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NETWORK ANALYSIS OF AN INDIAN STOCK MARKET USING THE MINIMUM SPANNING TREE ALGORITHM

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Abstract

This paper analyses the topological properties of one of the Indian stock markets, namely the National Stock Exchange (NSE), using the Minimum Spanning Tree (MST) algorithm to find the impact of the Subprime Financial Crisis on Indian stock market: how the crisis affected individual stocks, how the relative importance of the sectors shifted across different phases of the crisis, and how stocks clustered over time. This kind of a study of an Indian stock market is the first of its kind. The stocks belonging to S&P Nifty 50 (which is the headline index of NSE) are classified into 9 sectors of the Indian economy and the analyses are done both stock-wise and sector-wise. The study is expected to be useful in designing investment strategies and optimal portfolios. The research also aims to find the core sectors of the Indian economy and predict the state of the economy in the near future.

Keywords: Minimum Spanning Tree, Network Analysis, Indian Stock Market

JEL Classification Code: D85

1. Introduction

Networks exist in different areas of an economy. Some recent applications of complex networks to stock markets that have created a lot of interest among researchers are attempts to analyze the dynamics of the stock market; see for instance, Mantegna (1999), Mantegna and Stanley (2000), and Bonanno *et al*. (2004) among others. It not only allows one to visualize the relationship between the financial entities (like stocks, companies, and hedge funds), but also helps in analyzing the importance of different stocks and sectors of an economy. However, the major problem encountered with this methodology is that, the topology obtained has too many edges or interconnections. For example, a network of N stocks can have the total number of interconnections of the order N^2 which makes the graphical representation look very cumbersome, thus making it too difficult to extract any useful information from it.[3] To overcome this problem, one can use *link reduction algorithms.* These algorithms are used to filter the

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[3] Each of the N stocks can have some correlation with each other and thus there can be NC_2 interconnections which is equal to N×(N-1)/2.

unwanted or less important information to obtain an efficient dataset. One such link reduction algorithm which is also used in the present paper is the Minimum *Spanning Tree* (MST) algorithm. The advantages of using MST over other link reduction algorithms are threefold.

(i) MST gives the N-1 *strongest* (i.e. shortest) links that span the whole space;

(ii) it *reduces* the number of links present in the networks, helping in the visualization of the networks (for example, it reduces the number of links to N-1 for a network consisting of N stocks that actually can have the total number of links of the order N^2);and

(iii) it *preserves* the topological properties of the network to a great extent (Chen and Morris 2003).

Thus, the MST approach provides a simplified graphical representation of otherwise very complex networks, hence can be effectively used to study the dynamics of a stock market.

2. Objectives

Broadly speaking, the present study attempts to find the following.

(i) *Cluster stocks* that form a cluster as they are highly correlated with each other. Any external shock will affect them in a similar manner.

(ii) *Core sectors/stocks* that are the most important stocks with respect to the economy. Most of the other stocks are highly correlated with them.

(iii) *Changes in the topology* of the stock market network as we move from pre-crisis period to crisis period to post crisis period.

(iv) *How individual stocks behave* along with the change in their relevance and importance across different phases of a crisis. This is also useful for making investment decisions; and

(v) *Predict the state of the Indian economy*: a star-like topology suggests low volatility and robust economic growth while a chain-like topology suggests a period of high volatility and recession; see Zhang *et al.* (2010).

3. Definitions

NSE Nifty 50

This paper analyzes the stocks listed on the National Stock Exchange's Nifty 50. It is the headline index of the National Stock Exchange (NSE). It tracks the performance of the blue chip companies, the companies that are the largest and most liquid spanning across different sectors of the Indian economy. Nifty 50 accounts for around 60% of the total market capitalization of the Indian equity market and thus can be expected to truly reflect the Indian economy.[4]

[4] Market capitalization for a company is calculated as the product of total number of shares floated by the company and the price of each share.

Nifty 50 takes into account the following factors for selecting the companies: *liquidity, market capitalization, percentage of floating stocks,* and *others (related to regulatory measures)*.[5] The 50 stocks are classified into the following 9 sectors of the Indian economy: Basic Materials (BM), Consumer Goods (CG), Finance (FIN), Healthcare (HC), Utilities (UTIL), Conglomerates (CONG), Technology (TECH), Telecommunication Services (TELE) and Industrial Goods (IG).

