Impact of Covid-19 pandemic on Network of Asian stock markets

Emerald Abstract:

Purpose:

This paper examines the effects of the Covid-19 first wave on a network of ten different Asian stock markets between September 2019 to November 2020. The dynamics of the network is studied in three phases, namely, as before, during, and the stabilization phase of the pandemic's first wave.

Methodology:

The study computed correlation matrix to analyse hierarchical structure of the network by building a dendrogram which groups the stock indices into clusters. The study further visualizes the interdependence structure among Asian stock markets using Minimum Spanning Tree (MST).

Findings:

Our study results shows the degree of interconnectedness between Asian stock markets during the pre-pandemic phase, during first wave of pandemic phase and stabilization phase. The degree of interconnectedness is found to be reducing during the first wave of pandemic phase because of the country-wide lockdowns. Further, the study identified that Singapore and Hong Kong are the two stock markets that acted as a key bridge markets during the entire period. Stock market of Pakistan is found to be least linked with the other stock markets in Asia.

Originality:

The study enriches the growing literature on the impact of heath crises such as COVID-19 on the financial market contagion. It adds novelty by capturing and visualising the interlinkages in three phases of the studied time period using graph theory and network analysis.

Keywords: Covid-19, Networks; Minimum Spanning Tree (MST); Stock markets; Asia

JEL code: D85, G1, G11, G15, P34

1. Introduction

The world's stock market has a combined market capitalisation of 106 Trillion USD, with USA stock markets having the most significant market capitalization of 44.3 Trillion USD. The Asian stock markets play a crucial role in the growth of Asian companies. The Asian stock markets are emerging very fast and attracting a lot of investors. Chinese stock market is the largest stock market in Asia and the second largest globally, with a combined market capitalization of 11.1 Trillion USD. Hong Kong and Japan are the second and third largest stock markets in Asia, with a market capitalization of 7 Trillion USD and 6.8 Trillion USD, respectively. Due to the recent Coronavirus pandemic, many countries have faced recession, which directly impacted the financial institutions and stock markets of the world. For instance, Singapore is facing its worst recession ever as the country generates it's most of the revenues through tourism.

Asian economies GDP growth have fallen due to the Covid-19. During the first wave of Corona, many countries had imposed lockdowns to stop the spread of the deadly virus. This resulted into the panic in almost every stock market as they are somewhat correlated. Due to the panic, investors started selling and squaring off their positions, resulting in a crash in various stock markets. When some countries had imposed lockdowns, due to connectedness with other countries, the investors started squaring off due to lockdown fears in their countries. The crisis has stopped the growth of many countries indefinitely. There were a lot of job cuts as well. Due to lockdowns, the companies adapted work from home culture, which also impacted the companies' growth which resulted into decline various stock market prices.

Due to covid-19, the tourism industry has suffered a lot and impacted the country's whole financial conditions. India's GDP growth was also fallen due to the Covid-19. During the first wave of Corona, many countries had imposed lockdowns to stop the deadly virus spread. This resulted in panic in almost every stock market as they are somewhat correlated. Due to the panic, investors started selling and squaring off their positions, resulting in a crash in various stock markets. When some countries had imposed lockdowns due to connectedness with other countries, the investors started squaring off due to lockdown fears in their countries. The crisis has stopped the growth of many countries indefinitely. There were a lot of job cuts as well. Due to lockdowns, the companies adapted work from home culture, which also impacted the companies' growth, which resulted in their decline at various stock market prices.

The market efficiency theory indicates that stock prices do not depend on the preceding stock price, and past data cannot predict the future price. The stock market behaves differently depending on various factors such as supply and demand, natural disasters, economic, political, or psychological factors. Hence stock market behaves in a highly non-linear and complex manner. Many researchers claim that the stock market is a chaotic system. Stock markets are intricate, dynamic, stochastic, and follow non-stationary time series related to volume, price, and each other. Since prices fluctuate through time, investors are looking for techniques that help them provide information for taking proper investment decision-making to leverage gain while minimizing risk. Markowitz (1952), Rosenow et al. (2002), and Roll (2013) indicated that the diversification of investment in non-correlated assets reduces risk in times of crisis period as well. Correlation analysis established a link between diversification benefits and market volatility even in turbulent market conditions (Longin and Solnik;2001). These earlier results stimulated further research on the characteristics of the correlations. In recent times,

several physicists engaging in a multidisciplinary field of study known as econophysics which analyses the economic paradigm to solve the problems. Mantegna (1999) first conducted this kind of analysis and introduced graph theory into Economy and Finance. Mantegna (1999) proposed a topological approach to the portrayal of stock markets and specified that the stock market as a graph where stocks are nodes and edges are established based on similarities in stocks' return performance. His work employs correlation between price fluctuations of single stocks to construct hierarchical networks and replicate a market's topological properties. His study using the minimal spanning tree (MST) model for investigating the interaction among stocks. For studying the correlations of stock prices, network models have also been proposed recently by Vandewalle et al. (2001), Bonanno et al. (2001), Bonnanno et al. (2003), Bonanno et al. (2004), and Onnela et al. (2003). A possible approach is to map correlation to trees (Mantegna, 1999) and networks (Tse et al., 2010), possibly evolving in time (Onnela et al., 2003, 2004). Typically, in such networks, nodes represent stocks, and edges represent a strong correlation between stocks. The idea is to reduce the complexity of financial markets and retain the markets' core information. Minimal spanning trees (MST) is one of the models that received greater attention among researchers to reduce complexity and facilitated diversifying their portfolio investment for leveraging return in the stock market.

Our paper aims to help the investors through our model to analyze streaming the data of the stock market, revealing the most significant correlations between stock returns in the form of networks. In order to analyze the Asian stock markets and their dependencies, the study uses two methods. The first is the analysis of the hierarchical structure of the network by constructing a dendrogram, grouping the stock indices corresponding to each stock market into clusters according to their behavior in the market. The second method consists of creating the overall networks and Minimum Spanning Trees (MST), a graph whose elements or nodes will be stock indices and whose links are constructed from the Pearson correlation matrix.

