nodes in the network. It signifies the ability of a node to act as a source to spread information. The closeness centrality of i^{th} node, $CC(i)$, in a N node can be calculated using

$$CC(i) = \frac{1}{\sum_{j=1}^{N} d(i,j)} \qquad i,j \in \{1,2,\ldots,N\}$$

where $d(i,j)$ is the shortest path between the nodes i and j.

Betweeness Centrality

Betweenness centrality measures the ability of one node to connect two other nodes. Betweenness centrality measures the extent to which one node that lies in the shortest path of two other nodes. It can be formulated using

$$BC(i) = \sum_{i \neq j \neq k} \frac{g_{jk}(i)}{g_{jk}}$$

where g_{jk} is the total number of shortest paths between nodes j and k, and $g_{jk}(i)$ is the number of those shortest paths that contain node i.

Eigenvector Centrality

The Eigenvector centrality measures a node's ability to be connected to central nodes. The Eigenvector Centrality of node i, $EVC(i)$, can be calculated using

$$EVC(i) = \frac{\sum_j a_{ij} EVC(j)}{\lambda}$$

where, λ is a constant and a_{ij} is the i, j element of the adjacency matrix.

Modularity

Community detection enables the identification of set of nodes which are more densely linked with each other than those outside the community. Modularity of a partition for a weighted network is defined using

$$Q = \frac{1}{2m}\sum_{i,j}[A_{ij} - \frac{k_i k_j}{2m}]\delta(c_i, c_j)$$

where A_{ij} is the value of weighted adjacency matrix at index i, j, $k_i = \sum_j A_{ij}$ is the weighted degree of node i, c_i is the community to which vertex i is assigned, the δ function is 1 if $c_i = c_j$ and 0 otherwise, and $m = \frac{1}{2}\sum_{i,j} A_{ij}$.

Simply put, Modularity is the fraction of the edges that fall within the given groups minus the expected fraction if edges were distributed at random

Financial Performance Metrics

Debt to Equity Ratio is the ratio of company's total liabilities and equity held by shareholder. Higher values of D/E signifies a higher risk for shareholders.

Cash Returned on Invested Capital is the amount of cash flow a company generated for each unit of invested capital. Higher values of CROIC imply that the firm can generate higher cash flow with minimal capital.

Net Current Asset Value per Share measures the long-term sustainability of a firm. In case of a financial crisis, the assets can be liquidated and the firm can continue in an efficient manner. The NCAVPS acts as an insurance for shareholders.

Price to Earnings per Share Ratio value represents the view of the market on the company. A higher P/E value means that the shareholders believe in the company's potential to generate profits.

The Problem Statement

We have primarily focussed our study on two complex networks.

- Director Boards Network
- Directors Network

Director Boards Network

- In the director boards network, nodes are companies and edge formation occurs if two companies have at least one common director.
- The complex network analysis of this graph provides us with important information regarding the connection patterns of the firms.
- The effects of interlocking of directors on financial performance of firms is studied.

Director Boards Network

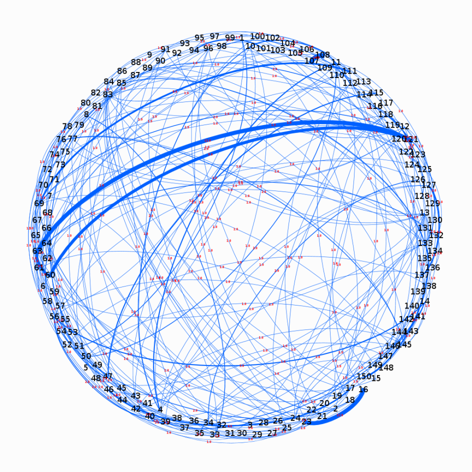


Figure 10: Director boards network [circular layout representaion]

No. of Nodes : 150
No. of Edges : 237
Average Degree: 3.160
Average Weighted Degree: 4.467
Average Clustering : 0.365
Diameter: 11

Directors Network

- The directors network has directors as nodes. An edge formation occurs if two directors serve on the board of the same company.
- The centrality distributions of the complex network provides us with insights regarding the concentration of power among directors.

