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Abstract

As importance of Asian Stock Markets (ASM) has increased after the globalization, it is become significant to know how this network of ASM behaves on the onset of financial crises. For this study, the Global Financial Crisis is considered whose origin was in the developed country, US, unlike the Asian crisis of 1997. To evaluate the impact of financial crisis on the ASM, network theory is used as a tool here. Network modeling of stock markets is useful as it can help to avert the spillover of crises by preventing the stock markets which are highly connected in the network. In this empirical work, weekly indices data from 2000-2013 for fifteen stock markets is used, which is further partitioned into three periods: pre, during and post crisis. This study shows how 13 important stock markets in Asia namely, India, Bangladesh, Philippines, China, Japan, Indonesia, Malaysia, Singapore, Hong Kong, Pakistan, South Korea and Thailand are connected to each other and how India, Japan, Hong Kong and Korea stock market appeared as the systemically important stock markets from them. Introduction of the US stock market into this network gives insight how the US stock market might had connected to systemically important markets which resulted into spread of crisis in the Asian region. Furthermore, using Kruskal algorithm spread of contagion is explained like how it first hit the Hong Kong stock market and from there it proceeds to the other systemic important stock markets like a virus. Addition to that, we quantified the network behavior in the form of metrics such as adjacency matrix, clustering coefficient, degree of nodes and Minimum Spanning Tree (MST), and on the basis of these some of the important questions like which stock markets are highly connected in Asia which if affected can induce the crises in the other stock markets of region are answered. This study can be used for the portfolio optimization as well as for policy making for which network analysis should be conducted on a regular basis.

Keywords: Financial Crisis, Stock Markets, Networks, Minimum Spanning Tree

JEL Code: C45; G1; G11; G15; P34

Acknowledgements:

I wish to express my sincere thanks to my supervisor, Dr.Rajeswari Sengupta, for her voluble guidance and endless encouragement at all stages of this study.

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1. Introduction

The impact of the Global Financial crisis of 2007-08 persisted through subsequent years of high unemployment, depressing housing market, declining growth, and inflating budgetary deficits, throughout the global economy (Knoke 2002). While financial markets in Asia had relatively limited exposure to subprime related instruments,due to growing global market integration, deleveraging process in advance economies led to a substantial liquidation of assets in the Asian markets followed by capital outflows. These developments caused sharp decline in the Asian equity markets, the widening of sovereign bond spreads, the depreciation of regional exchange rates and the decline in offshore bank lending in the region.

Network dynamics can help to understand how small disturbances escalated into the Global Financial Crisis. Under some network structure conditions, a bank failure quickly dampens out while in other circumstances it may trigger cascades of subsequent failures which threaten to bring down the entire system (Haldane, May 2011). Therefore, it is important to understand the interconnectedness between the institutions under consideration and about the systemically important or systemically risky institutions among them.

In section I of this paper, change in synchronization among the network of thirteen Asian stock markets in pre, during and post crisis is studied using network metrics like network density, degree of node and clustering coefficient. It is found that Bangladesh and Sri Lankan stock markets were isolated in the pre-crisis network but loosely connected in the during and post crisis networks from rest of the markets. And, by computing degree of nodes and clustering coefficient it is examined that Indian, Japanese, Hong Kong and South Korean stock markets have consistently maintained their positions in the network and acted as systemically important stock markets to which other small stock markets like Thailand, Philippines and Indonesia are connected. By comparing the network density, it is concluded that stock markets are more dependent during the crisis but less in pre and post crisis period. In the section II, US is introduced in the network of Asian stock markets and that shows how US was connected to all the systemically important stock markets in the pre-crisis which caused the high returns for them in the pre-crisis but the same thing also made these stock markets vulnerable which proved right when crisis hit the Asian region. In the last section, It is investigated how actually the crisis spread in the Asian markets as a contagion, this work is accomplished using Kruskal diagram or Minimum Spanning Tree (MST), and MST shows the route how first Hong Kong stock market got affected , then Korea, India, Japan and from there it dispersed to small stock markets of the region.

This study can be useful for the investors per se because it will give them hint about the systemically important stock markets and their vulnerability.And at the time of crisis, they can use this strategy to select the far off stock markets to manage their returns by portfolio diversification. On the other hand, policy maker can benefit from this study by knowing how the shock in one stock market can spread to others and which principal component should be controlled as a precautionary measure.

2. Background Literature

Thao and Daly (2012), used cointegration and VAR model to investigate the change in integration among six south Asian countries: Thailand, Malaysia, Singapore, Philippines, Indonesia and Vietnam using daily market indices collected over the period 2006-2010. It concludes that there is bilateral relationship among the Thailand- Singapore and Thailand-Philipines, and Vietnam is less connected to any of these four countries because of corruption. Although this paper founds the change in the relationships among these stock markets but this paper does not comment anything on the contagion effect. On the same note, Wang (2014), examined the interaction of US with six East Asian stock markets and revealed that global financial crises of 2007-2008 has strengthen the linkages among stock markets in East Asia. The same argument is supported by Sriyalatha and Torii (2013) , Mukherjee and Bose (2008) , Daly (2003) which concludes that interdependency among Asian stock markets increases during and after the crises.

Moving one step further, Walti (2005) finds that synchronization between stock markets which can be measured by coefficient correlation can be explained by variables which includes the intensity of trade relations, the degree of financial integration and the nature of the exchange rate regime, in which fixed exchange rate regime increases co-movements and trade and financial integration contributes positively to synchronization. Then further, Johnson and Soenen (2002), uses daily returns from 1988 to 1998 to investigate that at what degree twelve equity markets in Asia are integrated with Japans equity market and examined that higher import share as well as a greater differential in inflation rates, real interest rates, and gross domestic product growth rates have negative effects on stock market co-movements and increased export share by Asian economies to Japan and greater foreign direct investment from Japan to other Asian countries contribute to greater co-movement. Joe, Gong, Kim and Meric (2012), study the contemporaneous co-movements and lead/lag linkages between thirteen major Asian stock markets with daily returns data for the January 1, 2001-January 1, 2011 period. They used the principal components analysis (PCA) for this purpose and the results indicate that the co-movements of Asian stock markets have become closer and portfolio diversification benefits have decreased during this period. Granger causality (G-C) test used by them showed significant lead/lag linkages between Asian stock markets. They find that the Singapore, Indian, and Japanese stock markets are the most influential and the South Korean and Philippine stock markets appear are the least influential stock markets in Asia. The Singapore, Japanese, and New Zealand stock markets are the least affected and the Shanghai, Australian, and South Korean stock markets are the most affected stock markets by the movements of the other Asian stock markets

Iwatsubo and Inagaki(2007) investigate stock market contagion between US and Asian markets, using NYSE-traded stocks issued by Asian firms. They found significant bilateral contagion effects in returns and return volatility, and also, that contagion effects from the US market to the Asian markets are stronger than in the reverse direction, indicating that the US market plays a major role in the transmission of information to foreign markets. The intensity of contagion was significantly greater during the Asian financial crisis than after the crisis. There is a reasonably large body of empirical studies testing for the existence of financial contagion during financial crises. Although a range of different methodologies have been presented to analyze contagion effects, there is no theoretical or empirical procedure for identifying contagion on which researchers agree. Latent factor model (Bekaert, Harvey, & Ng, 2005), correlation analysis (Forbes & Rigobon, 2002), VAR frameworks (Favero & Giavazzi, 2002), and probability theory (Eichengreen, Rose, & Wyplosz, 1995) are different methodologies proposed in the literature. Boyer , Kumagai and Yuan (2005) , provided empirical evidence that stock market crises are spread globally through asset holdings of international investors. By separating emerging market stocks into two categories, namely, those that are eligible for purchase by foreigners (accessible) and those that are not (inaccessible), they estimated and compared the degree to which accessible and inaccessible stock index returns co-move with crisis country index returns. And the results by them showed the greater co-movement during high volatility periods, especially for accessible stock index returns, suggesting that crises spread through the asset holdings of international investors rather than through changes in fundamentals.

Till few years back, network study was limited to subjects of Physics, Sociology and Computation fields only recently it is permeated in the field of economics and finance. Therefore, sometimes to understand and applying network science papers from other fields can also be used. Barabasi and Albert (2002), describes topology of real networks like Internet , World Wide Web , Cellular Networks, Citation Networks, Power and Neural Networks , Protein Folding and others. It also defines the characteristics of network like Average path length, clustering coefficient, degree distribution and spectral properties. This paper further reviews recent advances in the field of complex networks , focusing on the statistical mechanics of network topology and dynamics .Setiwan (2011) , investigates stock market integration using the minimum spanning tree (MST) technique , a technique that finds minimum total distance of edges that connect vertices. The distance is a transformed variable of correlation coefficient of stock market returns. For this study, this methodology is used to convert the network into Minimum Spanning Tree (MST) to explain the contagion effect among stock markets during shocks or period of crises, MST also gives information what portfolio to choose at the time of crisis. Cupal, Deev and Linnertova (2013) examined changing topological characteristics of correlation based network of European stock markets on both national and supranational levels. On a national level, core stem of stock markets of highly developed countries is found to be stable over time with French market playing the central role and on the supranational level , stocks are clustered based on their economic sector , rather than countrys origin . Similarly, Roy and Sarkar (2013), research aim at developing a network based index to compute the change in the level and pattern of comovement in the global stock markets .In this study , a network is constructed using the stock markets indexes of US ,Europe and Asia and afterwords behavior of key metrics of networks such as clustering coefficient, power law exponent, length of Minimum Spanning Tree is analyzed. Thus work reveals the presence of regional influence on the network dynamics and confirms the interdependence of stock markets during the crisis.