Return on a Stock

Return on a stock comprises of two components: *capital gain/loss and dividend*. In the present paper we deal only with the former and neglect the latter due to unavailability of data. Algebraically, log returns which are easier to work with are calculated using the following formula

$$X_i(t) = \ln\left[S_i(t)\right] - \ln\left[S_i(t-\Delta t)\right] \quad \text{... (1)}$$

where $X_i(t)$ is log return at time t and Δt is the time interval over which two consecutive returns are calculated. Both these time parameters have important implications for the network topology; see Bonanno *et al* . (2004). $S_i(t)$ is the average of opening, closing, high and low prices of the i^{th} stock at time t. This average value helps to reduce the intraday volatility in the price of a stock.

Correlation

Let the return on stocks i and j be represented as *X* and *Y* respectively. The correlation between stock returns is given by the formula

$$\rho_{xy}(\Delta t) = \frac{E\left[\left(X - E(X)\right)\left(Y - E(Y)\right)\right]}{\sqrt{E\left[\left(X - E(X)\right)^2\right]}\sqrt{E\left[\left(Y - E(Y)\right)^2\right]}} \quad \text{... (2)}$$

where *E(X)* represents the expected value of *X*. The value of correlation between any two stock returns can vary between -1 and 1 where -1 for instance, represents perfect negative correlation implying that the stock returns move in exactly opposite directions. A correlation value of 0 implies that the stock returns move independently of each other, i.e. movements in the prices of one has no relation with the movements in the price of other.

Correlation Matrix

A nxn matrix C is said to be a correlation matrix where each element c_{ij} represents the correlation coefficient between the i^{th} and the j^{th} element. In the context of the present research the individual elements represent the correlation between the returns on a pair of stocks. The correlation matrix Nifty 50 is a 50x50 correlation matrix (C). These securities are further divided into 9 sectors for which a corresponding 9x9 matrix is also obtained.

[5] Floating stocks are those which are not held by the promoters and associated entities of the company. As per NSE rules the company must have at least 12% of its shares as float.

Distance Matrix

The correlation matrix is used to construct the distance matrix (D) which is also the adjacency matrix (explained in a later section) used for constructing the Minimum Spanning Tree (MST). The individual elements of this matrix can be interpreted as the distance between any two individual stocks, measured in terms of the length of an edge of the MST that forms the nodes of the MST. The distance is inversely related to the correlation between two stocks implying higher the correlation between the stocks closer they will be, and vice versa. The distance ($\boldsymbol{d_{ij}}$) between stocks i and j is given as

$$d_{ij}\left(\Delta t\right)=\sqrt{2\times\left(1-\rho_{ij}\right)} \quad \text{... (3)}$$

where $\boldsymbol{\rho_{ij}}$ is the corresponding correlation between stocks i and j. Clearly, the range of the distance matrix lies between 0 and 2. Since, it is derived from the correlation matrix, its properties are similar (but opposite) to the correlation matrix.

Network Topology

Network topologies can be depicted as the layout of the *inter-connections* between different components of a given system. In the case of stock market networks, the correlations between pairs of stocks are used for interconnections. There can be many types of network topologies like bus, ring, star, tree and mesh-like topologies. Out of these the star-like and the chain-like topologies are most important in the context of the present research; see Zhang *et al.* (2010). A star-like topology has one or a few central connection points called the “hub” to which most of the other nodes are connected. On the other hand, a chain-like topology consists of nodes connected with each other in a more linear fashion. While the star-like topology highlights the importance of a few stocks (hubs) which form the core of the economy and shows the high dependence of other securities on these core stock (s), the presence of a chain-like topology on the other hand indicate lack of powerful companies or central hub (s) with high market capitalization, i.e. it represents a more evenly distributed market capitalization among stocks.

Graphs

A graph is a collection of vertices called nodes and edges that connect them. A graph is called weighted if a label (usually a real number) is associated with each edge; else it is referred to as an un-weighted graph. The weight is usually the length of a particular edge; see Cormen *et al.* (2009).

A graph G is represented as G = {V, E} where, V and E are the sets of vertices and edges, respectively. A particular edge is represented as (u, v) where {u, v} belong to V and the weight of the edge is represented as w (u, v). The total weight W of the graph is the sum total of the weights of individual edges.

Each element of the nxn adjacency matrix c_{uv} represents the weight of the edge (u, v). The diagonal terms are 0 as there can be no edge between a node and itself. For an undirected graph, $c_{uv} = c_{vu}$.