Directors Network

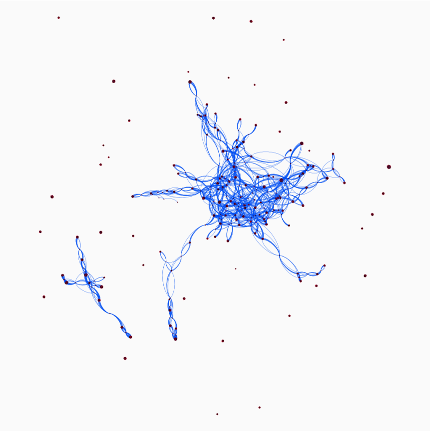


Figure 11: Directors network

No. of Nodes : 1535
No. of Edges : 103324
Average Degree: 13.462
Average Weighted Degree: 14.046
Average Clustering : 0.949
Diameter : 12
Average Path length: 4.76

Director Boards Network: Centrality

Rank	Degree	Weighted Degree	Closeness Centrality	Betweeness Centrality	Eigenvector Centrality
1	Ambuja Cements	Bajaj Finance	Petronet LNG	Ambuja Cements	Godrej Consumer Products
2	Godrej Consumer Products	Bajaj Auto	Oil & Natural Gas Corp	Asian Paints	Ambuja Cements
3	Tata Steel	Ambuja Cements	Bharat Petroleum	Apollo Tyres	Tata Steel
4	Larsen & Toubro	Godrej Consumer Products	MRPL	IndusInd Bank	Dr Reddy's Laboratories
5	Tata Motors	Bajaj Finserv	Indian Oil Corporation	Rural Electrification Corporation	Tata Motors
6	Asian Paints	Tata Steel	GAIL (India)	Larsen & Toubro	Max Financial Services

Table 1: Top companies based on centrality.

Director Boards Network: Centrality Analysis

1. Manufacturing companies occupy more central positions than service sector firms.
2. Indian banks do not occupy a central positons in the network.The only bank which is among the top 20 in terms of DC is ICICI bank with degree 7.
3. All the companies which have the highest closeness centralities are petroleum companies.
4. Of 150 companies, 44 have a clustering greater than or equal to 1/3.

Centrality and Financial Performance

- Multiple companies tend to hold the same value of degree centrality.
- Therefore, in a graph of financial metric versus degree, there exist multiple y values for a single x value.
- Fitting a trend in such a case is difficult.
- Hence, an average of the financial metric is considered with the standard deviation represented on the graph to give a general trendline.

Debt to Equity

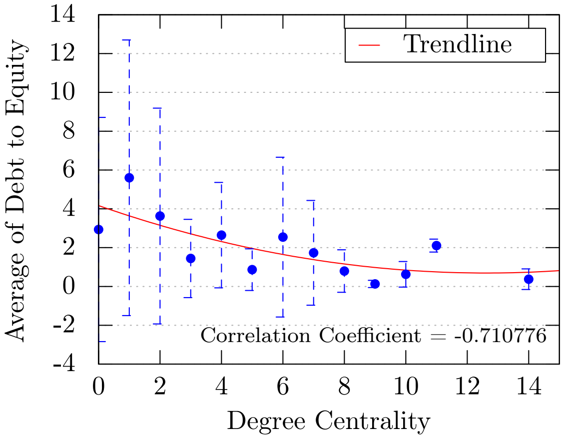


Figure 12: The figure shows a decreasing trendline but the standard deviation of the average is high. The decreasing trendline implies that risky practices tend to decrease as the degree centrality increases