3. Data

The data employed in this study is composed of weekly closing stock indices over the period from January 6, 2000 to September 14,2013 for fourteen Asian countries and one of US: DSE (Bangladesh), SET (Thailand), CASPI (Sri Lanka), BSE (India), Shanghai Composite Index (China), HSI (Hong Kong), Jakarta Composite Index (Indonesia), KSE-100 (Pakistan), SGX (Singapore), KOSPI Composite (South Korea), Nikkei 225 (Japan), TWII (Taiwan), Kuala Lumpur Composite Index (Malaysia) , PSEi (Philippines) and DJAE (United States). As the plot of stock market returns (in Figure 1) shows that stock markets were declining from 2007 onwards and that continued till 2009 approximately and after which markets saw the V-shape recovery.

Therefore keeping that in mind, data is divided into three sub groups: Pre- Crisis (2000-2006), During Crisis (2007-2009), Post- Crisis (2010-2013). All stock index prices used in this study are expressed in local currencies. If there was any missing point in time series, it is replaced by the last registered observation. This is a valid assumption as missing point can be due to closing of stock market which means no trading on that day therefore gap can be filled by the last observed value. Although, missing points can also be calculate by the time series techniques like Kalman filter or numerical estimation techniques like Newton Raphson Method but all these method would also provide approximate value.

Other than the closing stock indices, annual values from 2000 to 2013 of stock market capitalization per GDP for these countries are collected from the Federal Reserve Bank St Louis FRED database. Stock Market Capitalization per GDP for the Asian countries is given in Table 1.

To provide causation for correlations on which network is constructed, econometric model is developed using the variables like Export share (%), FDI Inflows in million USD , Interest Rate Differential and Portfolio Investment Assets : Total Equity Securities in million USD. The data for these variables are gathered from the Asian Development Banks integration indicators database. But variables are correlated to each other, therefore directly using them into the model can give the error due to multicollinearity, hence first Principal Component Analysis (PCA) is used to prompt the components which are function of these variables but uncorrelated to each other and then these components are used as variables in the econometric model.

4. Methodology

Network theory is recently introduced in the field of economics and finance but this concept is not new to fields of Physics, Sociology Biology and Mathematics.Actually, network theory is nothing just the offshoot of the graph theory which was founded by mathematician Euler in 1754 when he wrote paper on Seven Bridges of Konigsberg. In the graph theory or in network science, a graph G = (V, E) consists of a finite nonempty set V and a collection E of unordered pairs from V (i.e. two element subsets of V). Every element in V is called a vertex of the graph, and each unordered pair in E is called an edge of the graph. A graph without any parallel edges is a simple graph .If one or more real numbers are associated with each edge of a graph, the resulting structure is known as a weighted graph or network.

Characteristics of the Network

1. Degree of a Node: It is a integer count or number of other nodes with which a given node has direct contact.

2. Density of Network: It is a proportion that is calculated as the number of all ties occurring in the matrix divided by the number of the possible ties

$$Density = \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}/N^2 - N$$

; where N is no total no of nodes

3. Adjacency Matrix: The standard treatment of the network data is a tabular display called a matrix. The matrix elements are N2 numerical values that indicate the nature of the linkages between every pair of edges in the network. The simplest elements are binary values , with a 1 standing for the occurrence of a tie from node i to node j , and a 0 for the absence of such a tie between the pair.

4. Centrality of a node: The centrality of the node can be calculated as the ratio of aggregate relations involving i over all relations in a network i.e. the proportion of all network relations that involve i

$$c_i = \sum_{j=1}^{n} C_{ij} / \sum\sum C_{ij}$$

5. Clustering Coefficient: The clustering coefficient measures the average probability that two neighbors of a vertex are themselves neighbors. In effect it measures the density of triangles in the networks and it is of interest because in many cases it is found to have values sharply different from what one would expect on the basis of chance (Barbasi and Albert (2002), Knoke (2012), Newman (2009)).

To construct a network of Asian stock markets, we have used the stock markets as the vertices or nodes and correlation coefficient among returns of the indices as the criterion to make the edge between these nodes.

The weekly returns of the indices are computed as follows:

$$R_t = logP_t - logP_{t-1}$$

Where R_t is weekly return at time t. P_{t-1} and P_t are indices closing prices for two successive weeks, t-1 and t, respectively.

Correlation coefficient between the two indices is given by the standard formula:

$$C_{ij} = \frac{< R_i R_j > - < R_i >< R_j >}{\sqrt{< R_i^2 - < R_i >^2 >< R_j^2 - < R_j >^2}}$$

Where $< R_i >$ represents the average return of the index i over a specified time period T consisting of say n days then

$$< R_i >= 1/n \sum_{i=1}^{n} R_i(t)$$

But the rule is predefined to build the edge between any two indices and that rule is C_{ij} should be greater or equal to a specified threshold limit θ i.e. $C_{ij} \geq \theta$ where $\theta \varepsilon [0,1]$. The value of the threshold θ is calculated by using the Markowitz Portfolio Theory with slight modification.

Calculation of the Threshold limit (θ)

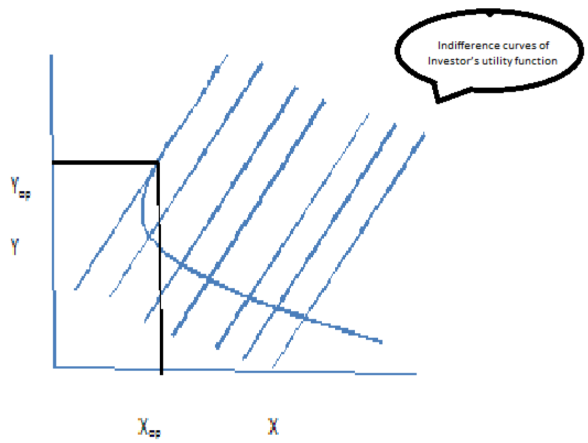
Utility of the Investor:

$$U = E(R) - 0.005 * A * \sigma(R)$$

Where, A is risk averse coefficient which lies between 1 to 6 and for this study, A has been taken as 3.E(R) is the expected return and 0.005 is the scaling factor for standard deviation, (R).

Threshold Limit θ	No of nodes in network	Return Index(X)	Index of Standard Deviation(Y)
$\theta 1$	N1	X1	Y1
$\theta 2$	N2	X2	Y2
$\theta 3$	N3	X3	Y3
$\theta 4$	N4	X4	Y4
$\theta 5$	N5	X5	Y5
$\theta 6$	N6	X6	Y6
$\theta 7$	N7	X7	Y7

Suppose $\theta 1$= 0.2 and at that threshold limit there are only 3 stock markets are forming a network that means N1 = 3. Then the return index for this network can be calculated by the



following formula:

$$X_1 = \sum MR / \sum M$$

That is weighted average of returns of those stock markets by market capitalization per GDP. Similar procedure can be repeat for the standard deviation. Furthermore, using these Return Index (X) and Index of Standard Deviation (Y) portfolio frontier diagram can be draw.

Corresponding to the optimized X and Y i.e.(X_{op}, Y_{op}) optimal threshold limit θ_{op} can note from the table and taking this threshold limit network can be constructed by making the edges between those nodes whose correlation coefficient is greater than or equal to this threshold limit.

For proving the hypothesis of change in interconnectedness among Asian Stock markets above methodology is sufficient but to find out the route of spread of crisis from US stock market to Asian stock markets Minimum Spanning Tree (MST) is generated using the greedy algorithm like Kruskal algorithm.

Minimum Spanning Tree and Kruskal Algorithm

A graph in which no sub graph is a cycle is called an acyclic graph and a connected acyclic graph is a tree. Here are some of the theorems given in the books and can be used as the properties of the tree diagram. The author thinks its important to mention these theorems here as these gives the story of transformation of the tree diagram from the graph or network.

Theorem 1

A graph is a tree if and only if there is a unique simple path between every pair of vertices in the graph.

Theorem 2

A graph is a tree if and only if every edge in it is a bridge.

Theorem 3

(i) A connected graph with n vertices is a tree if and only if it has n-1 edges.
(ii) An acyclic graph with n vertices is a tree if and if it has n-1 edges A spanning tree is a set

of paths that link vertices or nodes (in this case market indices) in such a way that there is one and only one path between any pair of vertices. The Minimum Spanning Tree (MST) which is obtained by iterating such processes so that total distance of paths in the tree is minimal.

