Research article

Correlation structure networks of stock market during terrorism: evidence from Pakistan

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Abstract: We study topology of correlation structures and construct Pearson correlation-based networks (MST-Pearson) and partial correlation-based networks (MST-Partial) during two time periods of extreme terrorist activities (High civilian and security forces fatalities) and relaxed period (low civilian and security forces fatalities). Our results find that probability density function of Pearson correlation coefficients for relaxed period and partial correlation coefficients for both periods slightly deviates from the gaussian function. MST-Pearson during the period of extreme terrorist activities is a crisis like less stable market structure in comparison with the meta-stable market state structure of relaxed period. Our studies also find presence of two most prominent clusters belonging to cement, and chemical and pharmaceutical sectors among four MSTs. In addition, we find important role of few sectors during the period of extreme terrorist activities in comparison with a more diversified sectoral role in the relaxed period. Furthermore, time varying topological properties indicate an expansion in both MST-Pearson and MST-Partial length in the relaxed period due to counter terrorism strategies. Thus, the study reveals interesting findings and implications for the policymakers and investors of Pakistan stock market during the event of terrorism.

Keywords: correlation structure; network topology; partial correlation; minimum spanning tree; terrorism; emerging market; stock market
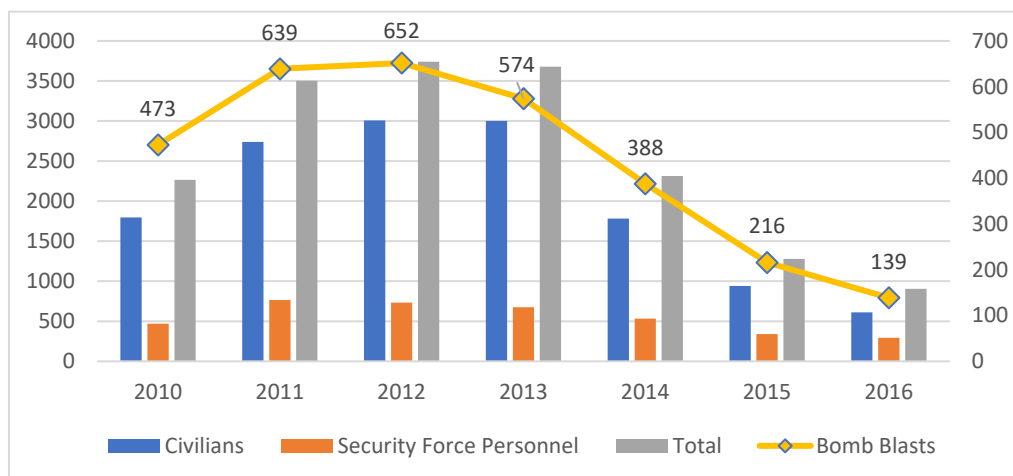
JEL Codes: G10, B4, D53, D85, F36

1.   Introduction

Terrorism produces a damaging impact on the development of economy. The extent of terrorist attacks can create panic and affect progress of the country. The implications of terrorism vary from direct civilian and security personnel causalities, infrastructure and property damages to indirect in deducing confidence of local and international investors for the prospects of a country. Terrorism is a complex phenomenon that have attracted a huge interest from researchers all over the globe (Llussá & Tavares, 2011; Barnett et al., 2013, 2015). Various studies have proved that terrorism is main cause of poor economic growth (Eckstein & Tsiddon, 2004; Blomberg et al., 2004; Shahbaz, 2013; Khan, et al., 2016), that leads to capital flights (Abadie & Gardeazabal, 2008; Efobi & Asongu, 2016) decreases foreign direct investment (Bandyopadhyay et al., 2014; Haider & Anwar, 2014), lower credit rating (Procasky & Ujah, 2016; Haddad & Hakim, 2008), affect stock market volatility (Arin et al., 2008; Mnasri & Nechi, 2016; Essaddam & Karagianis, 2014), and lower stock market returns (Kollias et al., 2011; Brounen & Derwall, 2010).

The magnitude of terrorist attacks after September 11, 2001 (9/11) on Pakistan, an ally of USA on "war on terror" are huge that not only paralyzed the country's economic growth (Shahbaz, 2013) but significantly affected investors' confidence. Being a terrorism-plagued country (Rehman & Vanin, 2017), Pakistan is on receiving end of extreme terrorism for more than a decade and country's military and government is in constant collaboration to curb terrorist activities. By controlling terrorism, Pakistan has attracted foreign direct investment (FDI)[1] from US$0.859 Billion in the year 2012 to US$2.488 Billion in the year 2016. The annual GDP growth[2] has also witnessed an increase from 3.507% in the year 2012 to 5.527% in the year 2016. Number of civilian and security personnel fatalities from year 2010 to 2016, owing to terrorist activities in the country are presented in Figure 1.

Figure 1. Civilian fatalities, Security force personnel fatalities, and bomb blasts in Pakistan (Data extracted from SATP)[3].

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[1]Please see: World Bank development indicator: (https://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD?end= 2016&locations=PK&start=2012).

[2]Please see: World Bank development indicator: (https://data.worldbank.org/indicator/NY.GDP. MKTP.KD.ZG?end= 2016&locations=PK&start=2012).

[3]Please see: http://old.satp.org/satporgtp/countries/pakistan/database/index.html.

According to South Asia Terrorism Portal (SATP), a terrorism database, the number of civilian and security force personnel fatalities peak during combined years of 2012 and 2013 to 7,416. However, the fatalities of civilians and security force personnel remained low during year 2015 and 2016 to 2184. Thus, in order to analyze the network topology of Pakistan stock market, these two periods are classified as "period of extreme terrorist activities" (Starting from January 1, 2012 to December 31, 2013) and "relaxed period" (starting from January 1, 2015 to December 31, 2016). Unlike conventional methods of examining the impact of terrorism on Pakistan stock market, the main objective of study is to analyze the correlation structure and topology of Pakistan stock Market during two periods of extreme terrorist activities and relaxed period. To the best of our knowledge this is first study that perform network analysis by taking wide range of 202 most active stocks from 33 industry sectors examining the impact of terrorism on the topology of Pakistan stock exchange network.

This study will contribute to the literature in many ways. First, the study extends financial network literature by applying network topology measures on wide range of 202 stocks from 33 sectors of Pakistan stock market. Second, the physics-derived method of minimum spanning tree is used, and comparative analysis is performed by constructing MST-Pearson and MST-Partial for the two periods of extreme terrorist activities and relaxed period, i.e. four Minimum spanning trees. Third, the study illustrates and explores the impact of non-economic event of terrorism on the topology and evolution of stock market. Forth, similar to the findings of (Wang et al., 2018) for world stock market network, the study shows that MST-Partial of Pakistan stock market network is structurally different than MST-Pearson, which means that individual stocks are influenced from the stocks of same or different industry sectors. Finally, the findings of this study will help all investors, regulators, and government officials in devising policies and taking appropriate investment decisions in Pakistan stock market.

The remainder of the paper is organized as follows. Section 2 mentions a brief literature review. Section 3 presents data and methodology of constructing Pearson and partial correlation-based networks and weighted network measures. Section 4 show main empirical results and discusses the results. Finally, we conclude the paper in section 5.