The study adopts a novel approach because it proposes a complete network of connections based on correlations for the stock market. It should be noted that the analysis of correlations is not uncommon in finance. Correlation analysis has played an important role in establishing the relationship between the benefits of diversification and market volatility. Therefore, knowledge of the correlations in a financial market can help investors understand price formation mechanisms and serve as a guide in diversifying their portfolios.

This paper is structured as follows: the following section describes the literature review, data and methodology for constructing the MST and networks elucidated in section 3. Section 4 presents the statistical analysis and network analysis of the results obtained, and section 5 presents the concluding observations.

2. Literature review

Past studies about network analysis for stock market has been a point of interest. In 2018 Carlos Jaureguizar Francés, Pilar Grau-Carles and Diego Jaureguizar Arellano studied the network analysis of cryptocurrency markets and they found that Etherum acted as central node and surprisingle the most known cryptocurrency Bitcoin did not appear as central. In 2019 Jan-Hendrik Schuenemann, Natalia Ribberink and Natallia Katenka analysed the correlation between different sectors of Japanese and Chinese equity markets using network analysis and the results show that the Japanese market reacts strongly to specific events during the observation and does not affect the Chinese market. Wenyue Sun,

Chuan Tian and Guang Yang analysed the performance of different sectors of US market for the financial crisis of 2007-2008. In 2014 Rui Yanga, Xiangyang Lia and Tong Zhang analysed linkage effects among industry sectors in China's stock market before and after the financial crisis and they concluded that hat significant industry clusters exist in the CITIC indices networks all of the time during 2006-2013. The networks were found to be stable all the time except between the financial crisis period i.e. 2008-2011 and in this period the market had a greater volatility. In 2019 Binqing Xiao, Honghai Yu, Libing Fang and Sifang Ding measured the connectedness of 18 commodity futures during 2005-2018 using network approach and results show that metal futures were net transmitters of shocks to other futures, and agricultural futures were vulnerable to shocks from the others. In 2019 Yujie Lai and Yibo Hu established complex network for global stock markets from Aug 2019 to Mar 2020 and concluded that COVID-19 leads to close relation of financial connections between various countries, the impact spreads in a shorter distance, and the crisis transmission is faster. In 2019 Fei Wu found financial integration among stock markets using both graph theory and VAR methods and concluded that stock market integration in East and Southeast Asia is not as strong as it looks. In 2015 Jitendra Aswani studied how network of ASM behaves on the onset of financial crises using network modelling and MST and concluded that the shock waves from US first hit the Hong Kong stock market and from there it proceeds to the other systemic important stock markets like a virus. In 2020 Mike K. P. So, Amanda M. Y. Chu and Thomas W. C. Chan studied the impacts of the COVID-19 pandemic on the connectedness of the Hong Kong financial market using dynamic financial networks based on correlations and partial correlations of stock returns and concluded that both network density and clustering are higher in the partial correlation networks during the COVID-19 outbreak. In 2021 Jose Pedro Ramos-Requena studied impact of COVID-19 on the Indian stock and commodity markets during the different phases of lockdown using relationship, the conventional Welch test, heteroskedastic independent t-test, and the GMM multivariate analysis and concluded that during the different phases of lockdown in India, COVID-19 has a negative and significant impact on oil prices and stock market performance. However, in terms of gold prices, the effect is positive and significant. In 2019 Biplob Chowdhury, Mardi Dungey, Moses Kangogo, Mohammad Abu Sayeed, Vladimir Volkov investigate the changing integration of Asian financial markets within the global financial network from 1995 to 2016 using direction of links between markets, the significance of these links, and their strength and concluded increase in interconnectedness during periods of stress and the fall in the number of links in post-crisis periods. In 2021 Prasenjit Chakrabarti, Mohammad Shameem Jawed & Manish Sarkhel studied the changes in G20 stock market dynamics and their interlinkages in the aftermath of COVID-19 using the Detrended Cross-Correlation Analysis (DCCA) and concluded that COVID-19 has caused contagion in the global equity market, which has increased the risk to international portfolio diversification benefits stock markets