Theorem 4
A spanning tree T in a graph G is a minimal spanning tree if and only if every chord of the tree is a maximum weight edge in the unique fundamental cycle defined by that edge. MST can be draw using any one of the greedy algorithms like Prims, Kruskal or Boruvkas but for this study Kruskal algorithm is used.

Kruskal algorithm is a MST algorithm which was written by the Joseph Kruskal in 1956 and used to finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized. To apply the Kruskal algorithm, firstly cross market correlation coefficients are transformed into ultra-metric distance using the formula given by the Kruskal,

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

Where the d_{ij} lies between the 2 and 0, when $C_{ij} = 1$ and $C_{ij} = -1$ respectively. Kruskal's algorithm builds a minimum weight spanning tree T using low weight criterion by adding edges to T one at a time. The algorithm selects the edges for inclusion in T in no decreasing order of their weight. An edge is added to T if it does not form a cycle with the edges that are already in T. Since G is connected and has n vertices, exactly n - 1 edge will be selected for inclusion in T (Kruskal (1956)).

Theorem 5
Let G be an undirected connected graph. Kruskal's algorithm generates a minimum cost spanning tree.
Proof of these theorems are provided in the APPENDIX.

Using the Kruskal algorithm and MST of the 15 stock markets mentioned above, we are trying to understand the spread of crisis or contagion among these markets.

5. Results and Discussion

5.1. Changing synchronization among the Asian stock markets

In this section, we have attempted to prove that stock market inter dependency increases during the crisis than pre and post crisis period and that can be due to financial integration or due to change in trade intensity. The proof of first hypothesis of the paper, network of stock markets become more interconnected during the crisis then pre and post crisis, can be inferred easily from the network diagrams in Figure 1, 2 and 3 as these images depicts that during crisis network is more densely packed than pre and post crisis. The same thing can be quantified in the form of metric like network density; Table 2 manifests that during crisis network density was 0.69 which is higher than of pre and post crisis value of 0.55 and 0.53.

Now lets discuss about the changes in the degree and clustering coefficient of individual stock markets:

Bangladesh, Sri Lanka and Singapore: In pre-crisis network of ASM in the Figure 2, we can get that Dhaka Stock Exchange (DSE) and Colombo Stock Exchange (CSE) are not connected with other stock markets of the region which can be due to low stock market capitalization to GDP during that period but afterwards in post crisis period, market capitalization improved and thats why these stock markets appeared connected in post crisis network. Even in the network of during crisis (Figure 3) these two stock exchanges are well connected with other members which is evident as degree of node increased from 0 to 4 for DSE and from 0 to 8 for CSE.

As per theory, global investor always looks for option of portfolio diversification and opportunity. Here opportunity means secluded stock markets (DSE and CSE) which are preferred because now the investor can invest on the index which is behaving differently rather than putting money on the stock markets which are giving same kind of return due to comovements. But author, on the contrary, argues that this statement is not certain. Stock markets which are isolated in the network does not necessarily will always provide better returns; take a case of Bangladesh and Sri Lankan stock markets, although they were not connected during the pre-crisis but that because their economy was mess; Sri Lanka was suffering from civil war between LTTE and army, on the other hand Bangladesh was suffering from energy crisis and poor infrastructure which prevented the foreign investment from flourishing. Therefore, stock markets which are not well connected in the network can be suffering from political instability, currency crisis, closed economy, limited financial openness and similar others problems. On the other side, Singapores stock market was also loosely connected in the network which can be confirmed by its degree of nodes which is 3 in pre-crisis and 1 in post crisis, and was also less affected by the crisis but that due to strict financial regulation and other controls. But from 2008 onwards (Figure 4), that is from time of global recession these economies became well synchronized with other Asian countries, and relative impact of crisis by factors like currency depreciation, interest rate change, foreign investment in form of FDI and remittances and similar others hit these Asian countries somewhat equally which demonstrates that stock market network in this region has become more denser and more interdependent than the pre-crisis period.

By analyzing the pre and during crisis network, it can say that Bombay Stock Exchange (India) , Hang Sang Index (Hong Kong), KOSPI Composite Index (Korea) and Philippines Stock Exchange Composite Index (Philippines) are major stock markets in Asia and it proved by their degree of nodes which remains consistently high in all the three sub periods: 8 to 10 pre-crisis and further increased to 10 to 11 in the crisis period.

Hong Kong: In all the network diagrams, Hong Kong stock exchange emerged as an important node but this should not be surprising as country have high financial and trade openness which served by 92 % service industry and its financial business is classified in detail , covering all aspects of the financial industry : stock and share companies , commodity futures , gold bullion and foreign exchange brokers/dealers , fund management companies and firms providing other financial services , and in 2006 the value added by financial business was whopping 4.1 % of GDP . But this entire glistening nos of financial sector growth also makes this index vulnerable to crisis.

India: Other systemic important exchange index is BSE. It is also the oldest stock market in Asia; worlds third largest stock market on the basis of investor base and has a collective pool of about 20 million investors. There are over 9,000 companies listed on the stock exchanges of the country. But this stock market start showing signs of integration with other stock markets of Asia and abroad after the 2000 due to robust growth, relaxed regulations and deluge of cross border capital flow. Its connectivity can be seen in its degree of nodes and clustering coefficient which were high throughout period. This consistently high network metrics for this stock exchange can be explained on the basis that in India central bank did not allow the Non-Banking Finance Companies(NBFC) to be used by the commercial banks as arbitrage for delivery vehicle, collateral requirement loosened up to promote the short term liquidity, managed liquidity by controlling cash reserve ratio, statutory liquidity ratio and open market operations. In precise way, central bank took calibrated approach to opening of capital account.

South Korea and Philippines: Countries like South Korea and Philippines, which were not affected the way they were in the 1997 crisis may be because of financial reforms, accumulated international reserves and less exposure to sub-prime related instruments. That is one of the reasons that strong position of these stock markets in this network maintained as major nodes during the crisis which is clear from rise in degree from 9 to 12 for the PSI supporting the notion of integration of the ASM. The reforms during the crisis period which qualifies it as systemically important stock market are relaxing the aggregate credit ceiling, currency swap of 30 billion USD with Federal Reserve and 100 billion Yuan with People Bank of China, reducing interest rate on six occasions and injecting the liquidity of worth 18.5 trillion Won to boost the economy.

Thailand: Another important stock exchange is Thailand Stock Exchange Index (TSEi),During the crisis it was fluctuating very much and moved downward with the retreat of foreign funds in the market of more than 2 billion US dollars in the space of a few months time. But the manner in which the Thai banking problem was tackled, beginning in 1998, shows how authorities might successfully overcome a systemic banking crisis. The government embarked on a comprehensive restructuring of the financial sector, intervening in weak banks and focusing on recapitalization, debt restructuring, reform of the regulatory and supervisory framework, strengthening corporate governance of banks, and introducing initiatives to deepen and broaden the capital market. Due to this robust financial structure before the crisis, TSEi was major player in the network with high degree of node and clustering coefficient of 8 and 0.87 and due to integration during the crisis period its degree of node and clustering coefficient increased to 11 and 0.976. But after the crisis, node degree of TSEi reduces to 2 and clustering coefficient plummeted to 0.136, this can be due to impact of capital flight and dormant export sector or may be due to civil war between red shirt vs. multi colored shirt that is between supporters of Thaksin Shinawatra, former prime minister and loyalists of Abhisit Vejjajva, newly throned prime minister. In that civil war, Thailand loses around 5 billion USD and which reduced the confidence of investors on this economy in the post-crisis period.

Japan: Nikkei 225 index was 18,621 on July 9, 2007 but due to capital reversal by the developed countries the index came down to mire four digit no, but according to IMF, financial crisis does not had much effect on japan because it had US $14 trillion pile of household savings from trade surpluses and frugal lifestyles to finance its immense $8.1 trillion fiscal deficit and still have enough money left over to be the worlds largest creditor nation. Albeit Japan did its endeavor to save the South Asia from the crisis so that it can protect its market for exports: currency swap with Korea of worth 39 billion dollars and investing in logistics systems and create new shipment links of ASEAN , China , India ,South Korea , Australia and New Zealand are few of such tactics . This may be the reason that its degree of node maintained at 9 during all the three sub periods but clustering coefficient reduce to 0.872

during crisis from 0.92 before crisis which can be due to change in relationships among its neighbors but clustering coefficient again rise to 0.9 which implies that Nikkei index will still be well connected to the Asian stock markets in the future too (World Bank (2008), Kawai and Takaji (2010)).

China: Shanghai Stock Market index of China also suffered due to capital reversal when in Oc- tober 2007 stock market crashes, wiping out two thirds of its market value but foreign capital flow rebounded soon as FDI which was decreased to 121.68 billion US$ in 2008 rise to 124.93 billion US$ (Zhang and Willet (2012)). And as FDI and equity investment are positively correlated we can comment that Shanghai stock market become more important even after crisis period which also indicated by the increase in degree of nodes from pre-crisis to post crisis by 2 and clustering coefficient from 0.672 to 0.87 (Das 2010).