Minimum Spanning Tree

Refer to Cormen *et al.* (ibid.) Let G = {V, E} be a graph of N nodes with edges (u, v) belonging to E and having weight = w (u, v).Then a non-cyclic tree T consisting of (N-1) edges is called a Minimum Spanning Tree if its edges are a subset of E, and w (T) is minimized where w (T) is defined as[6]

$$w(T) = \sum(u, v) \quad \text{... (4)}$$

Prim's Algorithm

Let a graph G = {V, E} be given with N nodes and any number of edges. The aim is to find a graph consisting of N nodes connected by exactly N-1 number of edges such that the total weight of these edges is *minimum* among all the possible sets of graphs consisting of N-1 edges.

- *Input:* A non-empty connected weighted graph with vertices V and edges E (the weights can be negative).
- *Initialize:* V_{new} = {x}, where x is an arbitrary node (starting point) from V, E_{new} = {}
- Repeat until V_{new} = V:
  - Choose an edge (u, v) with minimal weight such that u is in V_{new} and v is not. (If there are multiple edges with the same weight, any of them may be picked).
  - Add v to V_{new}, and (u, v) to E_{new}
- *Output:* V_{new} and E_{new} describe a minimum spanning tree.

4. Literature Review

Mantegna (1999), Mantegna *et al*. (2000) and Bonanno *et al*. (2004) made several important contributions in this area. In their paper Bonanno *et al.* (ibid)) showed how the network topology altered with changes in the time interval. They noted that the correlation between stock returns decreases with reduction in the time scale. This was termed as the Elps Effect. This effect also demonstrated that the change in intra-sector stock pairs was more rapid and steep as compared to the change in the inter-sector stock pairs. Chen and Morris (2003) demonstrated the importance of the MST algorithm over other link reduction algorithms like the Path Finder Algorithm. The authors concluded that the MST approach proves to be a better approach in the sense that it preserves most of the topological properties even after a significant amount of link reductions. Jung *et al.* (2006) studied the differences in the network topologies of a mature and an emerging market. They used S&P 500 as an indicator for the developed US market while KOSPI 200 for the emerging South Korean market. It was found that being an emerging market, South Korea lacked the presence of hubs and the stocks were not found to cluster as well as they do in the US market which the author argued was because of the difference in the development of the two countries. Tabak *et al*. (2009**)** observed that the Brazilian stocks tend to cluster by the sectors. They found financial, material and energy sectors to be central to the Brazilian economy and how the relative importance of the sectors fluctuated with time. A similar study was done earlier by Garas and Argyrakis (2007) on Greek stock market. Finally, Zhang *et al*. (2010**)** studied

[6] A tree is said to be cyclic if it forms a closed chain/loop.

the US economy over a 10 year period through different crises and concluded that a star-like topology is associated with high growth and robust economy while a chain-like topology reflects volatile and recessionary period. Using this analysis he predicted that the US economy would be on the path to recovery in 2011.

5. Data and Softwares

As mentioned earlier, this paper uses stocks listed on S&P CNX Nifty 50 to analyze the impact of financial crisis on Indian stock market. The data obtained is weekly in nature, and an average of opening, closing, high and low prices of a particular security are considered for calculating the returns. For the purpose of this study the stocks are selected at the beginning of the study period, i.e. August 2007 and are retained across different phases of the study period. The symbols used for them are mentioned in the Appendix of the paper. The data on returns is obtained from the websites of National Stock Exchange (India) and Yahoo! Finance-India, while the data on the Indian economy is obtained from RBI's Handbook of Statistics. MATLAB is used to find the covariance and correlation matrices for the stocks and sectors. The distance matrix is then calculated using the correlation matrix. A C-implementation of Prim's algorithm is used to find the MSTs. PAJEK is used for the networks and MST visualizations.

6. Hypotheses

(i) Stocks belonging to the same sector should form a cluster.

(ii) The important stocks in the Indian economy should lie at the center of the MST with other stocks connected with them.

(iii) MST for the *pre-crisis* period should have a star-like topology signaling a robust growth of the Indian economy which actually grew by more than 9% during that period. For the *crisis* period, MST should be more chain-like indicating volatility and recession.

(iv) While the importance of the financial sector should diminish during the *crisis* period due to the fact that the crisis led to a global financial meltdown, the importance of the Consumer Goods sector should increase as the Indian GDP during the *crisis* period was mostly driven by strong domestic demand.

(v) The *pre-recovery* period should show a transition from a chain-like topology to a star-like topology while the *post crisis* period should again result in more of a star-like topology.

7. Empirical Results

The study period is divided into the following four phases.