3. Data and Methodology

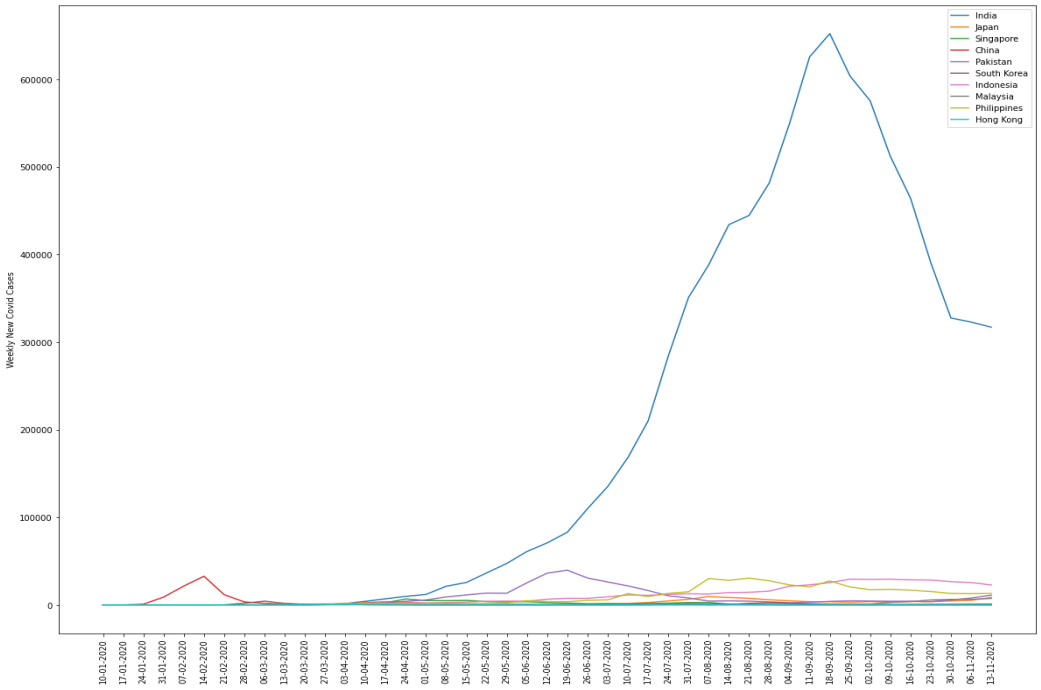
3.1 Data

The data on Covid-19 cases are collected from WHO website. The historical time-series of indices is extracted from Bloomberg database. As shown in Table a, the sample of the study consists of ten stock markets from Asia which forms the part of MSCI World Index and MSCI Emerging Markets Index. The total time period of the study is from 15 September 2019 to 13 November 2020. Figure b shows the weekly distribution of COVID-19 cases among Asian countries. The network of the Asian markets is further analysed in three different phases *viz*. before, during, and the stabilization period of the first wave of pandemic (Figure a). The WHO declared COVID-19 as a global pandemic on 11th March 2020. Most of the countries has a peak in terms of number of cases from 11th March 2020 to 6th August 2020. The number of cases seems stable or declining from 7th August onwards. Therefore, the period from 7th August 2020 to 13th November can be termed as stabilizing period. Appendix a shows the number of weeks in the time frame 7th August -13th November which has less number of cases than on 6th August.

Table 1: Stock markets and corresponding indices

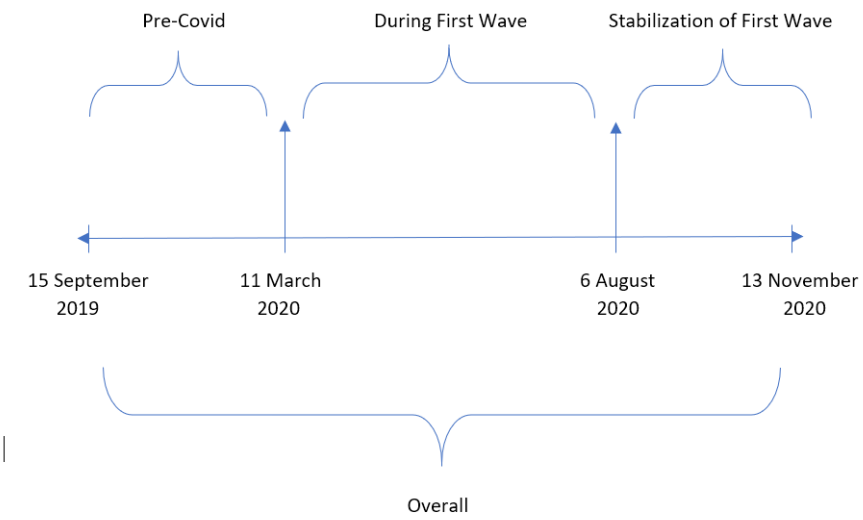
Country	Stock Indices	MSCI Index
India	Nifty 50 (NSEI)	MSCI Emerging Markets Index
Japan	Nikkei 225 (N225)	MSCI World Index
Singapore	Straits times index (STI)	MSCI World Index
China	SSE composite index	MSCI Emerging Markets Index
Pakistan	KSE 100	MSCI Emerging Markets Index
Korea	Korea Composite Stock Price Index (KOSPI)	MSCI Emerging Markets Index
Indonesia	Jakarta composite index (JKSE)	MSCI Emerging Markets Index
Malaysia	FTSE Bursa Malaysia KLCI (KLSE)	MSCI Emerging Markets Index
Philippines	PSEI index (PSEI.PS)	MSCI Emerging Markets Index
Hong Kong	Hang Seng index (HSI)	MSCI World Index

Figure 1: Weekly New Covid cases



Notes: Source of the figure is WHO data

Fig 1: Timeframe of the analysis



The descriptive statistics of the of index returns in the ten Asian stock markets is shown in Table 1. Over the sample period, all markets except Indonesia has given negative mean returns. Indonesia also witnessed the biggest fall in returns with the mean return of -0.09. The highest mean return is observed in the stock market of Philippines.

The top two markets with high levels of standard deviation are Philippines and India. This implies that these two markets are more volatile than the others over sample duration. The standard deviation for Malaysia is found to be lowest, followed by China, Singapore and Hong Kong.