Indonesia: Jakarta Stock Exchange Index (JSE) of Indonesia drop from 2,746 in fourth quarters of 2007 to 1326 in December, 2008 showed the arrival of Global Financial Crisis in the country. Further, sub manufacturing export like vegetable oils and fats, spinning, textiles, refined petroleum, paper and paper products, chemical and chemical products, rubber and plastics products, non-iron metal products, machinery and equipment, and furniture shown sign of decline (Djaja (2010)). All this captured by the decline in the degree of nodes during the crisis but as government took help of multilateral financial institutions such as from the World Bank and Asian Development Bank and country like Japan to support its financial market and result of which World Bank has approved two development policy loan amounting to USD 950.0 million, a part of its continuing commitment to support reform, improve investment climate, improve delivery of public services to the poor and address the hindrance to investment in new and better infrastructure. Therefore, Indonesian stock market has gain the systemic importance in the network after the crisis and its degree of node and clustering coefficient have increased.

Pakistan: Karachi Stock Exchange (KSE), KSE-100, plummeted around 60 % from the 2007 to 2009; however the outflow of the portfolio investment from Pakistan was just $510 million given the magnitude of market capitalization. This is an indication of the non-integration of the domestic market with international market during the crisis. Another possible reason for low degree of node can be that Pakistan gets lot of remittances from US, UAE, Saudi Arabia and UK. Even though , during the crisis , capital inflow from the US went down but from the other regions remittances were intact, in fact it was 7.8 billion USD in 2008-09 ; not falling of these inflows can be explained with the help of life cycle hypothesis of Modigliani (1954) (Din and Khawaja (2010)).

The most surprising result was the low degree of Singapores stock exchange (SGX) in pre-crisis as it was only linked to major stock markets like BSE, PSEi and KOSPI Composite index during that time . But as during crisis, Singapore used exchange rate and wage instruments effectively, introduce the Job Credit Scheme and Special Risk Sharing Initiative, and also adopt the financial reforms like liberalization of Singapore dollar to maintain the competitiveness of its economy its integration with other stock markets increased during the crisis but still loosely connected overall.

All above cases of different countries specify that network of Asian Stock Markets concentrated during the Global Financial Crisis and after the crisis it again start spreading which can be seen in the Table 3 and Table 4 of Degree of Nodes and Clustering Coefficient. By using the MST diagrams, investors can manage their portfolios like in pre-crisis period every Asian stock market was booming so by MST of pre-crisis he can choose stocks from Korea, Thailand, India and Hong Kong and during crisis he should choose from the stock markets who are far away like Taiwan, India and Pakistan to manage the risk and to control the contagion effect in his portfolio. Similarly, a policy maker can use networks and MST to draw outlines for financial regulation so that the stock market of the country can be shielded from the economies which are more vulnerable during the time of crisis.

5.2. US in the network of Asian Stock Markets

The US Stock market, Dow Jones Industrial Average (DSAJ), is introduced into the existing network of ASMs. It is important to know how US is connected to these Markets to analyze how it spread the crisis in them which is explained in the next section. The network diagrams which includes US stock market and Malaysian stock market (Kuala Lumpur Composite Index) is shown in figures 5,6 and 7 which is generated using threshold limit of 0.1 and this threshold value is again computed using the Markowitz Portfolio Theory. From these diagrams it is very clear that in pre-crisis period DJA was correlated to all the systemically important stock markets of Asia like Hong Kong, India, Korea and Japan other than that it was also connected to Philippines, Singapore, Indonesia, Malaysia, Thailand and Taiwan stock markets. And from the table of degree of nodes, interconnectedness of ASMs with US increases during the crisis as its degree of nodes rise to 13 than 10 in pre and post crisis period. In addition to above stock markets China, Sri Lanka and Pakistan stock markets were also get correlated to the US stock market during the crisis period. The possible reason behind these new connections can be as although equity investment dwindled due to shock in these stock markets but trade relations of US with these economies was intact even during the crisis and from 2009 onwards equity investment also resumed to the pre-crisis level. In network diagram, it is interesting to note that in the post crisis period linkages of US with Thailand, Singapore and Taiwan stock markets disappeared, and new edges formed with stock markets like Pakistan, Sri Lanka and China in the crisis period which also continued in the post crisis period too. In all the three sub periods, US was highly connected to all the systemic important stock markets of this region which is also the reason that crisis spread through these markets.

5.3. Spread of Asian Crisis from US to Asian Stock Markets

The Asian and global economies had enjoyed a period of boom since the beginning of the twenty-first century. The same applied to the global equity and financial markets. Not only Wall Street but equity markets in other parts of the world touched new heights. Asian equity markets were no different. Rising defaults in the US subprime mortgage markets began during the latter part of July 2007, sparking a sell-off in the equity markets. There was an obvious question mark regarding the health of the US economy. Failings and limitations in its financial markets in particular came to light. As global leverage and risk appetite declined, Asian equity markets also start losing its charm. For the Asian equity markets the latter half of 2007 became a period of volatility. This could be regarded as the contagion effect of the market turmoil in the US. As global equity investors began exiting, all major Asian markets turned negative. In September and October 2007 the downward movement of the stock indexes in Asia accentuated. In the third quarter of 2007, the contagion effect began to affect Asian financial markets more widely. There were obvious concerns regarding the US-led slowdown. Market players began surmising about the severity and length of the slowdown and its future impact.

Falling equity markets in the emerging Asia due to GFC broke the myth that Asia decoupling from the advanced industrial economies. Akin and Kose (2008) and He et al. (2007) established that the business cycles in the Asian EMEs and the advanced industrial economies are interdependent. By the end of the first quarter of 2008, most stock indices were down significantly. Their declines ranged between 15 percent and 25 percent. International investors sentiment had turned negative. In this ambience only two equity markets in emerging Asia performed well by recording relatively smaller declines. They were Taiwan and Thailand; in these two cases the indices fell less than 10 percent.

To study the spread of crisis in ASM ,US is introduced in the existing network to see how exactly the crisis spread among the ASM, we can see that US stock markets were highly connected to the stock markets of major nodes like Hong Kong , Korea , India , Philippines, Thailand , Malaysia and Japan and Taiwan therefore when we transform network or simple graph into spanning tree for which there are 2(n-1) 1 ways but we needed a network with minimum sum weight therefore we applied kruskal algorithm to that. In MST of pre-crisis (Figure 8) we can clearly see how the crisis which originate from US first reached the Hong Kong stock market which also seems intuitionally correct as this country is one of the most active and liberal debt markets and a leading asset management center in Asia and this country have presence of 152 out of 500 largest banks in the world. Hence when crisis hit this stock exchange its index falls by 15 % in September 2007 and further plummeted 22 % in October.

The Shanghai Stock Market index affected due to high correlation with Hang Sang index which can be easily understand by the fact that since July 1933 when the first Chinese state owned company was listed on the HKEx through issuance of H shares, the Hong Kong emerged as a major fund raising center for the mainland china and had become increasingly important for the Chinese business and by the end of 2007, there were 146 H shares listed on the HK Ex, with market capitalization of $ 5,080 billion. After hitting the Hong Kong stock market, it also influenced the KOSPI composite index of Korea and from the MST of pre-crisis we can easily say that as Korean stock market was acting as a central node; due to impact on this stock market crisis spread as a contagion to other systemic important stock markets like India and Japan and other smaller stock markets like Thailand and Philippines. There are many reasons for Korean stock market to act as a central node, firstly, by reducing the interest rate at 6 occasions it manage the economy well at the time of crisis and putting stimulus of 18.5 trillion KRW in the market to boost the investment is in itself a big step because this stimulus was equivalent of 28.5 % of revenue generated at end of 2008. The currency deprecation by 20-25 % also does not affected the Korea much as it already had currency swap with US and with China of 30 billion USD and 180 billion Yuan which came as saving grace at the high time.

From During Crisis MST and Post Crisis MST (Figure 9 and Figure 10), we can deduce that how the positions of nodes are changing, like pre-crisis BSE index was strongly linked to KOSPI index but during crisis and after the crisis its more strongly connected to Hang Sang index which can be due to further opening of the financial sector however in the calibrate manner.Similarly, Japan stock market connected to Thai stock market in the post-crisis MST which can be due to huge flow of FDI in Thai infrastructure as Japan invested in the Asian countries after the crisis to maintain its export sector which was facing slow down due to decline in global demand.

Till now, we used correlation coefficient of stock markets return to construct the net-

works and kruskal diagrams; and nothing is said on which factors are causing correlation coefficient to behave like this. Therefore,intuition behind the correlation coefficient is clarified using the two way approach, 1. By explaining the condition of financial sector and trade sector in each of this economy 2.Using the Principal Component Analysis (PCA) and econometric modeling
The first approach that justifies the causation by understanding the trade and finance reforms taking place in these countries during this period has already been given in the section I of this study, so in this section we will concentrate on PCA and econometric models.