(i) *The Pre-Crisis period*: August 13, 2007 to December 31, 2007

(ii) *The Crisis period*: January 07, 2008 to October 20, 2008

(iii) *The Post-Crisis period*: November 03, 2008 to February 24, 2009; and

(iv) *The Pre-Recovery period*: March 02, 2009 to June 29, 2009.

7.1 Sector-Wise Analysis

The following general observations can be made from Figures 1-4.

1. The central importance of Basic Materials (BM), Financial (FIN) and Consumer Goods (CG) sectors remain across different phases.
2. FIN remains the most important sector except for the *pre- recovery* period.
3. The presence of Health Care (HC), Conglomerate (CONG) and Technology (TECH) sectors on the fringe throughout the period of study indicate low relative importance of these sectors
4. Telecommunication (TELE) moves from the fringe towards the center of the MST during the *post crisis* period. This is also supported by the fact that India concluded its 3G spectrum auctions during that period.
5. Technology (TECH) seems to be a potentially upcoming sector of the Indian economy
6. The importance of the Utility sector (UTIL) vary from period to period which is mainly due to the fact that this sector is largely integrated with world oil and gas prices and moves accordingly.

The Pre-Crisis Period

The *pre-crisis* period (Figure 1) shows a perfect star-like topology for the Indian economy. This indicates robust growth of the Indian economy during this period. The fact that the Indian GDP growth rate was around 9% during this period (Table 1) provides tailwind to the above observation. FIN was the core sector of Indian economy. Basic Materials, Utilities and Industrial Goods form the other important sectors during this period.

Table 1. Indian GDP growth rate from 2003-04 to 2008-09

	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09
Agriculture, forestry and fishing	10	0	5.8	4	4.9	1.6
Mining & quarrying	3.1	8.2	4.9	8.8	3.3	3.6
Manufacturing	6.6	8.7	9.1	11.8	8.2	2.4
Electricity, gas & water supply	4.8	7.9	5.1	5.3	5.3	3.4
Construction	12	16.1	16.2	11.8	10.1	7.2
Trade, hotels & restaurants	10.1	7.7	10.3	10.4	10.1	9
Transport, storage & communication	15.3	15.6	14.9	16.3	15.5	9
Financing, insurance, real estate etc	5.6	8.7	11.4	13.8	11.7	7.8
Community, personal & social service	5.4	6.8	7.1	5.7	6.8	13.1
Total GDP at factor cost	**8.5**	**7.5**	**9.5**	**9.7**	**9**	**6.7**

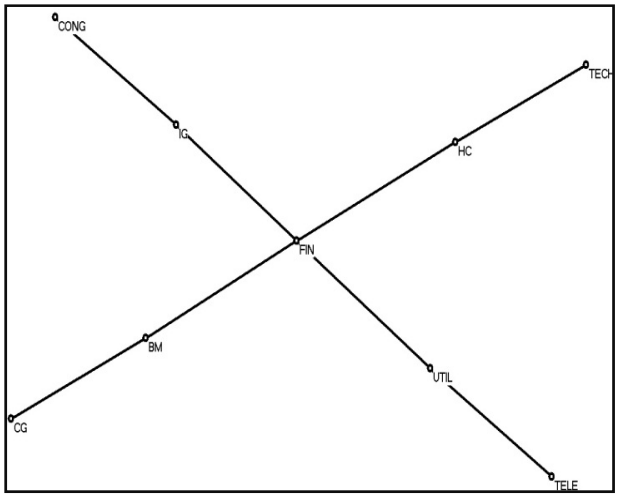

Figure 1. *Pre-crisis* period

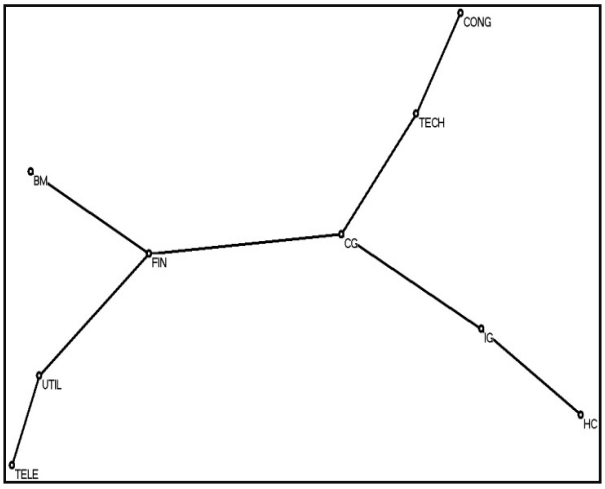

Figure 2. *Crisis* period

The Crisis Period

Note how the topology of the MST changes as we move from the *pre-crisis* period to the *crisis* period (Figure 2). The perfectly star-like topology seen earlier converted to a more chain-like topology which indicates a recessionary period with high volatility in the economy. Indian GDP growth rates in Table 1 support this observation. The Financial sector which was at the centre of MST and formed the core of the Indian economy earlier loses its degree of importance.[7] This as noted earlier, can be attributed to the fact that this sector was directly affected by the