Debt to Equity: Continued

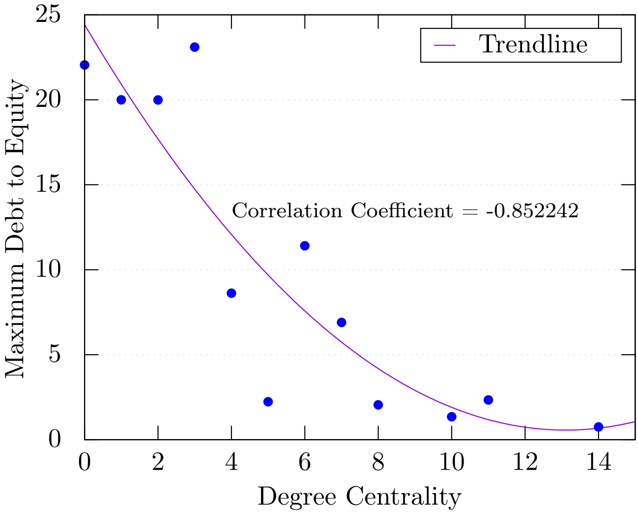


Figure 13: Maximum Debt to Equity vs Degree

NCAVPS

- A similar trendline is plotted for P/E ratio and CROIC. No significant trend line is observed.
- Below, we can find the relationship between NCAVPS and degree centrality.

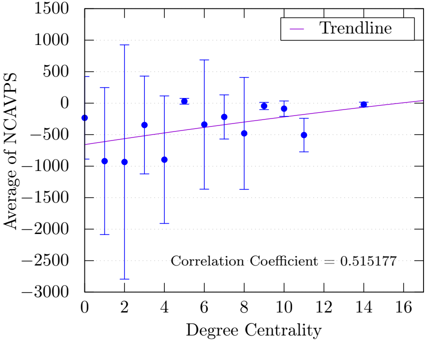


Figure 14: Average of NCAVPS vs Degree. Even though, average of NCAVPS is increasing with degree centrality the standard deviation is high.

Maximum NCAVPS

- Figure 15 represents the maximum value of NCAVPS any company exhibits for a particular degree centrality.
- Maximum value of NCAVPS tends to decrease with increasing degree centrality.

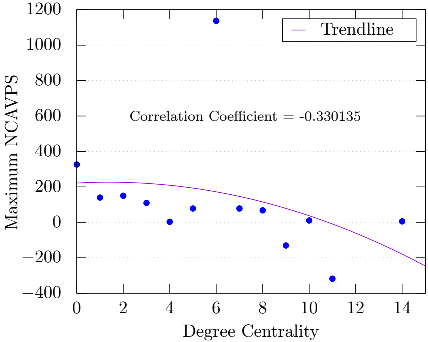


Figure 15: Maximum Value of NCAVPS vs Degree

Minimum NCAVPS

- Figure 16 represents the minimum value of NCAVPS any company exhibits for a particular degree centrality.
- Minimum value of NCAVPS tends to increase with increasing degree centrality.

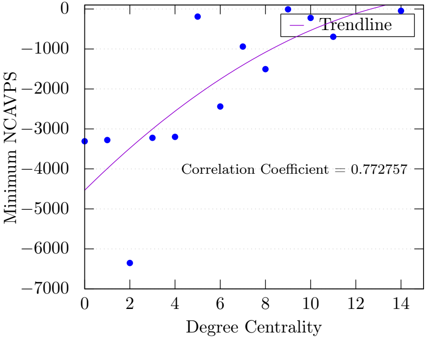


Figure 16: Minimum of NCAVPS vs Degree

Directors Network

Table 2: Top directors, based on different measures of centrality. The numbers with format Dxyz represents the Director with pseudonyms xyz.

Rank	Degree	Weighted Degree	Eigenvector Centrality	Betweenness Centrality
1	D508	D508	D826	D508
2	D826	D826	D508	D826
3	D1390	D423	D1390	D1400
4	D478	D1179	D251	D965
5	D30	D478	D749	D4
6	D344	D1390	D1331	D30
7	D4	D1018	D478	D801
8	D749	D30	D4	D344
9	D195	D344	D344	D905
10	D599	D4	D316	D142

Directors Network: Centrality Analysis

- The average degree of the directors network is 13.462
- The degree distribution of nodes, which is in the form of a Poisson distribution, can be seen in Figure 17.