2. Literature review

Among the most popular method of formulating financial network is Pearson correlation-based network presented by (Mantegna, 1999), who propose a filtering tool of minimum spanning tree (MST) for examining the correlation structure of financial markets. Thereafter, this method has been widely applied in the financial network literature see e.g., (Yin et al., 2017; Wang et al., 2013; Brida et al., 2016; Onnela et al., 2003; Song et al., 2011; Memon et al., 2020; Memon & Tahir, 2021). Network formed through MST contain $n - 1$ links, where n is total number of nodes, a minimum network that comprises important information and form a meaningful structure. However, such network approach is considered an extreme approach with greater information being lost. An extension of MST containing relaxed network constraints was proposed by (Tumminello et al., 2005), known as Planar Maximally Filtered Graph (PMFG). Thus, the PMFG network consists of MST links, and add some additional links reaching to a maximum of $3(n - 2)$ link network. However, Pearson correlation-based MST of constructing stock market network is widely used in financial network literate due to simplicity, better visualization, and extraction of important information, which otherwise is hard to achieve, and consequently used in this study.

While examining 22 stock market indices from three regions, (Setiawan, 2014) used minimum spanning tree approach between 2000 and 2010 and found demographic based segments with higher degree of integration among stock markets. In addition, (khoojine & Han, 2019) studied Chinese stock market turbulence in 2015–2016 through complex network method of MST. Their results showed turbulence period star-like MST in comparison with a linear MST during pre- and post-crisis periods. Similarly, a star-like structure of MST has been observed by (Nguyen et al., 2019) for Vietnamese stock market during turbulent period of 2011–2012. Moreover, (Li & Pi, 2018) studied the evolution and topological properties of 38 stock indices over the period of 2005 to 2010, while focusing on global financial crisis. Their results demonstrated substantial clustering and weakened edge numbers of important nodes after the crisis. Hence, previous literature shows strong evidence of changes structures and topological properties of MSTs during crisis events.

3. Data and methods

According to (Mantegna & Stanley, 2000), financial markets are complex systems that contain interwoven heterogenous agents. It is due to this complexity the correlation of network is affected by other financial agents. Therefore, in order to get "net" or ("Pure") correlation between two financial agents, for stock markets, to obtain net correlation between two stocks and to remove the influence of third stock belonging to the same or different industry sector, (Wang et al., 2018) proposed a novel method of constructing partial correlation matrix by determining partial correlation coefficient. Hence, it is evident that previous literature provides variety of correlation-based methods of studying static and dynamic properties of financial network. In order to cover both aspects, we obtain four correlation matrices by computing the Pearson and partial correlation coefficients for two periods of extreme terrorist activities (Year 2012 and 2013) and relaxed period (Year 2015 and 2016). We then follow the methodology of constructing MST by (Mantegna, 1999), of transforming four correlation matrices into four distance matrices and Pakistan stock market network of MST-Pearson and MST-Partial. Moreover, we analyze the topological properties of Pakistan stock market during and investigate differences.

We use daily closing prices of the most active 202 stocks of 33 sectors listed in the Pakistan stock exchange from January 2012 to December 2016. We build network using Pearson and partial correlation distances by dividing the time period into two periods based on terrorist activities and civilian and security personnel fatalities. As mentioned by SATP the period from 1st January 2012 to 31st December 2013 (496 stock trading days) includes high terrorist activities and fatalities are at peak, so we name this period as the "Period of extreme Terrorist activities". However, "Relaxed period" starts from 1st January 2015 to 31st December 2016 (497 stock trading days) that contain low terrorist activities and fatalities. There are various studies in financial network literature that divide the overall sample into different periods to perform network analysis and compare results see e.g., (Li & Pi, 2018; Yang et al., 2014; Kantar et al., 2012; Dias, 2012; Gilmore et al., 2010; Jo et al., 2018; Papana et al., 2017; Memon et al., 2019). Table 1 presents list of number of companies categorized by their respective sector, and used in this study. In addition, a complete list of 202 stocks of Pakistan stock market is mentioned in the "Appendix A".

Table 1. The Pakistan stock market sectors and number of companies.

S.No	Sector	Number of Companies
1	Automobile Assembler	9
2	Automobile Parts & Accessories	4
3	Cable and Electric Goods	5
4	Cement	13
5	Chemical	13
6	Close—End Mutual Fund	2
7	Commercial Banks	20
8	Engineering	6
9	Fertilizer	6
10	Food & Personal Care Products	11
11	Glass & Ceramics	4
12	Insurance	9
13	Inv. Banks/Inv. Cos./Securities Cos.	11
14	Jute	1
15	Leasing	2
16	Leather & Tanneries	2
17	Miscellaneous	7
18	Modarabas	7
19	Oil & Gas Exploration Companies	4
20	Oil & Gas Marketing Companies	6
21	Paper & Board	5
22	Pharmaceuticals	8
23	Power Generation & Distribution	9
24	Refinery	4
25	Sugar & Allied Industries	6
26	Synthetic & Rayon	1
27	Technology & Communication	8
28	Textile Composite	7
29	Textile Spinning	5
30	Textile Weaving	1
31	Tobacco	2
32	Transport	3
33	Woolen	1

Let closing price of a stock i, represented as node in a network, at time t be described as $p_i(t)$. We can calculate the log-return of stock as follows:

$$R_i(t) = lnp_i(t) - lnp_i(t-1) \tag{1}$$

To construct Pearson correlation coefficient among all pairs of daily returns of stocks, between stock i and j is given by:

$$C_{ij} = \frac{\langle R_i R_j \rangle - \langle R_i \rangle \langle R_j \rangle}{\sqrt{\left(\langle R_i^2 \rangle - \langle R_i \rangle^2 \right)\left(\langle R_j^2 \rangle - \langle R_j \rangle^2 \right)}} \tag{2}$$

where R_i and R_j is the return of stock i and j, and notation $\langle \dots \rangle$ represents mean value over the period of investigation. The Pearson correlation matrix C is represented as:

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \dots & C_{1N} \\ C_{21} & C_{22} & C_{23} & \dots & C_{2N} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ C_{N1} & C_{N2} & C_{N3} & \dots & C_{NN} \end{bmatrix} \tag{3}$$

The value of C_{ij} moves from -1 to $+1$, and N is total number of stocks, in our study N = 202. The correlation between two stocks i and j may contain spurious correlation information, and as proposed by (Wang et al., 2018), we calculate partial correlation coefficient from Pearson correlation matrix by using matrix inversion in order to get "net" correlation among two stocks. Therefore, inverse of matric C is given by:

$$C' = C^{-1} = \begin{bmatrix} C'_{11} & C'_{12} & C'_{13} & \dots & C'_{1N} \\ C'_{21} & C'_{22} & C'_{23} & \dots & C'_{2N} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ C'_{N1} & C'_{N2} & C'_{N3} & \dots & C'_{NN} \end{bmatrix} \tag{4}$$

Partial correlation coefficients between two stocks i and j are calculated using formula:

$$C_{ij}^* = -\frac{C'_{ij}}{\sqrt{C'_{ii} C'_{jj}}} \tag{5}$$

The value of Coefficient C_{ij}^* between two stocks i and j appears after removing the influences from other stocks, the partial correlation matrix C^* is therefore:

$$C^* = \begin{bmatrix} C_{11}^* & C_{12}^* & C_{13}^* & \dots & C_{1N}^* \\ C_{21}^* & C_{22}^* & C_{23}^* & \dots & C_{2N}^* \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ C_{N1}^* & C_{N2}^* & C_{N3}^* & \dots & C_{NN}^* \end{bmatrix} \tag{6}$$

In order to construct MST, we follow methodology of (Mantegna, 1999; Mantegna & Stanley, 2000), by transforming the Pearson correlation matrix C and partial correlation matrix C^* into distance matric among each pair of stocks i and j, given by:

$$d_{ij} = \sqrt{2(1 - C_{ij})}, \; or \; d_{ij}^* = \sqrt{2(1 - C_{ij}^*)} \tag{7}$$

The distance d_{ij} obtained from Pearson correlation coefficients C_{ij}, and d_{ij}^* obtained from partial correlation coefficients between two stocks i and j deviates from 0 to 2. The distance matrices of d_{ij} and d_{ij}^* among pair of stocks using $N \times N$ will be used to construct MST-Pearson and MST-partial networks. We apply (Kruskal, 1956) algorithm to construct our MSTs. In our network, 202 stocks of Pakistan stock exchange acting as nodes, the weighted linked graph $G = (N, E, W)$ contain $V - 1$ isolated edges are used for additional network measures.