For quantifying the causation, we used four variables: Total Trade (in millions USD), Equity Investment (in millions USD), Interest Rate Differential and Total FDI (in millions USD). But as these variables are correlated therefore conducting the regression activity using these as variables will give erroneous results.Hence,using PCA components are obtained then regression are run using these components(C1 and C2) as the dependent variable. Then by using the softwares like Mathematica comparative static can be done to find out how these variables can affect the correlation coefficient . This method has been explained below for the India-Singapore correlation coefficient and for the US-Hong correlation coefficient from the kruskal diagram.

For Ind-Sing link

Principal Component:$C1 = -0.504 * ir - 0.514 * fdi - 0.485 * ei - 0.497 * tt$

Model: $CC_{is} = 0.000198 + 8.94 * 10^{-13} * C_1^2 + \varepsilon$

Here, ir = Interest Rate Differential, fdi = Total Foreign Direct Investment, ei = Total Equity Investment, tt = Total Trade

For US-Hong link

Principal Components: $C1 = 0.474 * ir - 0.608 * ei - 0.638 * tt$

$$C2 = 0.869 * ir + 0.441 * ei + 0.225 * tt$$

Model: $CC_{uh} = 0.000924 + 2.27 * 10^{-8} * C_1 + 3.57 * 10^{-8} * C_2 + \varepsilon$

For Kor-Ind link

Principal Components: $C1 = 0.611 * ir - 0.491 * ei + 0.621 * tt$

$$C2 = 0.389 * ir + 0.869 * ei - 0.305 * tt$$

Model : $CC_{ki} = 0.001035 - 1.06 * 10^{-11} * C_1^2 - 4.4 * 10^{-8} * C_2 + \varepsilon$

Similarly, by using the principal component analysis and econometrics, model can be construct for any link and by applying the comparative statics it can be distinguish how by changing the ir, fdi, tt and ei correlation coefficient is changing and as threshold limit is known to us so it can be predict whether the link between the stock markets will persist or not or how it will changing.

6. Conclusion

Through this study, it is proved that during the crisis period Asian stock markets were more interconnected than pre and post crisis, and there was less opportunity for portfolio diversification in the period of crisis.We also find out that Hang Sang Index (HK), KOSPI Composite (Kor), BSE (Ind) and Nikkei225 (Jap) are systemically important stock markets in the Asian region which is justified by their high degree of nodes and clustering coefficient.

With the inclusion of US stock market (DJAE) in the existing network it is discovered that DJAE was highly connected to systemically important stock markets of Asia and also with some small stock markets like PSEi (Phi) and SET (Thai) in all the sub periods and these connections in pre-crisis were become medium of transmission of crisis. This point clarifies further when we construct the Minimum Spanning Tree (MST) using the Kruskal Algorithm next section; MST of pre-crisis explained how might have crisis spread among the Asian stock markets from US; first it hit the Hong Kong stock market then Korean stock market which played the central node and from there it affected other systemically important stock markets like India and Japan, and because of dependencies of small stock markets to these bigger ones affected them too. This study can be useful for the global investors in optimizing their equity portfolio by understanding the systemic risk in the Asian Stock Markets (ASM) and by keeping eye on the route by which shock can spread in the ASM network. The results of kruskal diagram can help the policy maker in introducing the reforms which can protect the financial institution like stock market from any shock or crisis which originated somewhere in the region or in the advanced country like US.

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Table 1: Stock Capitalization to GDP (in %)

observation_date	Malaysia	India	Singapore	China	Hong Kong	Bangladesh	Srilanka	Japan
2000-01-01	139.71060	34.260480	181.98270	38.343250	356.8759	2.114877	7.760103	84.11244
2001-01-01	127.41760	25.694070	147.48880	42.266920	335.7748	2.371995	7.271914	60.66623
2002-01-01	121.35780	22.955070	118.66840	34.424860	291.5280	2.374206	8.569454	54.09519
2003-01-01	132.83540	33.730680	177.01320	35.012110	313.8335	2.665123	11.453940	62.05379
2004-01-01	143.79690	46.808820	235.89710	34.882740	358.5841	4.306714	14.610560	74.54725
2005-01-01	132.49010	56.582460	242.77610	32.154430	374.1214	5.195916	19.058670	91.25156
2006-01-01	130.22100	71.246150	214.24590	59.735600	408.8358	5.191374	23.302340	105.9501
2007-01-01	148.35520	109.829400	189.09160	125.228300	480.2278	7.502488	22.964700	104.489
2008-01-01	116.09520	94.213230	169.41070	110.048600	569.4619	8.601203	15.867590	86.08955
2009-01-01	107.05890	64.820060	142.51870	79.233300	524.4122	7.640274	14.303490	68.76908
2010-01-01	138.86060	83.592390	158.24490	83.713370	431.3392	11.079710	27.983940	70.27532
2011-01-01	144.09380	69.689700	148.14730	58.752410	396.8376	17.274000	33.819930	68.77987

Table 2: Network Density

Pre-Crisis	0.54
During Crisis	0.69
Post Crisis	0.53

[0]Network Density is a proportion that is calculated as the number of all ties occuring in the matrix divided by the number of the possible ties.

Table 3: Adjacency Matrix of Asian Stock Markets

BEFORE THE CRISES

	Bangladesh	Phillipines	Thailand	Pakistan	Hong kong	India	Singapore	Korea	Japan	Srilanka	Taiwan	China	Indonesia
Bangladesh	0	0	0	0	0	0	0	0	0	0	0	0	0
Phillipines	0	0	1	0	1	1	1	1	1	0	1	0	1
Thailand	0	1	0	0	1	1	0	1	1	0	1	1	1
Pakistan	0	0	0	0	0	1	0	1	1	0	1	0	1
Hong kong	0	1	1	0	0	1	0	1	1	0	1	1	1
India	0	1	1	1	1	0	1	1	1	0	1	1	1
Singapore	0	1	0	0	0	1	0	1	0	0	0	0	0
Korea	0	1	1	1	1	1	1	0	1	0	1	1	1
Japan	0	1	1	1	1	1	0	1	0	0	1	1	1
Srilanka	0	0	0	0	0	0	0	0	0	0	0	0	0
Taiwan	0	1	1	1	1	1	0	1	1	0	0	1	1
China	0	0	1	0	1	1	0	1	1	0	1	0	0
Indonesia	0	1	1	1	1	1	0	1	1	0	1	0	0

DURING THE CRISES

	Bangladesh	Phillipines	Thailand	Pakistan	Hong kong	India	Singapore	Korea	Japan	Srilanka	Taiwan	China	Indonesia
Bangladesh	0	1	1	0	1	0	1	1	0	0	0	0	0
Phillipines	1	0	1	0	1	1	1	1	1	1	1	1	0
Thailand	1	1	0	0	1	1	1	1	1	1	1	1	1
Pakistan	0	0	0	0	0	1	0	0	0	1	0	0	0
Hong kong	1	1	1	0	0	1	1	1	1	1	1	1	1
India	0	1	1	1	1	0	1	1	1	1	1	1	1
Singapore	1	1	1	0	1	1	0	0	0	0	0	0	0
Korea	1	1	1	0	1	1	0	0	1	1	1	1	1
Japan	0	1	1	0	1	1	0	1	0	1	1	1	1
Srilanka	0	1	1	1	1	1	0	1	1	0	1	1	0
Taiwan	0	1	1	0	1	1	0	1	1	1	0	1	1
China	0	1	1	0	1	1	0	1	1	1	1	0	1
Indonesia	0	0	1	0	1	1	0	1	1	0	1	1	0

AFTER THE CRISES

	Bangladesh	Phillipines	Thailand	Pakistan	Hong kong	India	Singapore	Korea	Japan	Srilanka	Taiwan	China	Indonesia
Bangladesh	0	1	0	1	0	0	0	0	0	0	1	0	1
Phillipines	1	0	0	0	1	1	0	1	1	1	0	1	1
Thailand	0	0	0	0	0	0	0	0	1	0	0	1	0
Pakistan	1	0	0	0	0	1	0	1	1	0	1	1	1
Hong kong	0	1	0	0	0	1	0	1	1	1	0	1	1
India	0	1	0	1	1	0	0	1	1	1	0	1	1
Singapore	0	0	0	0	0	0	0	0	0	0	1	0	0
Korea	0	1	0	1	1	1	0	0	1	1	0	1	1
Japan	0	1	1	1	1	1	0	1	0	1	0	1	1
Srilanka	0	1	0	0	1	1	0	1	1	0	0	0	1
Taiwan	1	0	0	1	0	0	1	0	0	0	0	0	1
China	0	1	1	1	1	1	0	1	1	0	0	0	1
Indonesia	1	1	0	1	1	1	0	1	1	1	1	1	0

[0]The matrix elements are numerical values that indicate the nature of the linkages between every pair of edges in the network. The simplest elements are binary values , with a 1 standing for the occurrence of a tie from node i to node j , and a 0 for the absence of such a tie between the pair.