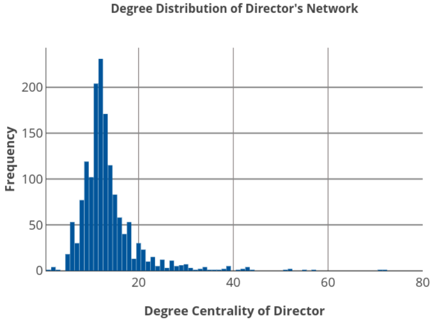
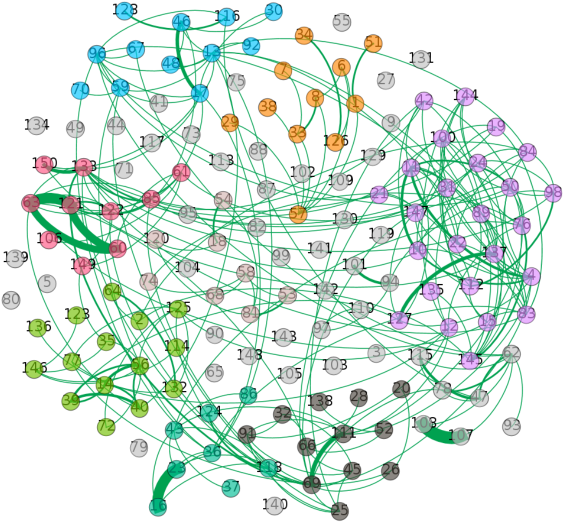


Figure 17

Further Details on Centrality

1. It is observed that the two directors who have the highest centralities are D508 and D826.
2. The two directors are connected not only to a large number of people, but also to other influential directors.
3. The director D251 is among the highest ten of Eigenvector centralities but not in other measures.

Communities



Communities

Table 3: List of the three largest Communities

Communities

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Company
Tata Motors
Tata Consultancy Services
Tata Steel
ICICI Bank
Bharti Airtel
Vedanta
Maruti Suzuki India
Wipro
HCL Technologies
Hindustan Unilever
Tata Power Company
Asian Paints
Siemens
Titan Company
Tata Chemicals
Bosch
Bombay Burmah Trading Corporation
Nestle India
Britannia Industries
United Spirits
Piramal Enterprises
ABB India

(a) The largest community of companies

Communities

Table 3: List of the three largest Communities

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Asian Paints
Siemens
Titan Company
Tata Chemicals
Bosch
Bombay Burmah Trading Corporation
Nestle India
Britannia Industries
United Spirits
Piramal Enterprises
ABB India

(a) The largest community of companies

Company
Canara Bank
Larsen & Toubro
Mahindra & Mahindra
Essar Oil
Canara Bank
Vodafone India
Tech Mahindra
Hero MotoCorp
Jet Airways (India)
Yes Bank
Max Financial Services
Cipla
MRF
Apollo Tyres
IDFC
IDFC Bank

Communities

Table 3: List of the three largest Communities

Company
Tata Motors
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Vedanta
Maruti Suzuki India
Wipro
HCL Technologies
Hindustan Unilever
Tata Power Company
Asian Paints
Siemens
Titan Company
Tata Chemicals
Bosch
Bombay Burmah Trading Corporation
Nestle India
Britannia Industries
United Spirits
Piramal Enterprises
ABB India

(a) The largest community of companies

Company
Canara Bank
Larsen & Toubro
Mahindra & Mahindra
Essar Oil
Canara Bank
Vodafone India
Tech Mahindra
Hero MotoCorp
Jet Airways (India)
Yes Bank
Max Financial Services
Cipla
MRF
Apollo Tyres
IDFC
IDFC Bank

(b) The second largest community of companies

Company
Adani Power
Federal Bank
Tata Communications
Shriram Transport Finance
Idea Cellular
Rain Industries
Adani Ports & Special Economic Zone
Thomas Cook (India)
Arvind
Reliance Industries
Hindalco Industries
UltraTech Cement
Grasim Industries
ITC

(c) The third largest community of companies

Modularity Maximization Based Communities

There are a total of 48 communities and the distribution in Figure shows that most nodes (companies) belong to single membered communities.