Furthermore, we use various network measures to examine the topological properties of Pakistan stock market network. To inspect the length of MST-Pearson and MST-Pearson network, we use Normalized tree length (Onnela et al., 2003), can be calculated using following formula:

$$L_{MST} = \frac{1}{n-1} \Sigma_{[ij] \epsilon MST graph} \, d_{ij} \qquad (8)$$

Influence strength (Kim et al., 2002), measures the significance of node in influencing other nodes in the overall network. It is defined as:

$$S_i = \Sigma_{j \epsilon \Gamma_i} \rho_{ij} \qquad (9)$$

In the above formula, ρ_{ij} is Pearson and partial correlation coefficient between node i and j, and Γ_i represents group of nodes directly linked to node i. In order to assess the closeness of a node with other nodes in the network, Closeness centrality (Sabidussi, 1966) is used to measure the power linked with a node. The mathematical formula for closeness centrality is as follows:

$$Cc\,(k) = \frac{1}{\Sigma_{h \in G} \, d_G\,(k,h)} \qquad (10)$$

where $d_G(k, h)$ represents minimum distance from node k to node h. To measure intermediary role of a node in the network, Betweenness centrality (Brandes, 2001) measures the importance of a node by its position between other nodes in the network.

$$C_B(k) = \sum_{s \neq k \neq t \epsilon V} \frac{\sigma_{st}\,(k)}{\sigma_{st}} \qquad (11)$$

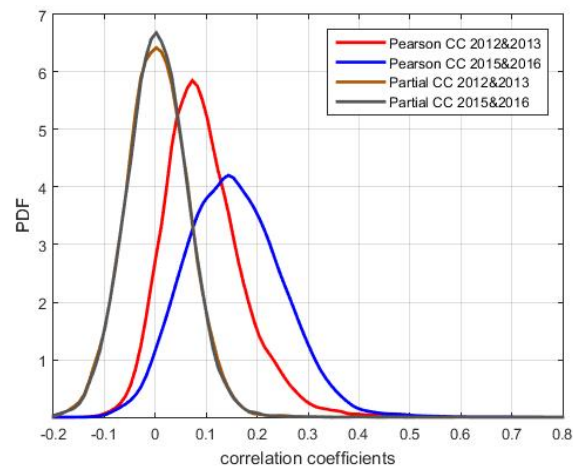where σ_{st} represents aggregate number of shortest links.

4. **Results and discussion**

4.1. PDF and descriptive statistics of Pearson and partial correlation coefficients

The probability density function (PDF) of Pearson and partial correlation matrices C and C^* for both periods of extreme terrorist activities and relaxed period consisting $N(N - 1)/2$ elements are shown in Figure 2. The probability density function of Pearson cross-correlation coefficients around extreme terrorism events deviates from the Gaussian function. The kurtosis value above 3 and high skewness for Pearson correlation coefficients for the period of extreme terrorism indicate that normal distribution is not appropriate to capturing the features of stocks returns during this period, as mentioned by (Yan & Han, 2019) for stock index returns. However, PDF function achieved from Pearson correlation coefficients for relaxed period, and partial correlation coefficients for both periods have high accuracy of a gaussian shape and deviate slightly from gaussian distribution. It implies that

period of extreme terrorist activities leads to higher nonsymmetrical distribution that largely diverges from bell shaped curve. Further, Table 2 presents descriptive statistics of Pearson and Partial correlation coefficients. The maximum values of Pearson correlation are greater in comparison with values of partial correlation coefficients for both periods. As shown by (Wang et al., 2018), the mean, maximum, and minimum value of world stock markets achieved from partial correlation is always lower than values of Pearson correlation coefficient. Similar results are achieved from partial correlation coefficients of Pakistan stock market during both periods of extreme terrorism and relaxed period, representing net correlation among stocks.

The mean correlation value achieved from Pearson correlation coefficients of Pakistan stock market during the period of extreme terrorist activities is lower in comparison with relaxed period. In contrast, several studies have reported higher mean correlation during events of crisis for example: (Nobi et al., 2014; Xia et al., 2018; Lee & Nobi, 2018; Memon & Yao, 2019; Yao & Memon, 2019). We can say that an increase in the mean correlation achieved from Pearson correlation method in relaxed period is due to influence of other stocks in the market, and after applying partial correlation method the net correlation between any two stock pairs resulted in same mean correlation for both the periods of extreme terrorism and relaxed period.

Figure 2. Probability density function of Pearson and partial correlation coefficients for the period of extreme terrorist activities (2012&2013) and relaxed period (2015&2016).

Table 2. Descriptive statistics of Pearson and partial correlation coefficients for the period of extreme terrorist activities and relaxed period.

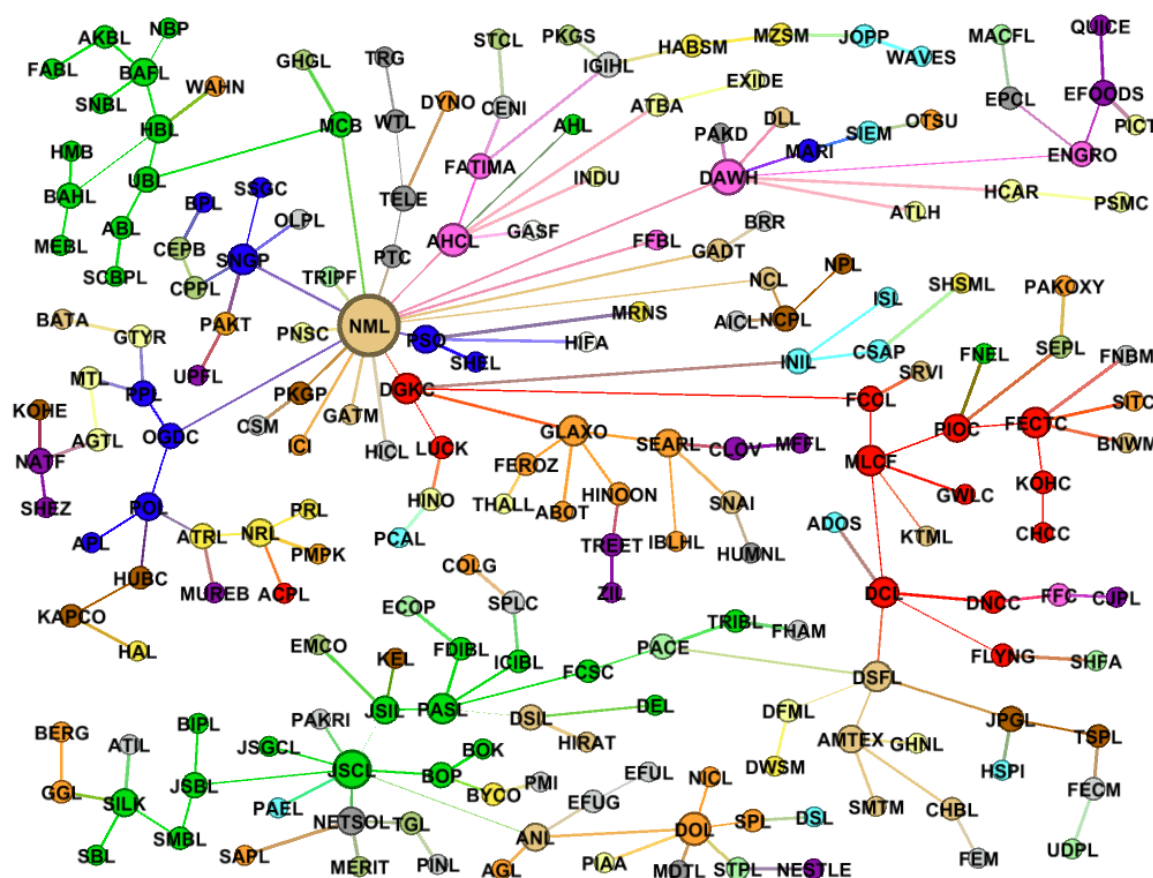|	Period of Extreme Terrorist Activities		Relaxed Period	
	Pearson	Partial	Pearson	Partial
Mean	0.096	0.004	0.155	0.004
Maximum	0.760	0.606	0.749	0.598
Minimum	−0.138	−0.253	−0.157	−0.268
SD	0.079	0.063	0.095	0.062
Skewness	1.070	0.350	0.447	0.294
Kurtosis	3.211	1.914	0.839	1.824
Observations	20,301	20,301	20,301	20,301