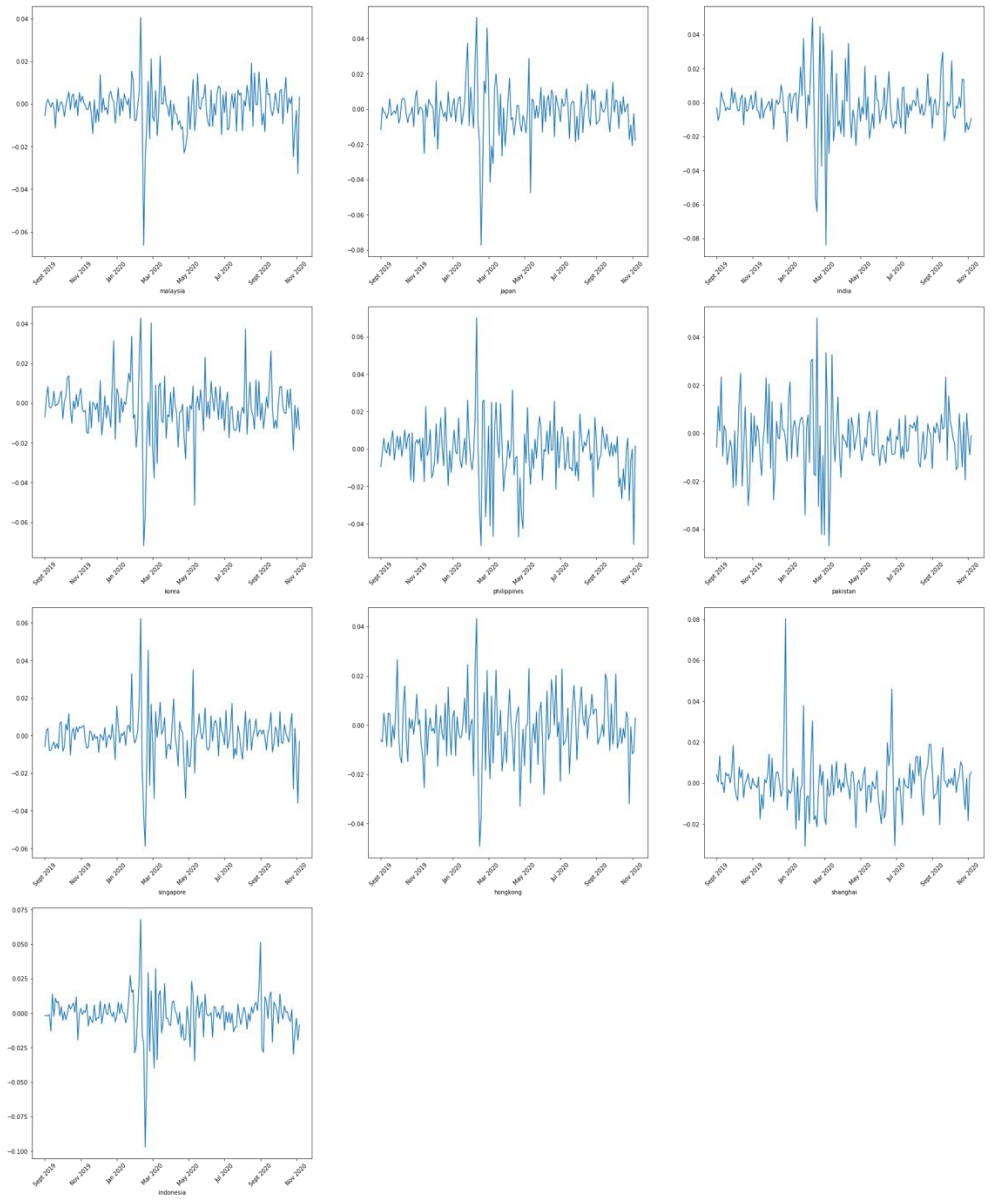
Table 3: Descriptive statistics

Country	Min	Mean	Max	Std	Skewness	Kurtosis
India	-0.084	-0.0008	0.086	0.018	0.554	6.814
Japan	-0.077	-0.0008	0.062	0.015	-0.352	5.919
Singapore	-0.058	-0.0003	0.062	0.013	-0.077	6.423
China	-0.030	-0.0001	0.080	0.012	1.591	9.027
Pakistan	-0.046	-0.0009	0.069	0.015	0.934	4.182

Korea	-0.082	-0.0012	0.087	0.017	0.109	6.268
Indonesia	-0.097042	0.0001	0.068	0.016	-0.248	7.537
Malaysia	-0.066	-0.0001	0.054	0.011	0.081	8.330
Philippines	-0.051	-0.0008	0.102	0.018	1.265	8.256
Hong Kong	-0.049	-0.0008	0.043	0.013	0.097	1.859

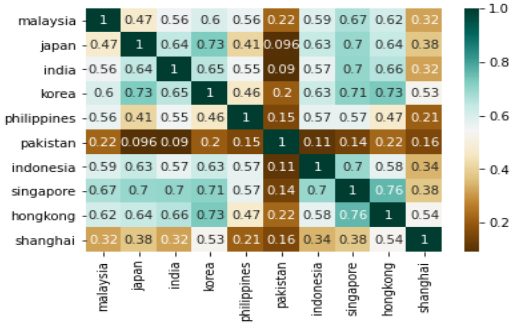
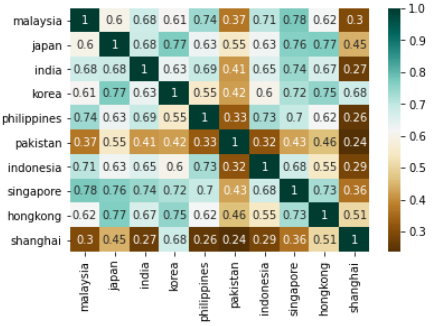
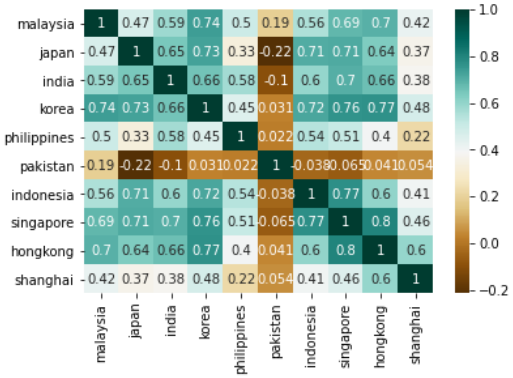
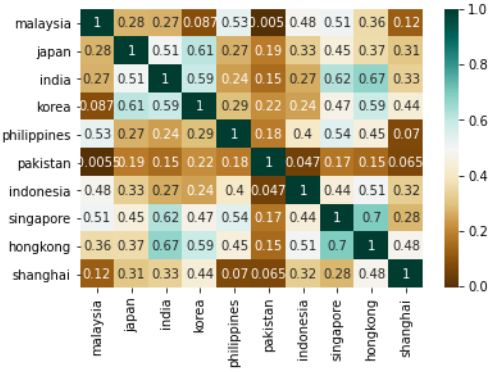
The plot of each index return series over the sample period is presented in Figure XYZ. WHO declared COVID-19 as global pandemic on 11th March 2020. This declaration caused fear of declining growth, job losses and inflated budgetary deficits. Consequently, high volatility is seen in the time period form 11th March to 20th March.