Table 4: Degree of Nodes

	Pre Crises	Crises period	Post Crises
Bangladesh	0	5	4
Phillipines	8	10	8
Thailand	8	11	2
Pakistan	5	2	7
Hong kong	8	11	7
India	10	11	8
Singapore	3	5	1
Korea	10	10	8
Japan	9	9	9
Srilanka	0	9	6
Taiwan	9	9	4
China	6	9	8
Indonesia	8	7	10

Table 5: Clustering Coefficient

	Pre Crises	Crises Period	Post Crises
Bangladesh	0.000	0.429	0.320
Phillipines	0.807	0.886	0.808
Thailand	0.867	0.976	0.133
Pakistan	0.488	0.111	0.591
Hong kong	0.867	0.976	0.800
India	1.000	0.938	0.873
Singapore	0.240	0.419	0.000
Korea	1.000	0.914	0.873
Japan	0.952	0.872	0.909
Srilanka	0.000	0.795	0.682
Taiwan	0.952	0.872	0.333
China	0.625	0.872	0.784
Indonesia	0.847	0.667	0.949

[0]Degree is an integer count or number of other nodes with which a given node has direct contact.

[0]The clustering coefficient measures the average probability that two neighbors of a vertex are themselves neighbors.

Table 6: Adjancency Matrix of Asian Stock Markets including US

BEFORE THE CRISES

	Bangladesh	Phillipines	Thailand	Pakistan	Hong kong	India	Singapore	Korea	Japan	Srilanka	Taiwan	China	Indonesia	Malaysia	US
Bangladesh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phillipines	0	0	1	0	1	1	1	1	1	0	1	0	1	0	1
Thailand	0	1	0	0	1	1	0	1	1	0	1	1	1	1	1
Pakistan	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0
Hong kong	0	1	1	0	0	1	0	1	1	0	1	1	1	1	1
India	0	1	1	1	1	0	1	1	1	0	1	1	1	1	1
Singapore	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1
Korea	0	1	1	1	1	1	1	0	1	0	1	1	1	1	1
Japan	0	1	1	1	1	1	0	1	0	0	1	1	1	1	1
Srilanka	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taiwan	0	1	1	1	1	1	0	1	1	0	0	1	1	1	1
China	0	0	1	0	1	1	0	1	1	0	1	0	0	0	0
Indonesia	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1
Malaysia	0	0	1	1	1	1	0	1	1	0	1	0	0	0	1
US	0	1	1	0	1	1	1	1	1	0	1		1	1	0

DURING THE CRISES

	Bangladesh	Phillipines	Thailand	Pakistan	Hong kong	India	Singapore	Korea	Japan	Srilanka	Taiwan	China	Indonesia	Malaysia	US
Bangladesh	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0
Phillipines	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1
Thailand	1	1	0	0	1	1	1	1	1	1	1	1	1	0	1
Pakistan	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1
Hong kong	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1
India	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
Singapore	1	1	1	0	1	1	0	0	0	0	0	0	0	0	1
Korea	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1
Japan	0	1	1	0	1	1	0	1	0	1	1	1	1	1	1
Srilanka	0	1	1	1	1	1	0	1	1	0	1	1	0	0	1
Taiwan	0	1	1	0	1	1	0	1	1	1	0	1	1	1	1
China	0	1	1	0	1	1	0	1	1	1	1	0	1	0	1
Indonesia	0	0	1	0	1	1	0	1	1	0	1	1	0	1	1
Malaysia	0	1	0	1	1	1	0	1	1	0	1	0	1	0	1
US	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0

AFTER THE CRISES

	Bangladesh	Phillipines	Thailand	Pakistan	Hong kong	India	Singapore	Korea	Japan	Srilanka	Taiwan	China	Indonesia	Malaysia	US
Bangladesh	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0
Phillipines	1	0	0	0	1	1	0	1	1	1	0	1	1	1	1
Thailand	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Pakistan	1	0	0	0	0	1	0	1	1	0	1	1	1	1	1
Hong kong	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1
India	0	1	0	1	1	0	0	1	1	1	0	1	1	1	1
Singapore	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Korea	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1
Japan	0	1	1	1	1	1	0	1	0	1	0	1	1	0	1
Srilanka	0	1	0	0	1	1	0	1	1	0	0	0	1	0	1
Taiwan	1	0	0	1	0	0	1	0	0	0	0	0	1	0	0
China	0	1	1	1	1	1	0	1	1	0	0	0	1	1	1
Indonesia	1	1	0	1	1	1	0	1	1	1	1	1	0	1	1
Malaysia	0	1	0	1	1	1	0	1	0	0	0	1	1	0	1
US	0	1	0	1	1	1	0	1	1	1	0	1	1	1	0