4.2. Minimum spanning tree results

This section is divided into two categories. In first section, we present two Pearson correlation-based MSTs for the period of extreme terrorist activities (Year 2012 and 2013) and relaxed period (Year 2015 and 2016). Simultaneously in section 2, we present two partial correlation-based MSTs for both periods. We further apply the degree centrality measure for all the MST networks. All nodes are sized based on their centrality score and classified by different colors based on their individual sector.
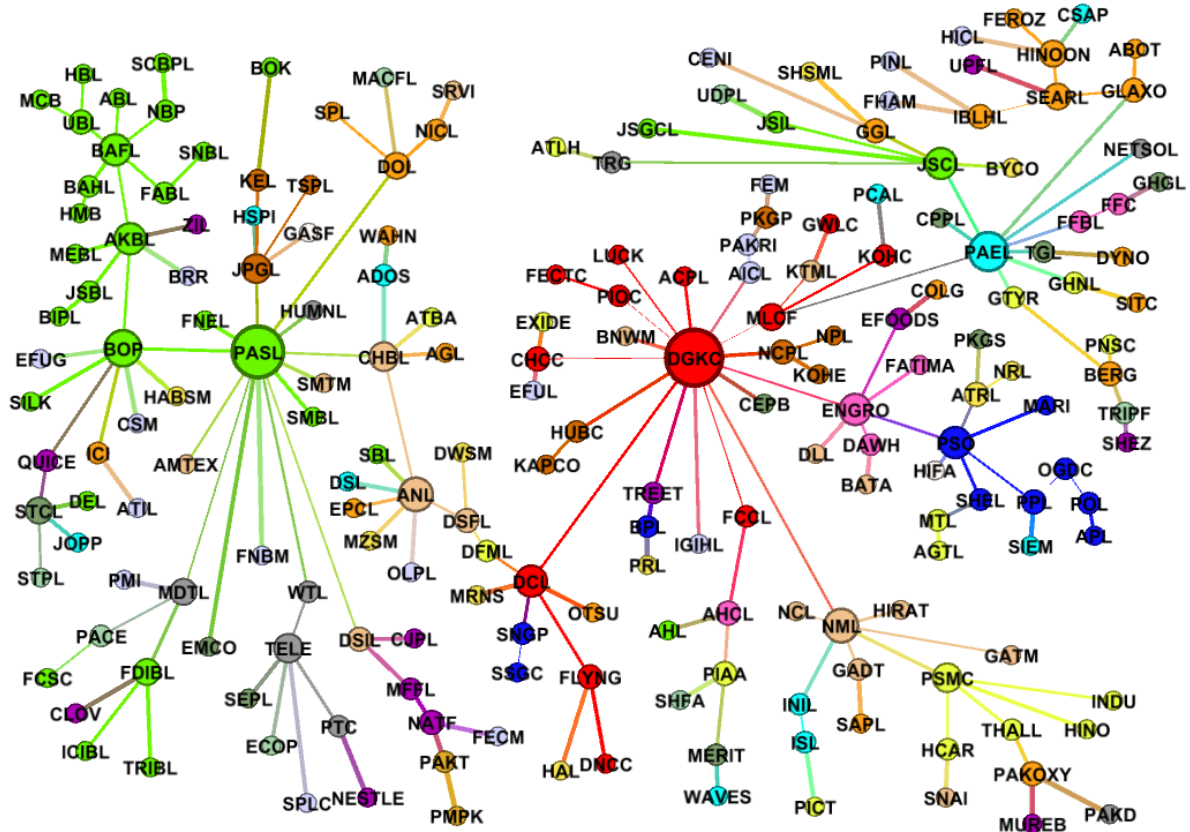
4.2.1. Pearson correlation-based networks

The MST-Pearson for the period of extreme terrorist activities and relaxed period are presented in Figures 3 and 4. The results show formation of four major clusters during both periods: Banking, investment and security companies sectors (Green), Cement sector (Red), Chemical and Pharmaceutical companies sectors (Orange), and Oil and Gas exploration and marketing sectors (Blue). The homogenous cluster formation based on specific industry is also reported in many studies, for example: Brazilian stock market network (Tabak et al., 2010), JSE stock market network (Majapa & Gossel, 2016), Italian stock market network (Coletti & Murgia, 2016), London stock exchange network (Coelho et al., 2007; Ulusoy et al., 2012; Yao & Memon, 2019), US financial market network (Song et al., 2018), and china stock market network (Yang et al., 2014).

The most prominent difference between the two MST-Pearson structures is that during the period of extreme terrorist activities stocks mostly tend to cluster around one star-like super hub node of Nishat Mills Limited (NML) belonging to textile composite sector, and having 17 number of links. However, after transition in the relaxed period, two dominant hub nodes of DG khan cement company (DGKC) and Pervez Ahmed Securities (PASL) belonging to cement and investment company sectors appear in the MST, having 16 and 15 number of links respectively. Similar change is observed in Korean stock market (Nobi et al., 2015), German stock market (Wiliński et al., 2013), and in Pakistan stock market (Memon & Yao, 2019) after financial crisis. Further, the emergence of cement sector highlights the importance of this sector for the development of Pakistan in the relaxed period. While studying developing country stock market of china from 2009 to 2015, (Qiao et al., 2016) also find first dominated cluster belonging to construction sector and highlights the importance of building industry on whole national stage. In addition, the period of extreme terrorist activities resulted in formation of low clusters in comparison with relaxed period, where market stables (Matesanz & Ortega, 2015). Further, the results reveal higher investors' confidence in the Pakistan stock market during the period of stability compared to a volatile period of terrorist activities. MST-Pearson structure during the period of extreme terrorist activities comprises, 51.49% of nodes' (i.e. 104 stocks) degrees are equal to one, around 26% (53 stocks) of nodes' degrees equal to two, almost 10% (20 stocks) of nodes' degrees equal to three, 5.94% (12 stocks) of nodes' degrees equal to four, and 4.95% (10 stocks) of nodes' carry degrees of five and six. The companies with number of links greater than six is around 1.50% from the total number of vertices in the network. In contrast, MST-Pearson structure during relaxed period comprises, 57.92% of nodes' (i.e. 117 stocks) degree equals to one, 22.77% (46 stocks) of nodes' degrees are equal to two, 7.92% (16 stocks) of nodes' degrees equal to three, around 3.4% (7 stocks) of nodes with degrees equal to four, and 4.95% (10 stocks) of nodes' degrees are equal to five and six. The companies with number of connections greater than six is about 3% from the total number