Figure 2: Log returns of stock indices



The study further extends the empirical investigation by analysing the heatmap of a correlation matrix using the values of cross-correlation coefficients of all Asian markets considered in the sample. Figure XYZ show the heatmaps of correlation values for the before, during, and the stabilization period of the pandemic. Heat map for the overall time period shows that the strength of correlation is highest between Singapore and Hong Kong whereas the strength is least between India and Pakistan. Moreover, in the pre pandemic period, Singapore and Malaysia has the highest correlation whereas China and Pakistan have least correlation. During the first wave, Singapore and Hong Kong have the largest correlation whereas Japan and Pakistan have least correlation. During the stabilization period, Singapore and Hong Kong have the largest correlation whereas Malaysia and Pakistan have least correlation.

Figure 4: Heat map for the overall time period and three sub-periods

Heat map for overall sample	Heat map for pre covid data
	
Heat map for data during first wave	**Heat map for data during stabilization period**
	

Notes: This figure shows heat maps for the overall time period and three sub-periods. The colour and brightness in these heat maps are based on the correlation of stock indices.

Table 4: ADF test statistic

Country	Overall	Pre Covid	First wave of Covid	stabilization period
Malaysia	-11.983	-1.539	-8.758	-6.664
Japan	-5.493	-7.595	-6.661	-5.864
India	-9.951	-0.476	-9.020	-5.075
Korea	-3.731	-7.091	-8.522	-6.718
Philippines	-13.310	-8.431	-8.431	-6.096
Pakistan	-6.608	-8.156	-4.642	-6.805
Indonesia	-3.775	-4.418	-8.153	-2.761

Singapore	-8.554	-0.627	-7.806	-1.385
Hong Kong	-10.964	-7.285	-8.590	-5.810
Shanghai	-11.652	-7.969	-4.811	-5.115

Table ABC presents the results of the augmented Dickey-Fuller test. The ADF statistic of all the series is found to be negative indicating the stability in the studied time series.

3.2 Methodology

Aswani (2017) argued that there is no single theoretical or empirical model in order to identify financial contagion. Bekaert et al. (2005) uses Latent factor model, Forbes and Rigobon (2002) employs correlation analysis, Favero and Giavazzi (2002) uses VAR framework and Eichengreen et al. (1995) makes use of probability theory to study the financial integration among markets. These techniques have the limitation of exploring only the direct linkages between markets.

To examine the impact of COVID-19 on the network of Asian stock markets, the study makes use of dendrograms and the graph theory. A brief description of these two methods is given below:

a. A dendrogram is a visual representation to show the hierarchical relationship between objects. It's a way to allocate objects to the cluster.

b. Graph theory deals with connection amongst nodes by edges. In this study, stock indices are the nodes and the distance between them as represented by correlation coefficient is considered as an edge. The theory finds great use in Mathematics and Computer science. One of the advantages with this theory is the ability to evaluate indirect connection between the nodes along with the direct ones.

The first step for constructing a network or minimum spanning tree (hereafter MST) is to find the correlation between all the possible pairs of stock indices. To compute this variable, the study makes use of coefficient of Pearson's Correlation-

$$C_{ij} = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2(y-\bar{y})^2}}$$

Each C_{ij} can have value between -1 and 1, and N is the number of Asian stock markets under study, which is ten for this study.

A correlation matrix is obtained where each C_{ij} corresponds to correlation between stock index i and j.

$$\begin{bmatrix} C_{11} & \cdots & C_{1N} \\ \vdots & \ddots & \vdots \\ C_{N1} & \cdots & C_{NN} \end{bmatrix}$$

Now, The elements of the matrix C_{ij}, can be transformed into a distance matrix using formula-

$$d_{ij} = \sqrt{2(1 - C_{ij})}$$

Range of $d_{ij}$is based on the correlation and lies between 0 to 2. More the distance, less the correlation and vice-versa.

Now for each time frame we made the overall network using this distance matrix where each node corresponds to a stock market index and each edge connecting 2 nodes corresponds to the distance between them. The link is made between 2 nodes if the correlation between the corresponding indices is greater than a threshold value i.e. mean of all correlations during that time-frame.

Multiple network diagrams are drawn using the distance matrix for the studied time period and sub-periods. The node of each graph corresponds to the stock market index while each edge connecting two nodes corresponds to the distance between them. Kruskal's algorithm (1956) is used to construct the minimum spanning tree (MST). For constructing MST, there is a sequence of steps that needs to be followed.

Step (I): N (N – 1) / 2 elements are taken from the distance matrix in increasing order.

Step (II): Selecting the stock index pair with the shortest distance and added the link to the graph.

Step (III): Selecting the next pair of stock indices with least distance between them and added the next link.

Step (IV): Step (III) is repeated until all the stock indices are linked together in the network diagram.

For calculating the network density we used the following formula for each overall network:

$$d = \frac{2m}{n(n-1)}$$

Where *n* is the number of nodes and m is the number of edges in network graph *G*.

Furthermore, the study employ centrality measures such as degree of node in order to capture the structural dynamics among Asian stock markets. Centrality is defined as the number of direct connections that the node have within a network.