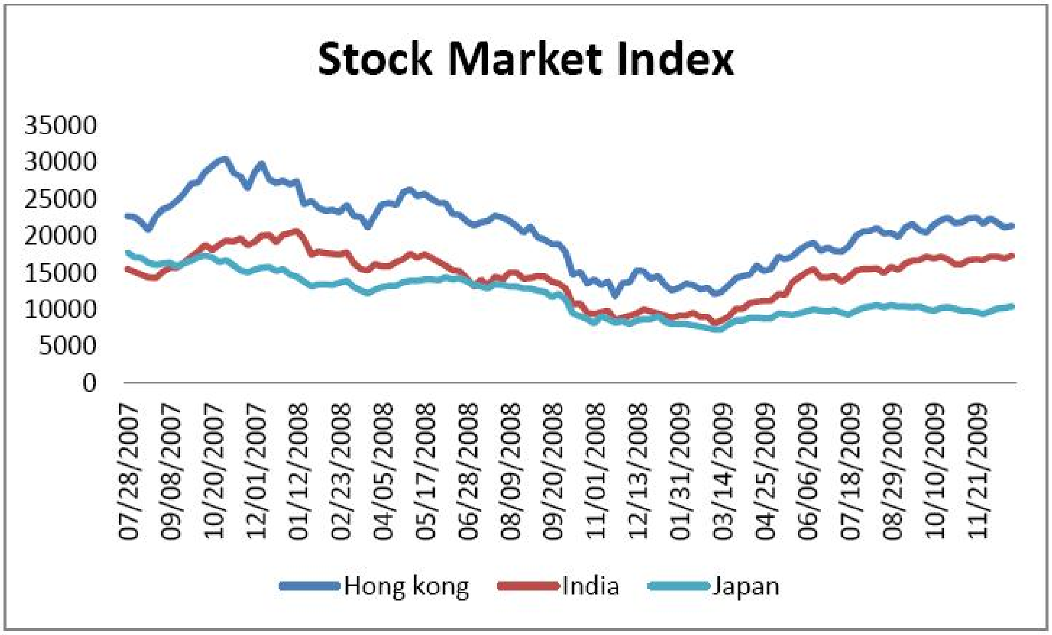

Fig. 1: V-Shape Recovery of Asian Stock Markets

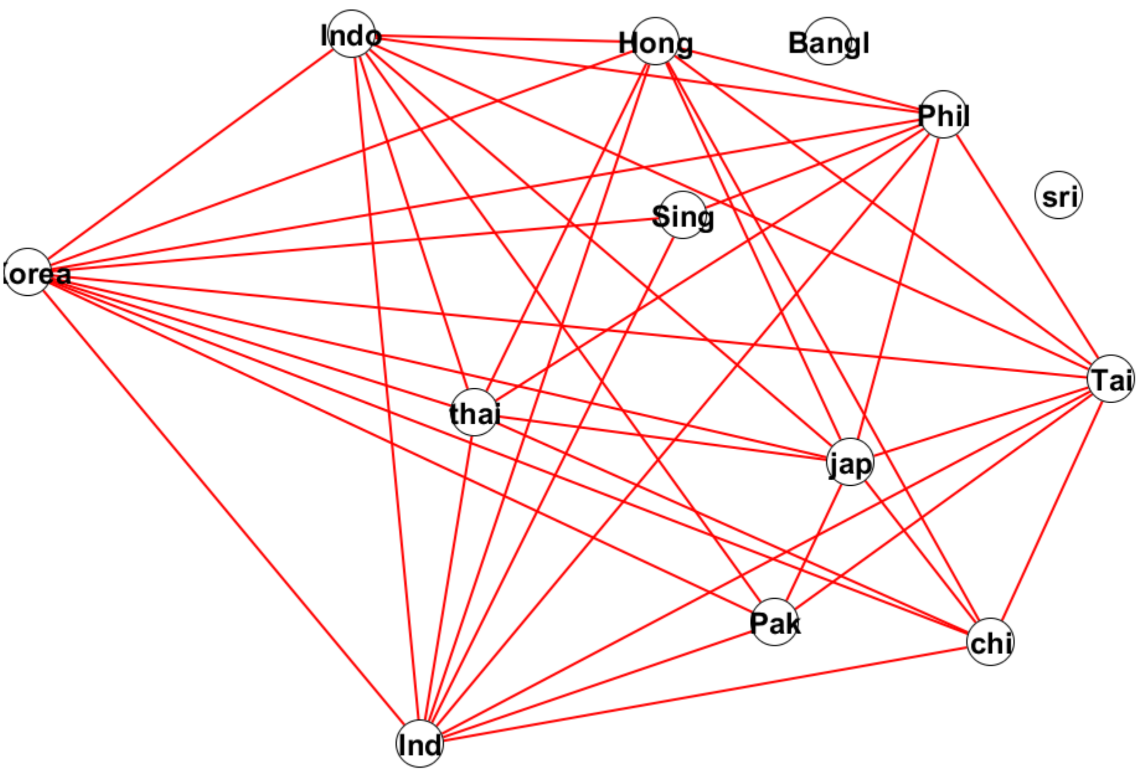

Fig. 2: Network of Asian Stock Markets in Pre-Crisis Period

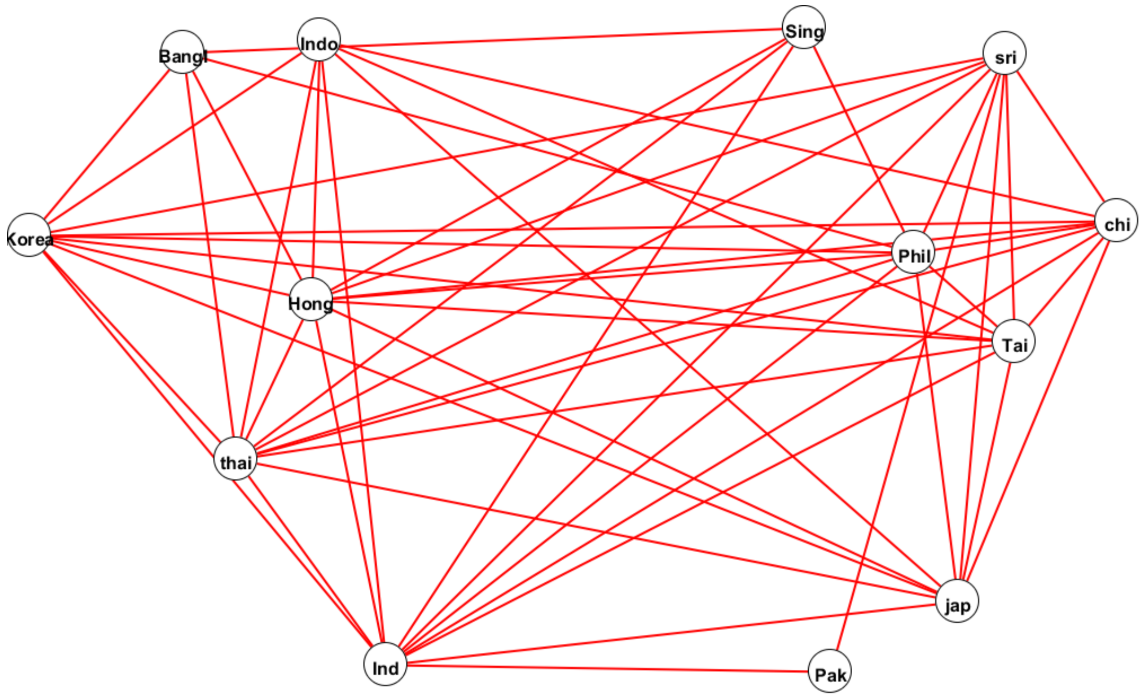

Fig. 3: Network of Asian Stock Markets in Crisis Period

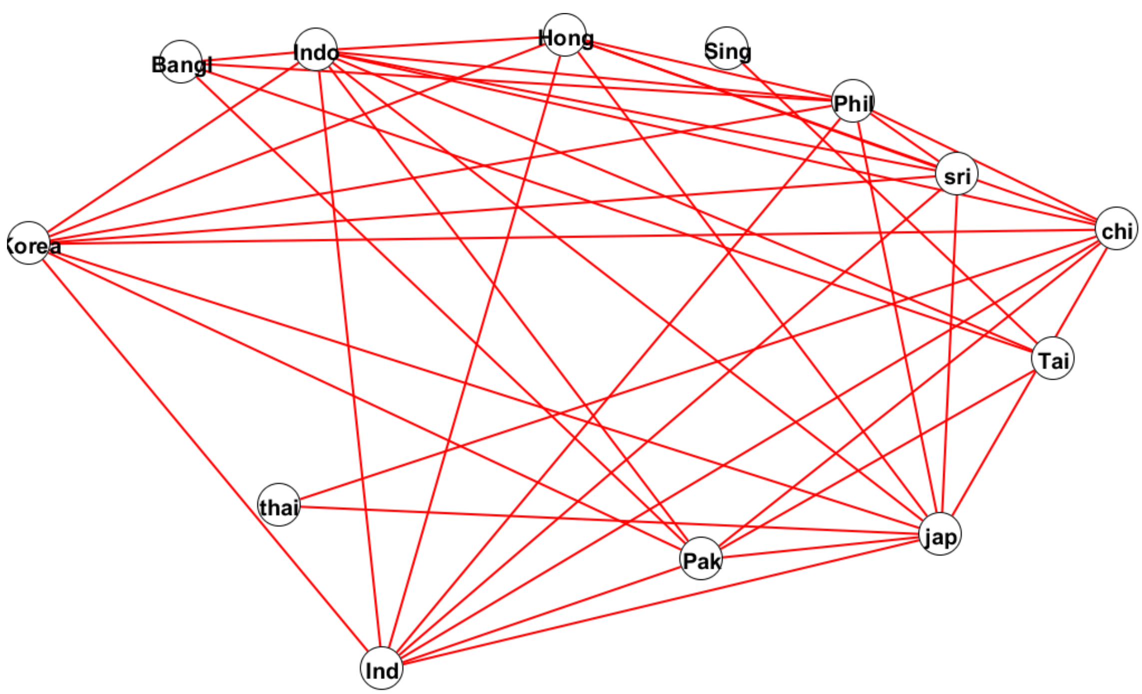

Fig. 4: Network of Asian Stock Markets in Post-Crisis Period

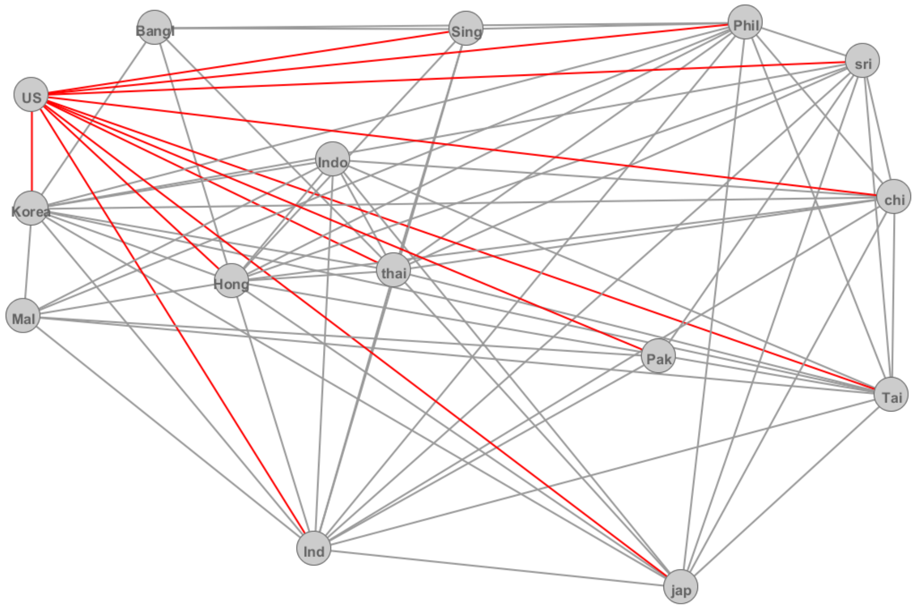

Fig. 5: US in Network of ASMs in Pre-Crisis Period

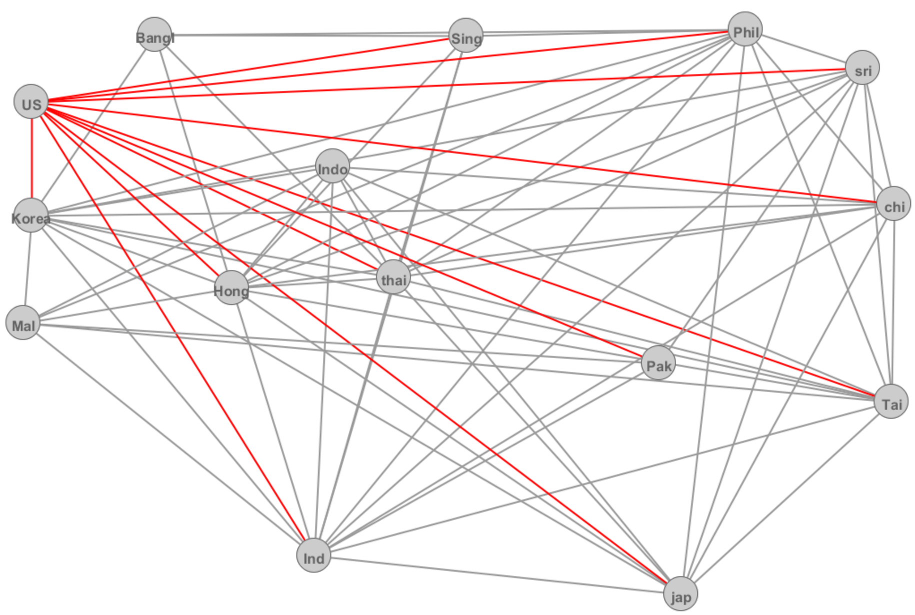

Fig. 6: US in Network of ASMs in Crisis Period

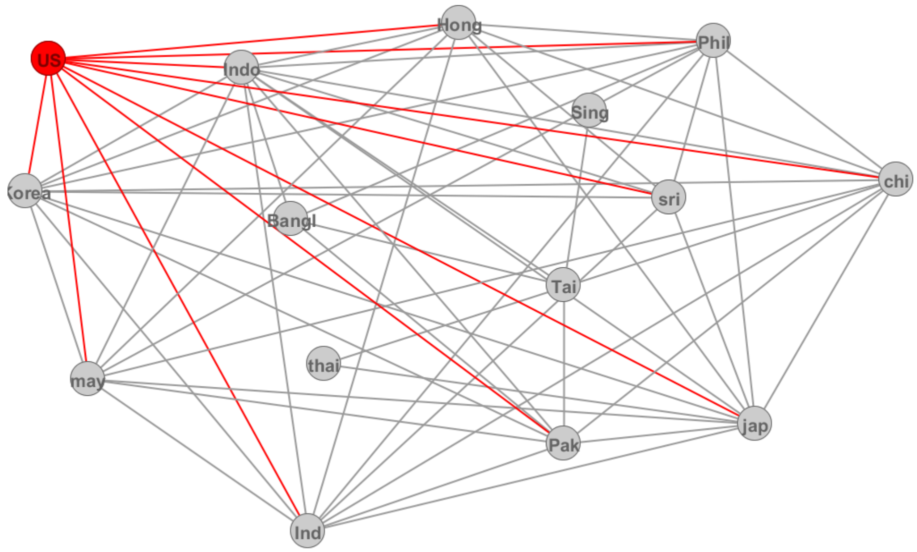

Fig. 7: US in Network of ASMs in Post-Crisis Period

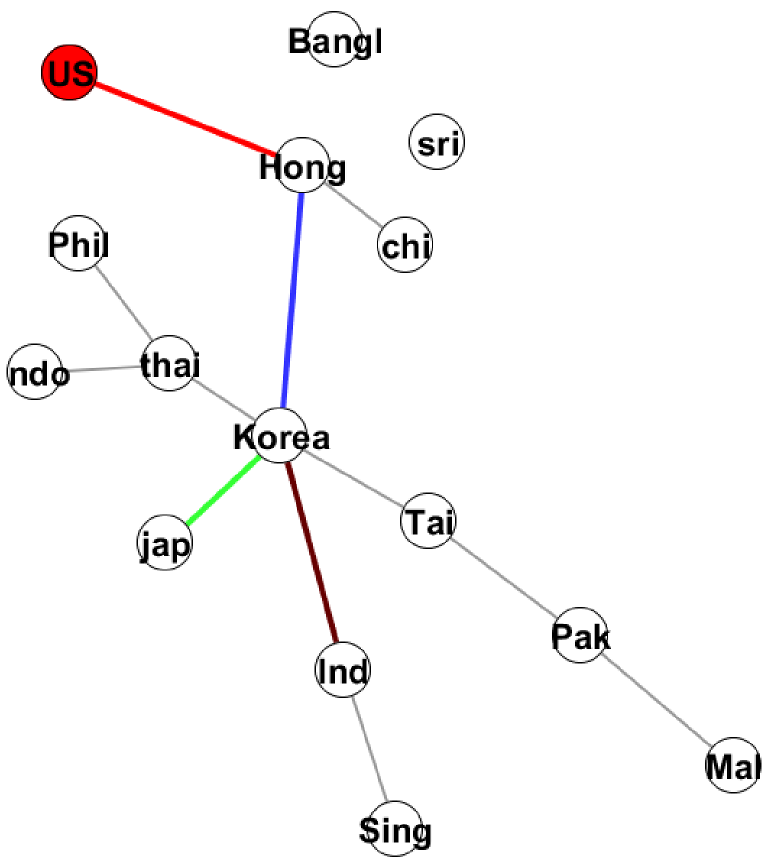

Fig. 8: Spread of Crisis from US stock market to Network of ASMs

APPENDIX

Theorem 1

A graph is a tree if and only if there is a unique simple path between every pair of vertices in the graph.

Proof

Let G be a graph such that between every pair of vertices there is a unique simple path. So G is not a tree , then there is at least one cycle in G creating two simple paths between every pair of vertices in this cycle . So G is a tree. On the other hand, suppose G is a tree and x and y are two vertices in G. Since G is connected there is a simple path P between x and y . Suppose P is another simple path between x and y . If the two paths are not the same , then let e = (v_i, v_{i+1}) be the first edge in P that is not in P as we go from x to y in the graph along the edges .Let W and W' be the set of intermediate vertices between v_i and y in P and P', respectively . If W and W' have no vertices in common, there is a cycle consisting of all the vertices in W and W' and the vertices v_i and y .If W and W have common vertices , then let w be the first common vertex as we go from vi to y along either P or P'. Then we have a cycle in G using the vertices in P between v_i and w and the vertices in P' between w and v_i. Thus in any case G has a cycle, which is a contradiction.

Theorem 2

A graph is a tree if and if every edge in it is a bridge.

Proof

Suppose e = (x,y) is any edge in a graph G. Then (x,e,y) is a path between x and y in G . If G is a tree, this is the only path between x and y , and if this path is deleted then the vertices x and y will not be connected . Thus in a tree every edge is a bridge .
On the other hand, suppose G is a graph in which every edge is a bridge .So G is connected. Suppose G is not a tree. Then there is at least one cycle C in G .Let x and y be adjacent vertices in C. Then the edge e = (x,y) cannot be a bridge in G since there is another path between x and y using the other vertices of the cycle . This contradicts the hypothesis that every edge is a bridge. Thus G is a tree.

Theorem 3