of vertices in the network. After comparing the two MST-Pearson, it can be observed that the degree of connections for greater amount of peripheral stocks in the relaxed period equals to one. Relaxed period MST also form many hub companies clustered with other stocks, in comparison with period of extreme terrorist activities MST of 1 star-like super hub node. Hence, we can conclude that rise and fall of NML in the period of extreme terrorist activities will impact on the stability structure of the Pakistan stock market, and companies surrounded to this hub node will be influenced directly. Similar interpretation was given by (Sharif et al., 2016) for HWAN and MRES companies for Malaysian stock market during financial crisis. However, the stability structure of relaxed period will depend on the constancy of many hub companies. Therefore, we can conclude that the MST-Pearson for relaxed period is more stable and balanced tree in comparison with MST-Pearson for the period of extreme terrorist activities.

Figure 3. MST-Pearson network of 202 stocks of Pakistan stock market for the period of extreme terrorist activities (Year 2012 & 2013). Color coding for the nodes and their respective sector is mentioned in "Appendix A".
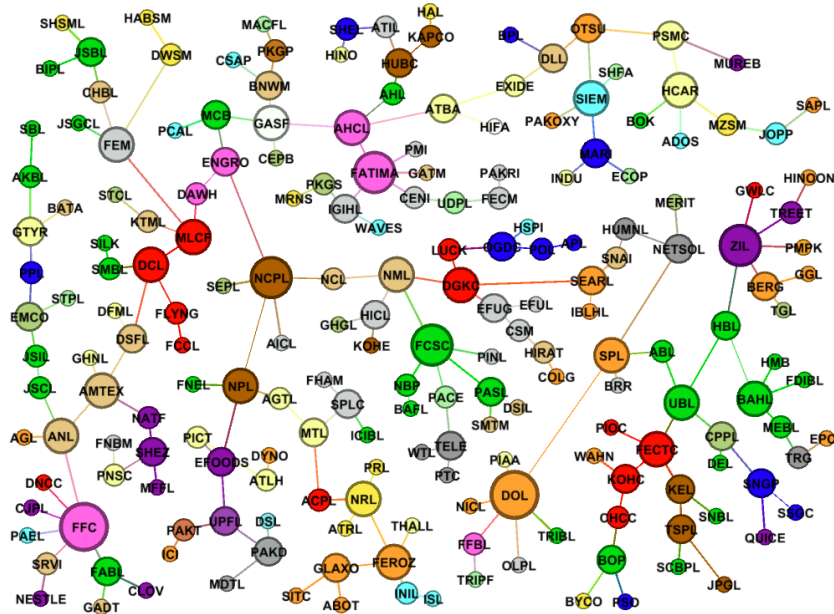
Figure 4. MST-Pearson network of 202 stocks of Pakistan stock market for relaxed period (Year 2015 & 2016). Color coding for the nodes and their respective sector is mentioned in "Appendix A".

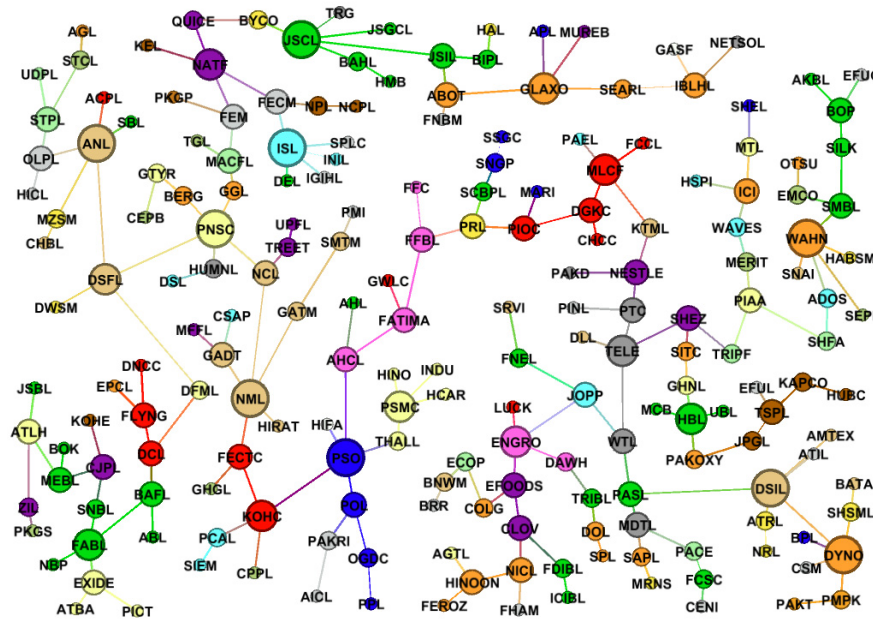### 4.2.2. Partial Correlation based networks

The MST-Partial for the period of extreme terrorist activities and relaxed period are presented in Figures 5 and 6. The results show broken clusters where many commercial banks are detached and connected with companies from other sectors. For example: during period of extreme terrorist activities Faysal bank (FABL) is connected to Fauji fertilizer company (FFC), Askrai Bank (AKBL) is connected to Automobile parts and accessories sector company General type and rubber (GTYR), Bank of Punjab (BOP) is connected to Oil and Gas marketing companies, refinery and cement sector, Muslim commercial bank (MCB) is connected to fertilizer sector company ENGRO, close end mutual fund company Golden arrow (GASF) and cable and electric goods sector company Pakistan cables (PCAL) etc. In contrast, during the relaxed period commercial bank sector form homogenous industry-based cluster. Broken cluster in MST-partial network has also been observed by (Wang et al., 2018) in their study. Further, two prominent clusters of cement sector (Red), chemical and pharmaceutical sectors (Orange) are present in both MST-partial networks.

In terms of connectivity, MST-Partial structure during the period of extreme terrorist activities comprises, around 47% of nodes' (i.e. 95 stocks) degrees are equal to one, 22.77% (46 stocks) of nodes' degrees equal to two, around 18% (37 stocks) of nodes' degrees equal to three, almost 9% (18 stocks)

of nodes' degrees equal to four. Remaining 6 stocks comprising around 3% of nodes' carry degrees of five and six. In contrast, MST-Partial structure during relaxed period comprises, 44.55% of nodes' (i.e. 90 stocks) degree equals to one, around 25.7% (52 stocks) of nodes' degrees are equal to two, 20.3% (41 stocks) of nodes' degrees equal to three, almost 5% (10 stocks) of nodes with degrees equal to four. The maximum number of links in the whole MST-Partial network for relaxed period is five, representing 4.46% of nodes covering 9 stocks. Thus, MST-partial during both periods reveal net correlation of stocks in the network.

Figure 5. MST-Partial network of 202 stocks of Pakistan stock market for the period of extreme terrorist activities (Year 2012 & 2013). Color coding for the nodes and their respective sector is mentioned in "Appendix A".

Figure 6. MST-Partial network of 202 stocks of Pakistan stock market for relaxed period (Year 2015 & 2016). Color coding for the nodes and their respective sector is mentioned in "Appendix A".