4. Analysis of Results

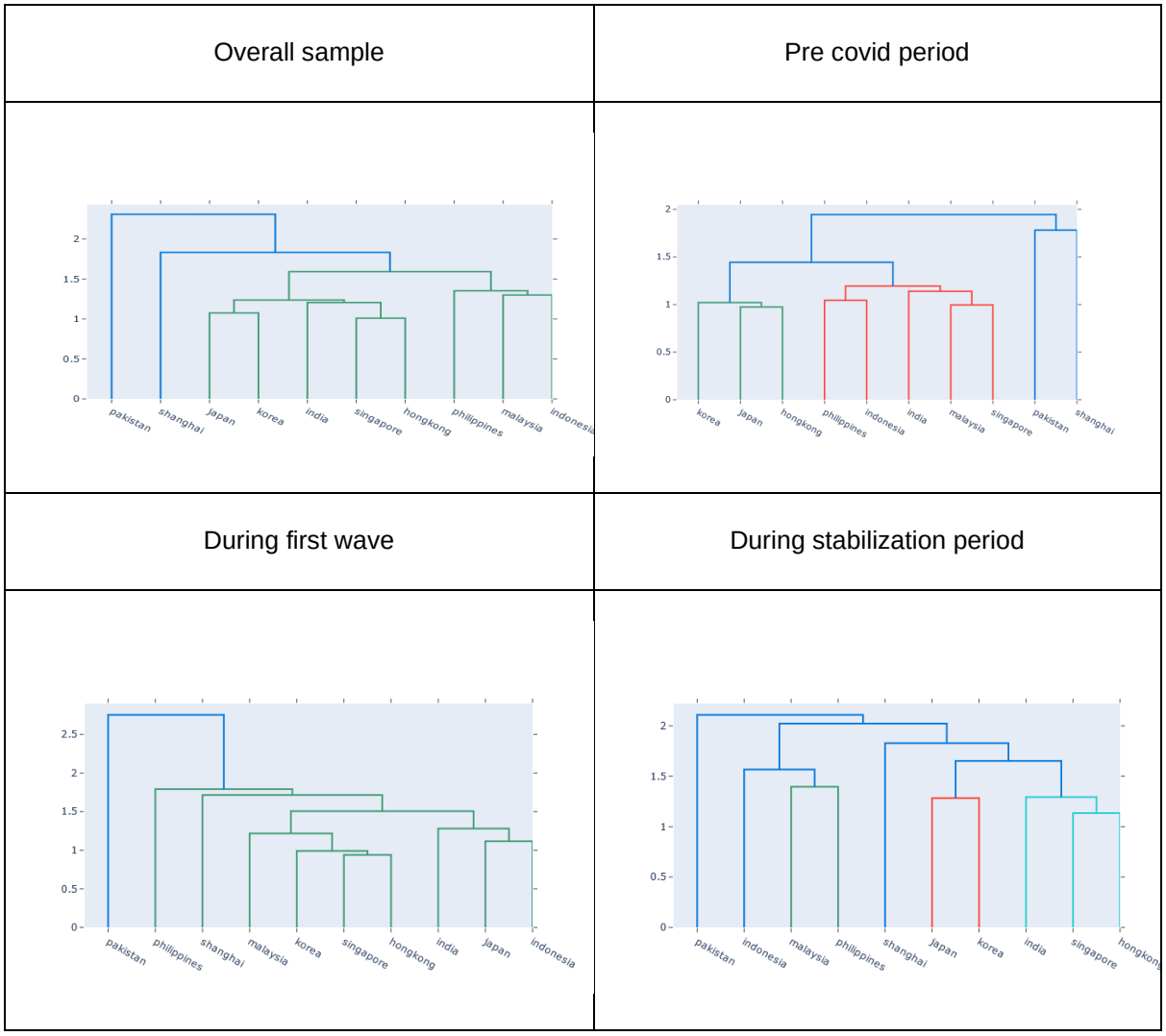
The results are divided in to two parts: the first part analyses the network using dendrograms and the second part makes use of graph theory to study financial networks.

Part A:

The dendrogram is a visual representation of the correlation data. Basically, this statistical method tries to group objects that are close one from another. As seen in Figure XYZ, Japan and Korea; Singapore and Hong Kong; and Malaysia and Indonesia are forming clusters. Observations are allocated to clusters by drawing a horizontal line through the dendrogram. If

we draw the line at the topmost part of dendrogram, it is observed that for overall time period; during the first wave; and during the stabilization period, Pakistan is forming a single cluster. All other Asian countries are forming a different cluster. This indicates non-integration of the Pakistan stock market with the other Asian markets during the period of study. For pre-covid time period, Pakistan and China is forming a single cluster, and all other Asian countries are a part of different cluster. The study observes that in most of the cases, markets in the same geographic area tend to cluster together. However, despite having geographic proximity, India and Pakistan turns out to be exception in almost all cases.

Figure 3: Dendrogram for the overall time period and three sub-periods



Notes: This figure shows dendrograms for the overall time period and three sub-periods. These dendrograms are based on the hierarchical clustering of ten Asian markets under study.

Part B:

Given the computed correlation matrix, the study proceed to distances between the pairs of stock indices. Table XYZ shows the minimum and the maximum distances between the pairs. The table reports that Singapore and Hong Kong is having the minimum distance between the

nodes in all time periods of study except the pre-covid period. This indicates that these two markets are highly integrated. The maximum distance of 1.559 is observed between Japan and Pakistan before the COVID-19 pandemic. During the same time period, the minimum distance of 0.626 is observed between Singapore and Hong Kong.

Table 5: Min and Max distances between nodes

Overall data			
Min Distance	Singapore	Hong Kong	0.688
Max distance	India	Pakistan	1.349
Pre Covid data			
Min Distance	Singapore	Malaysia	0. 669
Max distance	Shanghai	Pakistan	1.236
First wave of Covid			
Min Distance	Singapore	Hong Kong	0.626
Max distance	Japan	Pakistan	1.559
Stabilization period			
Min Distance	Singapore	Hong Kong	0.773
Max distance	Malaysia	Pakistan	1.418

The study further investigates the changing synchronization among Asian stock markets on the basis of network density. Table XYZ reports that the density of the network during pandemic's first wave is diminished when compared with the network density before the pandemic. This less interconnectedness may be attribute to reduced trade and investment intensity because of the lockdowns imposed by Asian countries. The network remain more or less the same in the stabilization period. A plausible explanation is that after undergoing the pandemic phase, the investors become more prudent to information and risk emancipating from external sources, especially in the interlinked markets.

Table 6: Density of Networks

Time-Period	Density
Overall	0.82
Pre	0.95
During First Wave	0.8
Stabilization	0.82

Figures 5, 6, 7 and 8 shows the Network (Panel A) and MST (Panel B) for the full time period of study and sub-periods. The study notices the change in the graphics of Network and MST in each time period. This indicates the significant role of global economic dynamics in shaping regional financial networks.