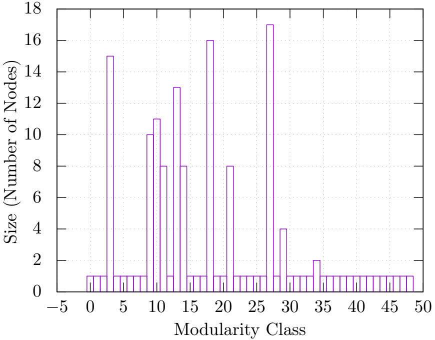

Figure 18: Communities - Size Distribution

Communitiy Detection Results

- The largest community has many companies which belong to the Tata Group..
- All the companies in the Reliance Group belong to the modularity class 8.
- Further, Reliance Industries, another business conglomerate, belongs to the third largest community with other prominent firms such as Adani Power, Ultratech Cement, and ITC.

Modularity and Financial Performance

- This is a novel perspective used to identify the relationship between firm performance and director board interlocking.
- In our work, we plotted the relationship between modularity and various financial performance metrics.
- We find that Most companies, as seen in Figure 19, in single membered communities have moderate values of NCAVPS, however the large outliers (especially negative) tend to lie in larger communities.
- This indicates that companies, even though having unusually negative performance might actually have dense connectivity with a specific group of companies.

NCAVPS and Modularity Class

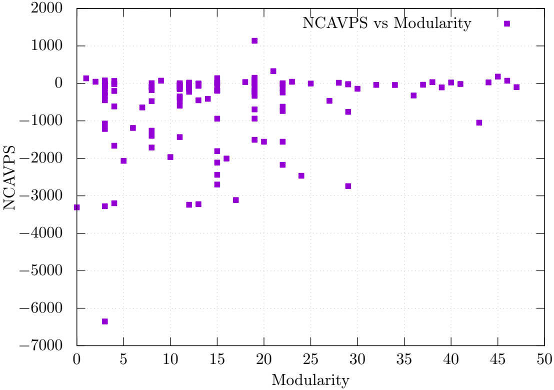

Figure 19: NCAVPS vs Modularity Class. The figure shows that outliers tend to belong to larger communities.

Conculsions and Future Work

- Manufacturing companies occupy more central positions than service sector firms.
- Indian banks do not hold central positons in the network.
- Firms belonging to the same big business group are generally members of the same community
- Companies with unusaully negative companies tend to belong to non single membered communities.
- There is a need to further study the Indian network on a larger dataset of around 500 companies to understand if our results can be universalized.

Main References

- W. Roy, Interlocking directorates and the corporate revolution, vol. 7, p. 143, 09 1984.
- P. H. Franses et al., Interlocking boards and firm performance: evidence from a new panel database, Tinbergen Institute, Tech. Rep., 2007.
- F. N. Stokman, J. Van der Knoop, and F. W. Wasseur, Interlocks in the netherlands: Stability and careers in the period 19601980, Social Networks, vol. 10, no. 2, pp. 183208, 1988.
- C. Drago and R. Ricciuti, Communities detection as a tool to assess a reform of the italian interlocking directorship network, Physica A: Statistical Mechanics and its Applications, vol. 466, pp. 91104, 2017.
- J. Naudet and C.-L. Dubost, The indian exception: the densification of the network of corporate interlocks and the specificities of the indian business system (20002012), Socio-Economic Review, vol. 15, no. 2, pp. 405434, 2016.
- S. Chandrashekar and K. Muralidharan, Networks of power and influence: Board interlocks in india 1995-2007an empirical investigation, 2012.
- B. S. Manoj, A. Chakraborty, and R. Singh, Complex Networks: A Networking and Signal Processing Perspective. Pearson, February 2018.
- V. D. Blondel, J.-L. Guillaume, R. Lambiotte, and E. Lefebvre, Fast unfolding of communities in large networks, Journal of statistical mechanics: theory and experiment, vol. 2008, no. 10, p. P10008, 2008.
- R. Brealey, S. C. Myers, and A. J. Marcus, Fundamentals ofCorporate Finance. McGraw-Hill, New York, 1995.
- B. K. Boyd and A. M. Solarino, Ownership of corporations: A review, synthesis, and research agenda, Journal of Management, vol. 42, no. 5, pp. 12821314, 2016. [Online]. Available: https://doi.org/10.1177/0149206316633746

Thank You.