Table 3 presents summary of all the four MST networks. We list top five companies in the overall network by their degree and influence strength. As shown in Table 2, nodes that appear to be most important in the MST-Pearson are of less significance in the MST-Partial network during that period. For example: Nishat mills company (NML) is most important node in MST-Pearson for the period of extreme terrorist activities, and influence strength and degree of connections of DG khan cement company (DGKC) is much larger in the MST-Pearson for relaxed period than all other nodes in the network. However, NML and DGKC in MST-partial during same period does not qualify to be among top five important nodes in the network. It shows that NML and DGKC is influenced by stocks belonging to same or other sector, and net correlation of NML and DGKC resulted in degrees are equal to 4 and 3 during same period. Further, MST-Pearson and MST-partial constructing methods mention DOL company having same degree distribution during the period of extreme terrorist activities, a stock that is not influenced from the stocks of same or other industry sectors. With the exclusion of NML, both periods of extreme terrorist activities and relaxed period presents different companies varied with their degree distribution and influence strength among the top five important positions in the network. To sum up, there is structural change in the MST-Pearson and MST-Partial networks, and during both periods of extreme terrorist activities and relaxed period.
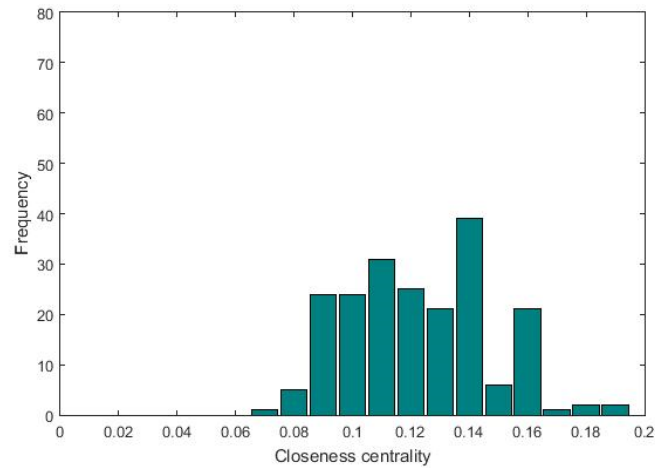
Table 3. Degree distribution and influence strength of top five nodes during the period of extreme terrorist activities and relaxed period.

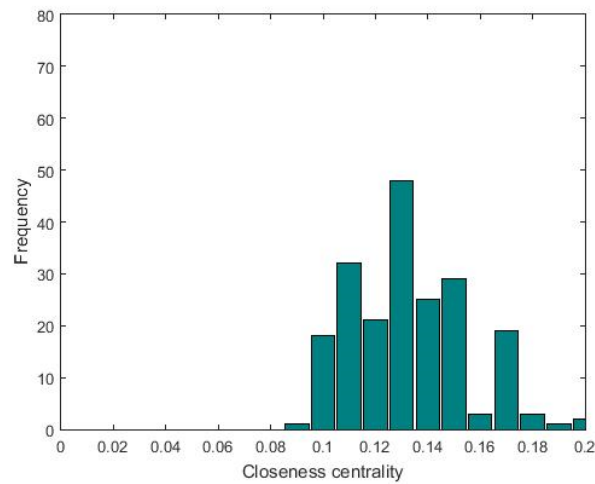| Period of extreme terrorist activities						Relaxed period					
MST- Pearson			MST-Partial			MST-Pearson			MST-Partial		
Listed Company	Degree	IS	Listed Company	Degree	IS	Listed Company	Degree	IS	Listed Company	Degree	IS
NML	17	6.068	DOL	6	1.283	DGKC	16	8.010	ISL	5	1.187
JSCL	8	3.829	FFC	6	1.093	PASL	14	5.746	NML	5	1.152
DAWH	7	2.229	NCPL	5	1.259	PAEL	9	3.598	JSCL	5	1.012
AHCL	6	2.098	FCSC	5	0.947	BOP	8	2.687	PSO	5	0.977
DOL	6	1.901	FATIMA	5	0.900	NML	7	3.311	PNSC	5	0.957

4.3. Closeness centrality

Closeness centrality is used to assess the effectiveness of information flow by nodes in the network. In our case, the stocks (nodes) of MST network carrying high closeness centrality value represents the closeness of stock to all stocks of the MST network. Closeness centrality distribution for MST-Pearson and MST-Partial networks during the period of extreme terrorist activities and relaxed period is shown in Figures 7(a), 7(b), 7(c), and 7(d). MST-Pearson shows distribution of closeness centrality ranging from 0.07 to 0.19 for the period of extreme terrorist activities and 0.09 to 0.2 for relaxed period. In contrast, MST-partial lowers the distribution of closeness centrality ranging from 0.06 to 0.14 for the period of extreme terrorist activities and 0.05 to 0.09 for relaxed period.
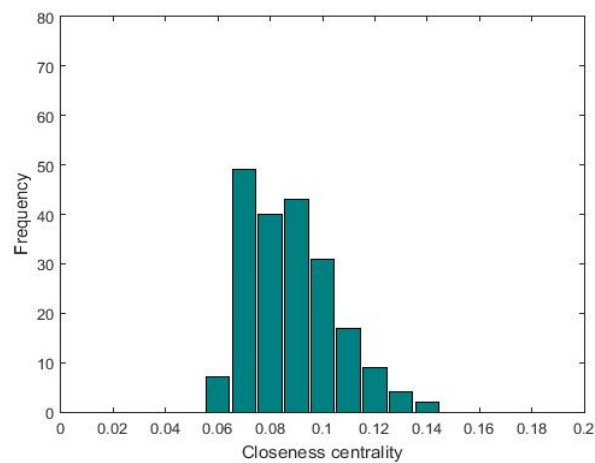
Table 4 presents top five stocks of Pakistan stock exchange during the period of extreme terrorist activities and relaxed period with largest closeness centrality score. In MST-Pearson network companies from two sectors of Textile composite and Cement sector dominates with high closeness centrality during period of extreme terrorist activities, in comparison with relaxed period where companies from three sectors mainly: Cement, Synthetic and Rayon, and Automobile Assembler appears in the top five position with high closeness centrality. This represents important role of few sectors in the period of extreme terrorist activities in comparison with relaxed period. It is also evident that three companies from cement sector appearing in the top five position, while DGKC appearing in top position with largest closeness centrality during both periods of MST-Pearson network highlights the importance of cement sector for Pakistan stock market network. Similar interpretation has been given by (Tabak et al., 2010) while analyzing Brazilian stock market where financial sector carry high closeness centrality. In MST-Partial network, companies from four sectors including: Power Generation and Distribution, Textile Composite, Fertilizer, and Commercial bank hold top five positions with largest closeness centrality during period of extreme terrorist activities. While comparing with relaxed period, companies from three sectors of Oil and Gas marketing, Cement and Fertilizer hold key positions in the network with high closeness centrality. As can be seen, MST-Partial network lowers the range of distribution of closeness centrality and presents more diversity by including companies from many sectors in comparison with MST-Pearson network.

Figure 7(a). MST-Pearson Closeness Centrality frequency for the period of extreme terrorist activities.
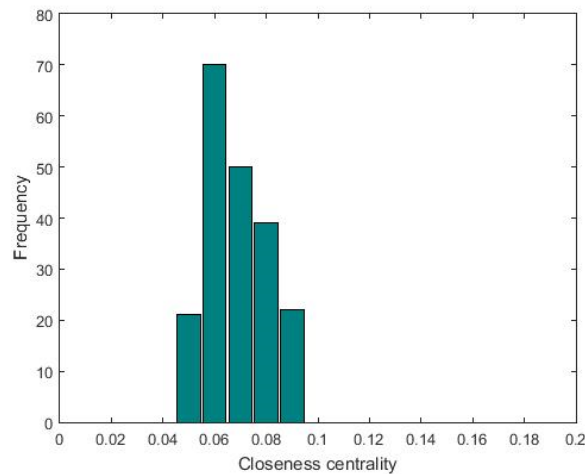

Figure 7(b). MST-Pearson Closeness Centrality frequency for relaxed period.