[7] The degree of a node can be measured by the number of other nodes attached to it.

global financial meltdown. It is however interesting to note that although the origin of the crisis was in the financial sector, the Indian financial sector could manage to insulate itself up to some extent. This is may be the result of the strong basics and the effective regulatory framework of the Indian banking sector.

Another important observation that deserves a mention here is the shift in the position of the Consumer Goods (CG*)* sector from the fringe of MST (pre-crisis period) to become one of the core sectors of the Indian economy. The growth of CG can be attributed to the strong domestic demand which also helped the Indian economy compensate for the loss due to falling exports. The conclusion of Venu (2010) that it was the companies belonging to the Consumer Goods (CG) sector which clocked the highest growth during the crisis period, provide support to our observation.

The Pre-Recovery Period

The pre-recovery period (Figure 3) was a period of high volatility for the Indian economy. However, the economy did start to show signs of recovery by this time. The importance of the financial sector was further lowered as it moves to the fringe of the MST due to the global financial meltdown. The Basic Material sector assumed central importance and the CG-BM-IG backbone drove the Indian Economy. The topology lies somewhere in between a star-like and a chain-like indicating that the economy had started showing signs of recovery but it is still not back on track.

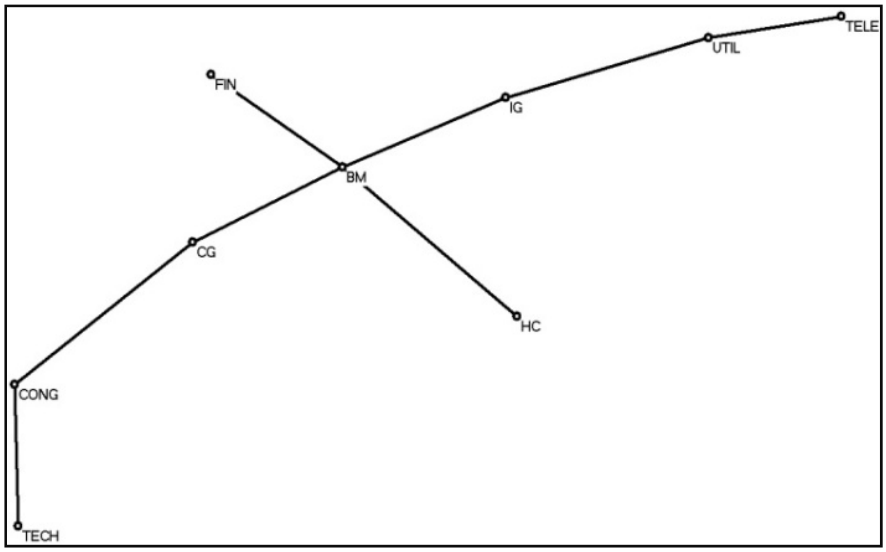

Figure 3. *Pre-recovery* period

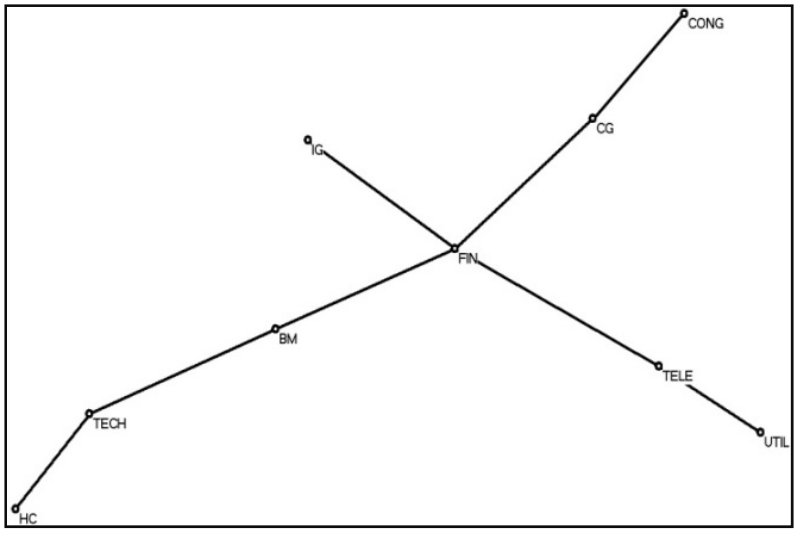

Figure 4. *Post-crisis* period

The Post-crisis Period

Finally, during the *post-crisis* period (Figure 4) FIN once again became India's core sector and the major driver of growth, while CG and BM played the next most important role in the recovery of the Indian economy. The number of primitive rearrangements needed to transfer the MST of a given period into a star-like topology indicates how close we are to the actual recovery. The near star-like topology shows that the Indian economy was on its way to recovery.[8] [9][10]

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[8] On analyzing the Correlation Matrices for each phase, we observe that the cross correlation between the stocks increased as the Indian economy moved from *pre-crisis* to *crisis* to *pre-recovery period.* With highest correlation in the *pre-recovery* period indicates that it was a period with highest volatility. The *post-crisis* Correlation Matrix paints a much calmer picture of the Indian economy. This can be explained by the arguments presented in Bonanno *et al*. (2004) that the tendency of the traders to panic and thus buy/sell stocks from different sectors at the same time during periods of high volatility leads to high values of cross-correlation between the stocks, whereas, the correlation is found much weaker during the calmer period.

[9] The difference between high and low values of the index indicates the volatility prevalent during each phase of the study. Volatility is seen to be low and mostly constant during the *pre-crisis* phase. The *crisis* period was more volatile with frequent peaks and troughs. The *pre-recovery* period shows maximum volatility with the difference between high and the low values converging towards the end of the pre-recovery phase. Finally, volatility in *post-crisis* period can be seen to be constantly on the lower side with the high and low values converging even further towards the end of the period.

[10] The trend of the returns of the NSE Nifty 50 stocks also confirms the occurrence of specific type of topology in each phase of the Financial Crisis. That is, the general level of returns in the pre-crisis phase seems to rise continuously. The general trend of returns in the *crisis* period is downwards clearly highlighting the adverse impact of the Financial Crisis. On the other hand, returns are more or less constant in the *pre-recovery* period; however, they can be seen to gain an upward trajectory in the *post crisis* period. The growth in the *post crisis* period is however not as conclusive as that in the *pre-crisis*

7.2 Security-Wise Analysis

The individual security-wise MSTs are shown in the Figures 5-7. The clustering is particularly evident in sectors like Healthcare, Financial and Industrial Goods (IG) sectors, showing greater correlation between the stocks belonging to these sectors. The topology for *pre-crisis* period is star-like,[11] whereas, the MST for the *crisis* period is chain-like indicating slowdown and recession in the economy.[12] The near star-like topology for the *post-crisis* period proves that the Indian economy was back on the path of growth and would probably continue to grow in future.[13]