Figure 5: Networks for Overall data

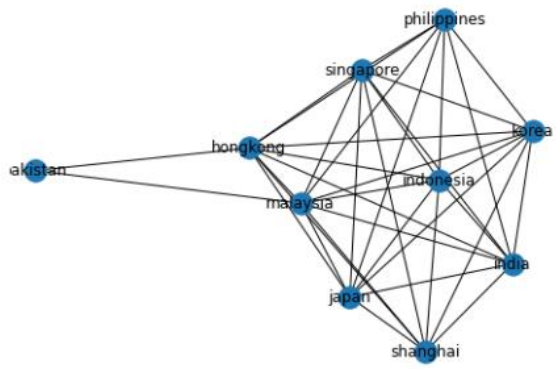
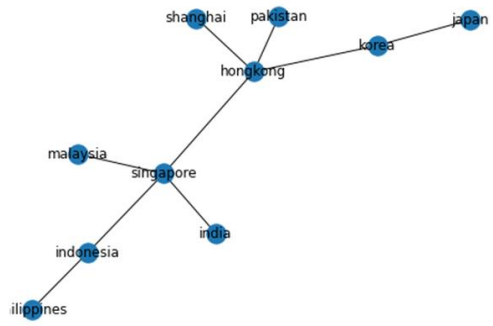
Panel A: Network of stock indices	Panel B: MST of stock indices
	

Figure 6: Networks for Pre Covid data

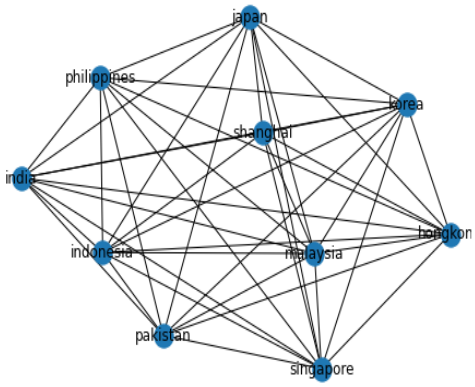
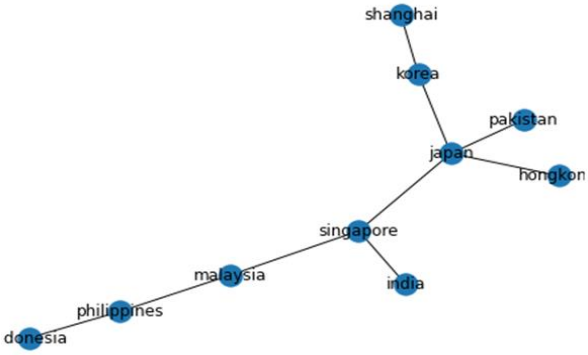
Panel A: Network of stock indices	Panel B: MST of stock indices
	

Figure 7: Networks for data during first wave of Covid

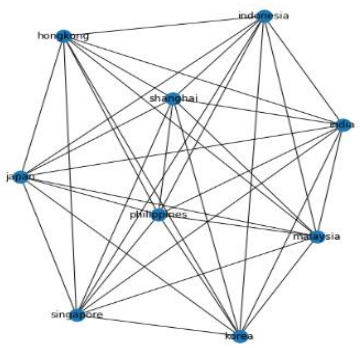
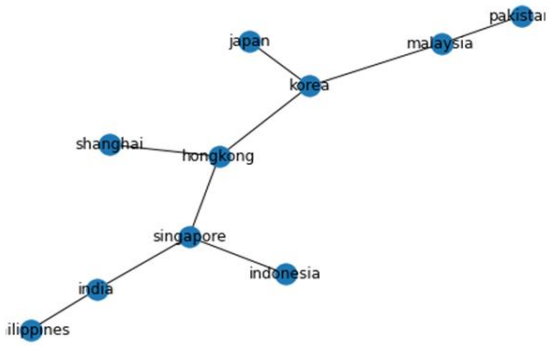
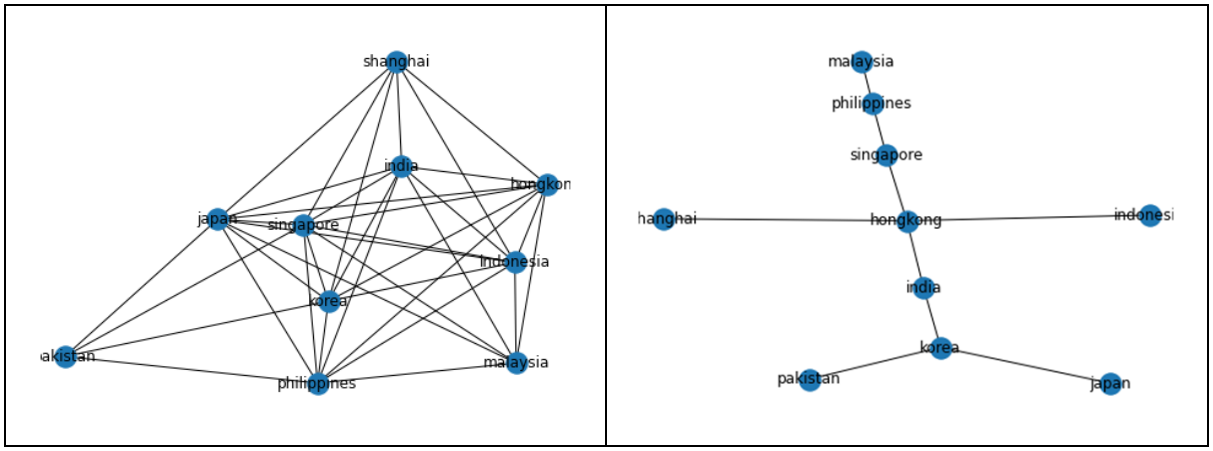
Panel A: Network of stock indices	Panel B: MST of stock indices
	

Figure 8: Networks for data during stabilization period

Panel A: Network of stock indices	Panel B: MST of stock indices



The distance between each pair of nodes is inversely proportional to the correlation between them. The more the distance between any two nodes, the less the correlation between them. For the Overall period, Singapore and Hong Kong were central nodes which tells us that all the other markets were highly correlated with these two markets. Any shock in these markets would transmit to all the countries quickly, and the Philippines was at the end that implies that the Philippines had almost zero effect on what happens in Singapore or Hong Kong. For the Pre Covid-period, Japan was a central node that tells us that all the other markets were highly correlated. During the first wave, Singapore, Hong Kong, and Korea all these were representing central nodes. The point to note is that Shanghai and Japan were significantly less correlated with other markets in this period. During the stabilizing period of the first wave, Hong Kong was a central node, and here, India was also somewhat a market that transmitted its shock to other countries quickly. Shanghai was also not very much correlated with other countries.