Figure 7(c). MST-Partial Closeness Centrality frequency for the period of extreme terrorist activities.

Figure 7(d). MST-Partial Closeness Centrality frequency for relaxed period.

Table 4. Top five stocks with the largest closeness centrality for period of extreme terrorist activities and relaxed period.

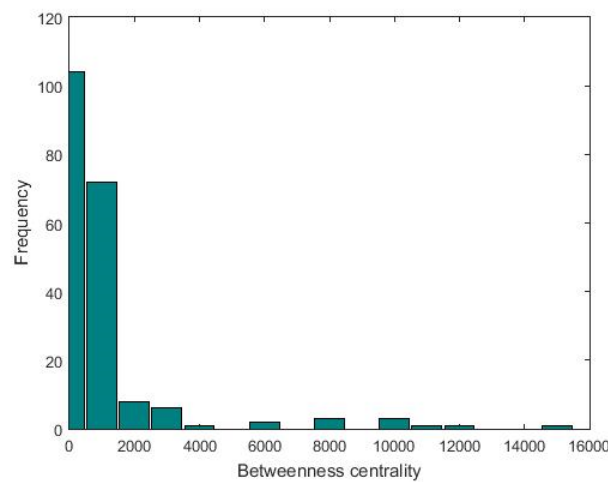| Period of extreme terrorist activities						Relaxed period					
MST- Pearson			MST-Partial			MST-Pearson			MST-Partial		
Node	CC	Sector	Node	CC	Sector	Node	CC	Sector	Node	CC	Sector
DGKC	0.183	Cement	NCPL	0.131	Power Generation & Distribution	DGKC	0.194	Cement	PSO	0.088	Oil & Gas Marketing
NML	0.181	Textile Composite	ENGRO	0.130	Fertilizer	DCL	0.190	Cement	AHCL	0.088	Fertilizer
FCCL	0.177	Cement	NCL	0.127	Textile Composite	DFML	0.184	Automobile Assembler	KOHC	0.087	Cement
MLCF	0.171	Cement	NML	0.123	Textile Composite	DSFL	0.179	Synthetic & Rayon	FATIMA	0.087	Fertilizer
DCL	0.162	Cement	MCB	0.122	Commercial Bank	MLCF	0.174	Cement	FFBL	0.087	Fertilizer

4.4. Betweenness centrality

We apply betweenness centrality measure to examine the tendency of a stock to be more central compared to all other stocks in the MST network. It is a prime centrality measure used to find out the important nodes, acting as "bridges" among nodes in the network (Yao & Memon, 2019). Figures 8(a), 8(b), 8(c), and 8(d) show frequency distribution of betweenness centrality for the period of extreme terrorist activities and relaxed period. The key difference between both MST-Pearson and MST-Partial during both periods is the range of distribution which is lower for MST-Partial network, similar to closeness centrality measure. In addition, the nodes with zero betweenness centrality in MST-Pearson network is greater in the relaxed period to 117, in comparison with 104 nodes during the period of
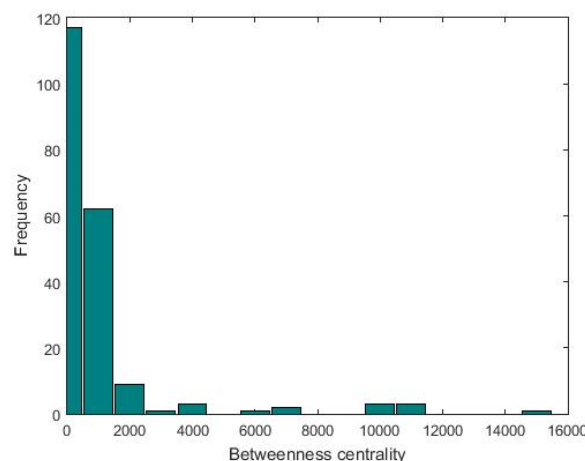
extreme terrorist activities. This means number of nodes with no shortest path is higher during relaxed period of MST-Pearson network. In Contrast, this measure is inverse for the MST-Partial network, where 95 nodes exist with zero betweenness centrality during the period of extreme terrorist activities compared to 90 nodes in the relaxed period.
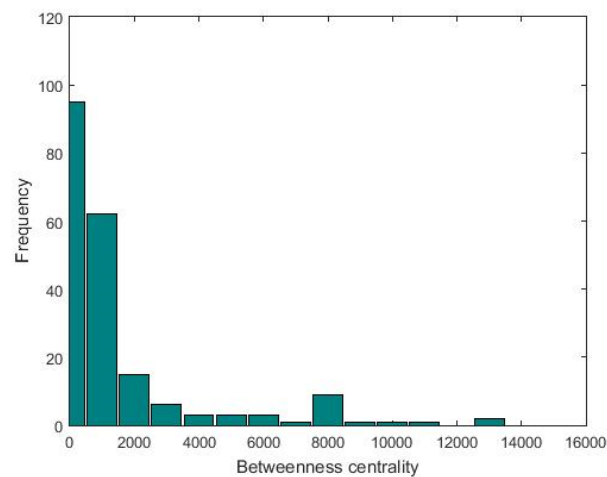
Table 5 show top five stocks of Pakistan stock exchange with largest betweenness centrality. In MST-Pearson network, strong intermediary role is presented by DCL and DGKC, companies belonging to cement sector, during both periods. However, In the MST-Partial network, a spike in the intermediary role by PSO during relaxed period is observed, that highlights the importance of oil and gas marketing company during the relaxed period. Similar observation is noticed for South African JSE network (Majapa & Gossel, 2016), and Brazilian stock market network (Sandoval, 2012). To sum-up, MST-Partial network presents importance and spike in the role of many sectors during both periods in comparison with few sectors intermediary role of MST-Pearson network.
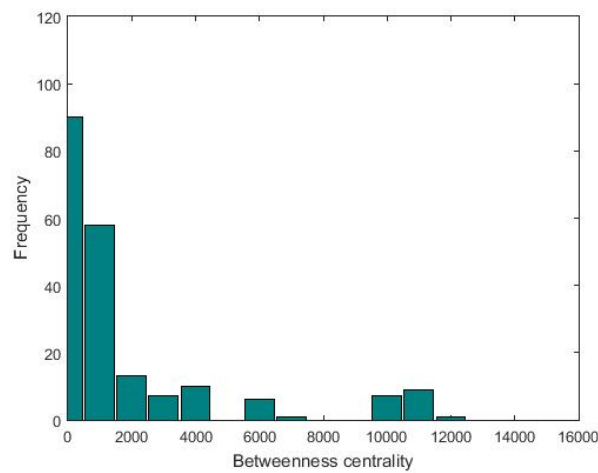

Figure 8(a). MST-Pearson Betweenness centrality frequency for the period of extreme terrorist activities.

Figure 8(b). MST-Pearson Betweenness Centrality frequency for relaxed period.

Figure 8(c). MST-Partial Betweenness Centrality frequency for the period of extreme terrorist activities.

Figure 8(d). MST-Partial Betweenness Centrality frequency for relaxed period.