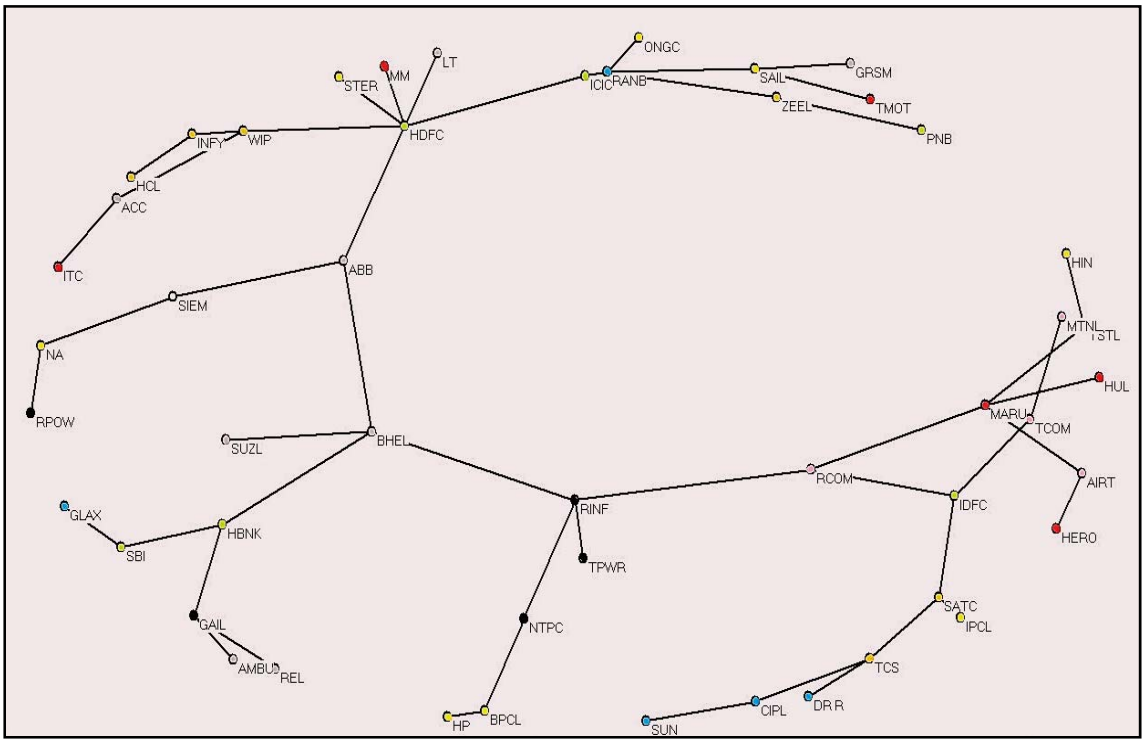

Figure 5. A perfect star-like topology during the *pre-crisis* period

period. Thus, the results are more or less in sync with the type of topology that we have obtained for different phases of the financial crisis.

11 HDFC, Maruti and BHEL hold the most important position in the Indian economy during this period.

12 SBI, HDFC and NTPC were the most important companies during this period.

13 Reliance Power, Tata Power and ICICI bank were the most important companies during this period with securities of other companies strongly correlated with them.