Table 7: Degree of Nodes

Country	Overall Data	Pre-Covid	During First Wave	Stabilization
India	1	1	2	2
China	1	1	1	1
Japan	1	4	1	1
Korea	2	2	3	3
Hong-Kong	4	1	3	4
Malaysia	1	2	2	1
Indonesia	2	1	1	1
Philippines	1	2	1	2
Pakistan	1	1	1	1

5. Conclusions-

This study shows that the use of hierarchical methods is useful to analyse the joint behaviour of the different Stock Markets. In particular, the structure of the correlation between 10 different stock indices was researched by constructing a complex network. Using daily price data between September 2019 and November 2020, the MST (Minimum Spanning Tree) was developed, placing Hong Kong and Singapore in a central position in the network obtained from the correlations, leaving Pakistan in one of

the branches of the network. In addition, the cluster analysis through the construction of the dendrogram reaffirms this conclusion and places Pakistan in different cluster from other countries almost every time. The networks obtained came out to be very useful and effective to be able to provide the interrelationships between the financial markets that appear in it. The results obtained in the analysis could be of help to investors when making decisions about their portfolios, assessing their risk exposure as the networks show how any impact in one market transmits to the other.

6. References-

Kruskal, J. B. (1956). On the shortest spanning subtree of a graph and the traveling salesman problem. *Proceedings of the American Mathematical society*, *7*(1), 48-50.

Mantegna, R. N. (1999). Hierarchical structure in financial markets. *The European Physical Journal B-Condensed Matter and Complex Systems*, *11*(1), 193-197.

Liu, X. F., & Tse, C. K. (2012). Dynamics of network of global stock market. *Accounting and Finance Research*, *1*(2), 1-12.

Francés, C. J., Carles, P. G., & Arellano, D. J. (2018). The cryptocurrency market: A network analysis. *Esic Market Economics and Business Journal*, *49*(3), 569-583.

Sun, W., Tian, C., & Yang, G. (2015). Network analysis of the stock market.

Schuenemann, J. H., Ribberink, N., & Katenka, N. (2020). Japanese and Chinese Stock Market Behaviour in Comparison–an analysis of dynamic networks. *Asia Pacific Management Review*, *25*(2), 99-110.

Eberhard, J., Lavin, J. F., & Montecinos-Pearce, A. (2017). A network-based dynamic analysis in an equity stock market. *Complexity*, *2017*.

Morales, A. J., Losada, J. C., & Benito, R. M. (2012). Users structure and behavior on an online social network during a political protest. *Physica A: Statistical Mechanics and its Applications*, *391*(21), 5244-5253.

Xiao, B., Yu, H., Fang, L., & Ding, S. (2020). Estimating the connectedness of commodity futures using a network approach. *Journal of Futures Markets*, *40*(4), 598-616.

Wu, F., Zhang, D., & Zhang, Z. (2019). Connectedness and risk spillovers in China's stock market: A sectoral analysis. *Economic Systems*, *43*(3-4), 100718.

Saeedian, M., Jamali, T., Kamali, M. Z., Bayani, H., Yasseri, T., & Jafari, G. R. (2019). Emergence of world-stock-market network. *Physica A: Statistical Mechanics and its Applications*, *526*, 120792.

Gomez-Gonzalez, J. E., Hirs-Garzon, J., & Gamboa-Arbelaez, J. (2020). Dynamic relations between oil and stock market returns: A multi-country study. *The North American Journal of Economics and Finance*, *51*, 101082.

Majapa, M., & Gossel, S. J. (2016). Topology of the South African stock market network across the 2008 financial crisis. *Physica A: Statistical Mechanics and its Applications*, *445*, 35-47.

Zhang, W., & Zhuang, X. (2019). The stability of Chinese stock network and its mechanism. *Physica A: Statistical Mechanics and its Applications*, *515*, 748-761.

Zhang, W., & Zhuang, X. (2019). The stability of Chinese stock network and its mechanism. *Physica A: Statistical Mechanics and its Applications*, *515*, 748-761.

Lai, Y., & Hu, Y. (2021). A study of systemic risk of global stock markets under COVID-19 based on complex financial networks. *Physica A: Statistical Mechanics and its Applications*, *566*, 125613.

Wu, F. (2020). Stock market integration in East and Southeast Asia: The role of global factors. *International Review of Financial Analysis*, *67*, 101416.

Aswani, J. (2015). Analyzing the impact of global financial crisis on the interconnectedness of Asian stock markets using network science.

So, M. K., Chu, A. M., & Chan, T. W. (2021). Impacts of the COVID-19 pandemic on financial market connectedness. *Finance Research Letters*, *38*, 101864.

Ahmed, F., Syed, A. A., Kamal, M. A., de las Nieves Lopez-García, M., Ramos-Requena, J. P., & Gupta, S. (2021). Assessing the Impact of COVID-19 Pandemic on the Stock and Commodity Markets Performance and Sustainability: A Comparative Analysis of South Asian Countries. Sustainability 2021, 13, 5669.

Chakrabarti, P., Jawed, M. S., & Sarkhel, M. (2021). COVID-19 pandemic and global financial market interlinkages: a dynamic temporal network analysis. *Applied Economics*, 1-16.

Chowdhury, B., Dungey, M., Kangogo, M., Sayeed, M. A., & Volkov, V. (2019). The changing network of financial market linkages: The Asian experience. *International Review of Financial Analysis*, *64*, 71-92.

Appendix A: Countries and No. of weeks

Country	No. of weeks	Country	No. of weeks
India	4	Korea	1
Japan	15	Indonesia	1
Singapore	15	Malaysia	2
China	15	Philippines	14
Pakistan	9	Hong Kong	15