4.5. Dynamic evolution of MST-Pearson and MST-Partial networks

Normalized tree length (NTL), diameter, and average path length (APL) achieved from MST-Pearson for period of extreme terrorist activities and relaxed period is lower in-comparison with MST-Partial network as shown in Table 6. This means that the size of MST-Pearson is smaller in comparison with MST-Partial. While examining foreign exchange market during crisis (Jang et al., 2011) find an increase in the normalized tree length during crises. It is also observed that diameter expands during period of economic expansion (Khashanah & Li, 2016), and additional links creation (high correlations) resulted in shrinkage of average path length (Radhakrishnan et al., 2016; Yao & Memon, 2019). Comparing it with our results, MST-Partial network fits well with the relaxed period by showing an expansion in the NTL and highest diameter and average path length amongst all.

Table 5. Top five stocks with the largest betweenness centrality for period of extreme terrorist activities and relaxed period.

Period of extreme terrorist activities						Relaxed period					
MST- Pearson			MST-Partial			MST-Pearson			MST-Partial		
Node	BC	Sector	Node	BC	Sector	Node	BC	Sector	Node	BC	Sector
NML	14083	Textile Composite	NCPL	12425	Power Generation & Distribution	DGKC	14693	Cement	PSO	11134	Oil & Gas Marketing
DGKC	11871	Cement	ENGRO	12206	Fertilizer	PASL	10953	Investment Cos.	TELE	10961	Technology & Communications
MLCF	10569	Cement	NML	10337	Textile Composite	DCL	10615	Cement	PNSC	10846	Transport
FCCL	9876	Cement	NCL	9500	Textile Composite	ANL	10065	Textile Composite	NML	10382	Textile Composite
DCL	9427	Cement	DGKC	8985	Cement	DSFL	9839	Synthetic & Rayon	PRL	10295	Refinery

Table 6. Normalized tree length, diameter, and average path length of MST-Pearson and MST-Partial network for the period of extreme terrorist activities and relaxed period.

	Period of extreme terrorist activities		Relaxed Period	
	MST-Pearson	MST-Partial	MST-Pearson	MST-Partial
Normalized Tree Length	1.162	1.263	1.115	1.268
Diameter	22	29	17	39
Average Path Length	8.796	12.482	8.062	16.171

In Addition, Table 7 show time varying yearly results of NTL, diameter and average path length. The NTL of MST-Pearson and MST-Partial networks present an inverse trend from year 2012 to 2014. Similar results of NTL are achieved by (Wang et al., 2018) during year 2012, due to crisis in the world economy the "net" correlation among world stock market increases, while correlation among stock markets declined. The APL and diameter during all periods are higher for MST-Partial than MST-Pearson network indicating role of more intermediary stocks to transmit information. Although there is decline in civilian and security personnel casualties from year 2012 onwards the reaction of Pakistan stock market is varied. Pakistan military launched operation named as "Zarb-e-Azb"[4] in the

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[4]The military operation "Zarb-e-Azb" was hallmark decision by civil military institutions, due to wave of terrorist attacks in the country mainly from northern parts of Pakistan bordering to Afghanistan. The operation started on 15 June 2014 in North Waziristan, area nearing Pakistan-Afghanistan border, soon after attack of Taliban on Karachi Airport on 8 June 2014.

year 2014, followed by National action plan[5] (NAP) by government that leads to reduction of terrorism and revised investors' confidence. Both of these counter-terrorism strategies worked well in reducing terrorist activities from Pakistan (Rehman et al., 2017). After proper implementation of counter-terrorism strategies, the Karachi stock exchange benchmark index (KSE 100 index) crossed 35,500 points mark on July 6, 2015, and closed at all-time high points of 42,703 on December 30 2016. These counter terrorism measures resulted in expansion of tree length of Pakistan stock market for both MST-Pearson and MST-Partial networks in the year 2016.

Table 7. Time varying Normalized tree length, Diameter and Average Path Length of MST-Pearson and MST-Partial networks.

	2012		2013		2014		2015		2016	
	MST-Pearson	MST-Partial	MST-Pearson	MST-Partial	MST-Pearson	MST-Partial	MST-Pearson	MST-Partial	MST-Pearson	MST-Partial
Normalized Tree Length	1.158	1.101	1.101	1.110	1.117	1.099	1.056	1.102	1.120	1.117
Diameter	20	28	14	25	19	24	15	34	22	24
Average Path Length	8.896	11.463	6.911	10.267	7.842	10.744	6.802	12.244	9.956	10.706

5. Summary and conclusions

In this paper, we investigated the correlation structure and evolution of 202 most active stocks of Pakistan stock exchange. Pearson cross correlation and partial cross correlation-based distances are used to construct MST-Pearson and MST-Partial networks across two samples: a period of extreme terrorist activities (high civilian and security personnel casualties) covering from 1st January 2012 to 31st December 2013; and relaxed period (low civilian and security personnel causalities) starting from 1st January 2015 to 31st December 2016.The result of Partial and Pearson correlation coefficients reveals that PDF of Pearson correlation coefficients for relaxed period and partial correlation coefficients for both periods show slight deviation from gaussian function. The mean, maximum and minimum values of partial correlation coefficients are lower in comparison with Pearson correlation coefficient during both periods representing net correlation among stocks.

With regard to minimum spanning tree results, the overall structure of MST-Pearson and MST-Partial network during both periods differs completely. MST-Partial network contains many small hub nodes in comparison with MST-Pearson network that contains one star-like super hub node during the period of extreme terrorist activities and two hub nodes during relaxed period. MST-Pearson during the period of extreme terrorist activities form a crisis like unstable market structure in comparison with

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[5]The NAP (National action plan) was implemented by government and military of Pakistan due to movement of well-established militants to other parts of country. It was implemented in January 2015 with an aim to broaden the operation by controlling all aspects related to terrorism.

meta-stable market state structure in the relaxed period. We also observed two prominent clusters belonging to cement, and chemical and pharmaceutical sector in MST-Pearson and MST-partial networks during both periods. Moreover, MST-partial form broken clusters where most of banks are split and connected to different sectors during the period of extreme terrorist activities.

The results of degree distribution and influence strength of four MSTs reveal that most significant nodes of MST-Pearson network carry no or less significance in the MST-partial network, represents that individual stocks are greatly influenced by stocks from the same or other industry sectors. Further, the centrality measures of closeness centrality reveal a contracting distribution range for MST-Partial network in comparison with an expended range for MST-Pearson network. We also observed important role of few sectors in MST-Pearson network for the period of extreme terrorist activities in comparison with relaxed period. The importance of cement sector during both periods of MST-Pearson represents significant role of cement sector for the development of Pakistan economy. Moreover, MST-Partial presents a diversified sectoral role with largest closeness centrality in comparison with few sectors in the MST-Pearson network. The results of betweenness centrality match with the closeness centrality results of lower frequency range for MST-Partial network in comparison with MST-Pearson network. The spike in intermediary role of oil and gas sector in the relaxed period of MST-Partial network is also observed. Furthermore, the time varying topological measures indicate a higher diameter and average path length for MST-Partial network during all periods. Due to counter terrorism measures an expansion in the tree length of MST-Pearson and MST-Partial is also observed in the relaxed period.

The information extracted in this paper will help both international and local investors to make appropriate investment decisions. It will also assist government officials and regulatory agencies of Pakistan in setting out framework that will aid specific sectors necessary for the progress of the country. Our future work will enhance the application of correlation structures on rolling windows of many durations in a temporally dynamic network to examine the impact of various terrorist attacks on the topology of stock market in more detail. We can also extend the methodology by constructing threshold networks and Planar maximally filtered graph (PMFG) to achieve two PMFG-Pearson and PMFG-Partial. The results obtained in this study shall be used to compare differences in the cluster formation between individual stocks and their respective sectors.

Conflict of interest

The authors declare no conflict of interest.

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