(i)A connected graph with n vertices is a tree if and only if it has n-1 edges
(ii)An acyclic graph with n vertices is a tree if and if it has n-1 edges

Proof

(i) Suppose G is a tree with n vertices. We prove by induction on n that G has n-1 edges .This is true when n = 1. Suppose it is true for all m , where 1¡m¡n . If we delete an edge e = (x,y) from G, we get two sub graphs H = (V,E) and H = (V,E), with k and k vertices , respectively , such that there is no vertex common to V and V. Since both k and k are less than n , H has k-1 edges and H has k-1 edges . So both H and H together have k+k'-2 = n -2 edges .If we combine H and Hby using the edge e, we get the graph G . So G has (n-2) + 1 =

n-1 edges.
On the other hand , let G =(V,E) be a connected graph with n vertices and n-1 edges . Suppose G is not a tree .Then there is an edge in G which is not a bridge. If we delete this edge we have a connected sub graph G = (V,E) . Continue this process till we get a connected sub graph H = (V,F) in which every edge is a bridge . So H is a tree with n vertices. So H has n-1 edges leading to a contradiction since G has n-1 edges .

(ii) If an acyclic graph with n vertices is a tree, then it has n-1 edges by (i) above. On the other hand , let G = (V,E) be an acyclic graph with n vertices and n-1 edges . Suppose G is not connected .Then there are r connected sub graphs $G_1, G_2 G_r$where $G_i = (V_i, Ei)$, the cardinality of v_i is n_i for each i and (V1 , V2 Vr) is a partition of V .Each Gi is a connected component of G .Since G is a acyclic , each Gi is acyclic and therefore a tree with ni-1 edges . Thus the total number of edges in G is $(n_1 - 1) + (n_2 - 1) + . + (n_r - 1)$ = n-r .But the number of edges in G is n-1 . Thus r=1 , which implies that G is connected and hence a tree .

Theorem 4

A spanning tree T in a graph G is a minimal spanning tree if and if every chord of the tree is a maximum weight edge in the unique fundamental cycle defined by that edge .

Proof

Let T be a minimal spanning tree in G. Suppose there is a chord e of T such that w(e) ¡ w(f) for some edge f in the cycle C(e). Then the tree T obtained by adjoining e and deleting f is indeed a spanning tree such that $w(T) = w(T) + w(e) - w(f) < w(T)$, violating the assumption that T is an MST .Thus the condition is necessary.

Let T be a spanning tree in G satisfying the given condition and let f be any edge in this tree T. Now any edge e (other than f) in the fundamental cutset D(f) is a chord of T defining the fundamental cycle C(e), and hence by the hypothesis $w(e) \geq (f)$. This inequality should hold for every e in the cutsetD(f). In other words, $w(f) \leq (e)$ for every e in D(f). This proves that T is an MST. Thus the condition is a sufficient condition.