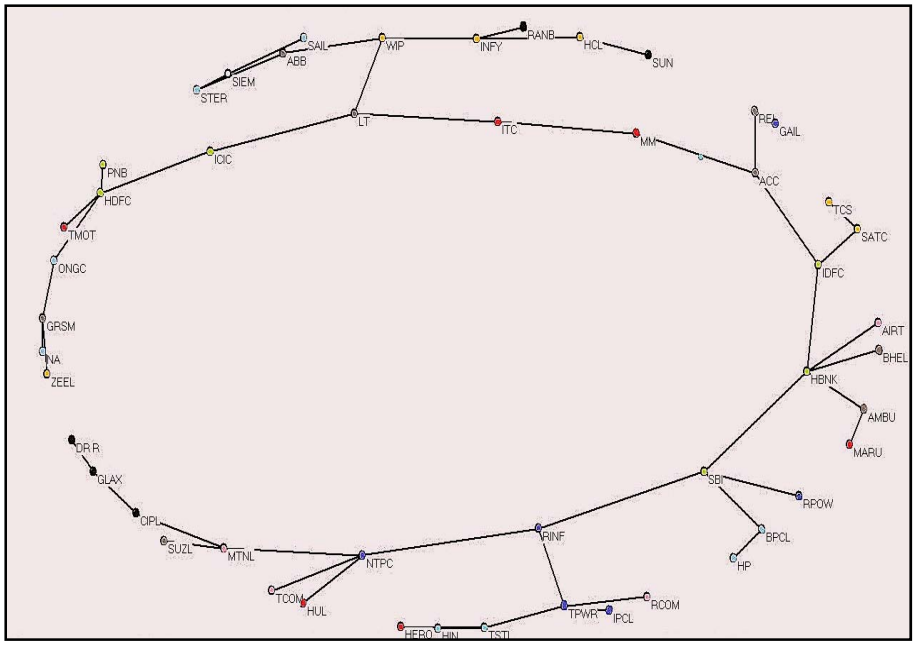

Figure 6. Chain-like topology during the *crisis* period

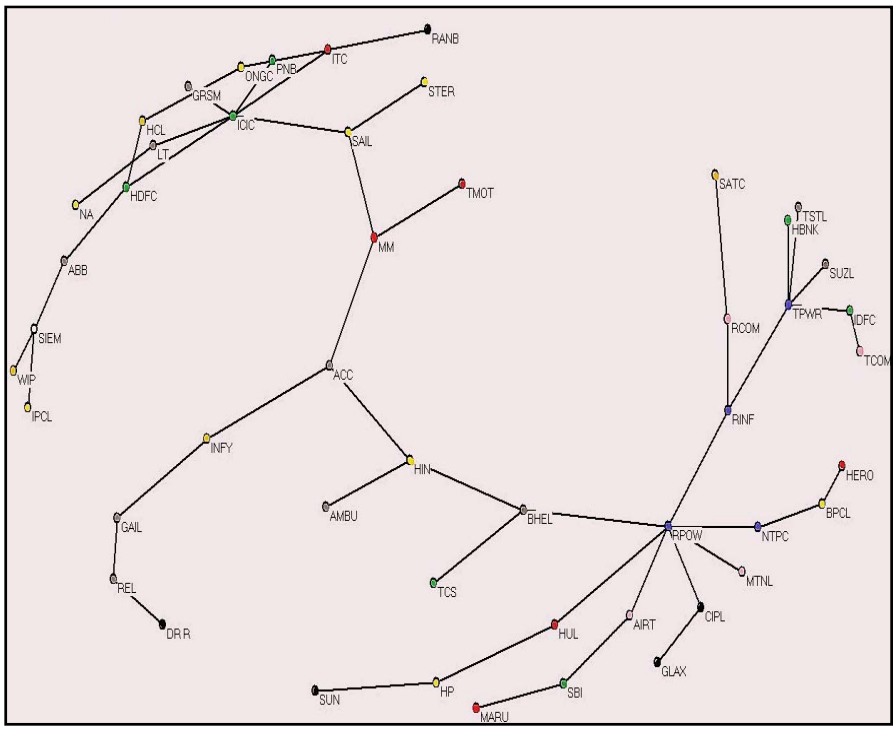

Figure 7. Close to star-like topology during the *post-crisis* period

8. Conclusion

The correlation network obtained using the Minimum Spanning Tree approach is more efficient than the original correlation network. This is because the MST approach not only reduces the number of links present in the correlation network but also provides the strongest links (ones with the highest correlation) between the stocks. The study in this paper shows that the Financial and the Basic Materials sectors are the two most important sectors in the Indian economy. They have the greatest influence and correlations with the other sectors. Consumer Goods is another important sector in the Indian economy, while the Telecommunications sector has proved to be an upcoming sector with continuous introduction of new technologies. Therefore, the trading and the investment strategies should be designed in such a way so as to give more weight to these sectors in the portfolio. The findings also show that the Indian economy was adversely affected by the Subprime Financial Crisis with the Financial sector getting affected the most. India's performance was not as bad when compared to developed countries because of strong domestic demand and the subsequent rise of the Consumer Goods sector. However, in order for India's growth to be more inclusive than what it has been, a much higher level of public spending and efficiency is required in the Health Care and the Education sectors.

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APPENDIX

COMPANY NAME	SYMBOL
ABB	ABB ABB
ACC	ACC
BHARTI AIRTEL	AIRTEL
AMBUJA CEMENTS	AMBU
BHEL	BHEL
BPCL	BPCL
CIPLA	CIPL
DR REDDY LABS.	DR R
GAIL	GAIL
GLAXOSMITHKLINE	GLAX
GRASIM INDUSTRIES	GRSM
HCL	HCL
HDFC	HDFC
HDFC BANK	HBNK
HERO HONDA (HERO MOTO CORP.)	HERO
HINDUSTAN PETROLEUM	HP
HINDALCO	HIN
HINDUSTAN UNILEVER LTD.	HUL
ICICI BANK	ICIC
IDFC	IDFC
INFOSYS	INFY
IPCL	IPCL
ITC	ITC
LARSEN & TURBO	LT
MAHINDRA & MAHINDRA	MM
MARUTI SUZUKI	MARU
MTNL	MTNL
NATIONAL ALUMINIUM COMPANY LTD.	NA
NTPC	NTPC
ONGC	ONGC
PUNJAB NATIONAL BANK	PNB
RANBAXY LTD.	RANB
RELIANCE COMMUNICATIONS	RCOM
RELAINCE INDUSTRIES	REL
RELIANCE INFRASTRUCTURES	RINF
RELIANCE POWER	RPOWER
STEAL AUTHORITY OF INDIA LTD.	SAIL
SATYAM INDUTRIES	SATYAM
STATE BANK OF INDIA	SBI
SIEMENS	SIEM
STERILITE	STER
SUN PHARMACEUTICALS	SUN
SUZLON	SUZLON
TATA COMMUNICATIONS	TATACOMM
TATA MOTORS	TMOT

TATA POWER	TPWR
TATA STEEL	TSTL
TATA CONSULTANCY SERVICES	TCS
WIPRO	WIP
ZEE ENTERTAINMENT ENTERPRISES LTD.	ZEEL

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