ABSTRACT

Interesting structures of interdependence among various countries keep emerging due to economic liberalisation and globalisation of trades in financial assets, goods, and services. The interdependence and inherent non-linearity in the response of financial market players increase the risk of financial instability affecting the entire world economy. Any change, such as policy, political regime, or collapse of leading companies in the global economy may influence the economy of several other countries. The interdependence and interaction involving a large number of agents, in the continuously evolving business environment, often lead to an unpredictable emergent behaviour of the system. Agents in such systems often learn to adapt their behaviour in response to the changing environment. The systems with such networked structure of large number of adaptive agents displaying emergent macroscopic behaviour are broadly known as complex adaptive systems (CAS). These systems evolve in a distributed and self-organising manner without intervention of any central control. The global financial markets and social networks of people are two intriguing examples of such complex adaptive systems, and they play key role in the economic development of the society.

There has been profound interest in the study of complex adaptive systems, and their applications to the analysis of financial markets. The devastating impact of the recent financial crisis in the USA & Europe, and its cascading effects on the global economy highlights the need of a unified system level approach with prudent tools for analysing complex financial market system especially during out-of-equilibrium situations. Understanding the mechanism of occurrence of financial crisis and identifying the levers for effective intervention and control is crucial for sustainability of financial systems. Occasional failures are inevitable in such systems due to a large number of actors and associated non-linearity, and hence there has been a paradigm shift to design systems to have 'safe-fail' features rather than 'fail-safe' features. A unified theory of complex adaptive systems is not yet achieved, and hence apart from efforts on developing a unified theory, the researchers resort to empirical or simulation based study to get insights into their internal structure and underlying mechanisms.

The network representation of financial markets is gaining attention among research community for exploring and understanding the emergent interdependence structure as determined by the cross-correlation between the equity returns. As the structure and the evolution of networks are interdependent, studying the dynamics of networks may reveal underlying mechanisms of network growth and evolution. Most of the research works in the literature have discussed only the static snapshot of interdependence structure in the stock markets. The research on network based methodologies on capturing the dynamics of financial markets is inadequately explored. Characterising the dynamics of the stock market network is a complex problem and it needs further research. Another interesting area of network research is the social network analysis primarily used for analysing the overall social structure that emerges due to the interactions among the social actors. Network approach and social network analysis methods have potential to analyse the dynamics of financial markets that is inadequately explored. In an attempt to fill this void, we have developed network based methodologies to characterise the dynamic behaviour of global stock markets and analyse the emergent interdependence structure with an emphasis on 'detecting changes' in their interdependence structure and evolutionary patterns.

The global stock market is a good example of a complex adaptive system with rich empirical real data available for research. We have used it as a proxy for a complex system to validate the methodologies developed in this dissertation. The dissertation explores to find possible solutions to the following research issues: how to capture abnormal comovements of stock returns in the global stock market, how to identify dominant stock indices and capture the change in the interdependence structure among the stock indices, how to capture the macroscopic interdependence structure among various economic sectors and major stock markets using the microscopic interdependence structure among stocks from the world, identification of dominant economic sectors and stock markets from the emergent microscopic interdependence structure among stocks, and the sensitivity of centrality and centralisation measures on the level of decentralisation in the network structure.

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We have proposed network-based comovement indices to capture the evolutionary pattern and level of comovement of stock returns in the regional and global stock markets. Further, we have analysed these comovement indices using non-parametric statistical methods to test for any significant variation in these indices during a period of eight years from January 2002 through December 2009. We used stock market data from ten major North American, European and Asian stock markets obtained from Bloomberg for this study. The study revealed the presence of regional influences on the network dynamics. It also unearthed the emergence of synchronised global pattern in the dynamics of comovement indices around the onset of the crisis during the year 2008 confirming interdependence of the global stock markets. The findings provide empirical evidences of statistically significant drift in the mean of the comovement index and presence of non-random pattern in the evolution of the comovement indices of the stock market networks around the period of crisis.

Further, we extend the notion of actors in a social network to include abstract non-living entities such as stock indices to study their behaviour in the emergent social network of stock indices. A novel method to rank the stock indices from across the globe using the well established centrality measures is formulated in order to capture the changes in the dominance of an index with respect to other indices. Temporal evolution of the minimum spanning tree (MST) derived from the correlation network of 93 global stock indices has been analysed with real data obtained from Bloomberg for five-year period from year 2006 through 2010. It is investigated how the stock market turbulence can be detected by measuring the relative change in the ranks of the stock indices or in the network centralisation of the emergent network structure. A significant change has been detected in the evolutionary pattern pointing to some extreme event in the global stock market. The chosen period of the study happens to include the event of the collapse of Lehman Brothers in the USA, revealing interesting counter-intuitive findings that the turbulence in the stock market following that event had a structure loosening impact on the global stock market. In the post event period, the relative dominance of the US and the European stock markets over global stock markets seems to decrease as some of the regional indices appear to dominate in the respective regional stock markets.

Subsequently, we develop methods to capture the macroscopic interdependence structure among various economic sectors and major stock markets using the emergent microscopic interdependence structure among stocks from across the world. Cross-correlations between weekly returns of 2698 stocks selected from 17 major stock market indices from across the globe have been used to construct a Minimum Spanning Tree (MST) of the stocks. This MST links stocks with similar behaviour and has been considered as the emergent social structure of stocks in the stock market. Closing price data of the stocks for the thirteen year period from January 1998 through January 2011, obtained from Bloomberg, has been used in the analysis. The MST has been analysed to investigate whether geographical proximity of stock markets and economic sectors, to which the stocks belong to, influence the evolutionary behaviour of stock returns. A method is proposed to identify dominant economic sectors and stock markets from the emergent network structure using various centrality measures. The study reveals that the influence of geographical proximity dominates over the sector-specific characteristics in shaping the topological structure of stock market network. The findings demonstrate that the stocks from the European and the North American markets and those belonging to Financial, Materials, Industrials, and Consumer Discretionary economic sectors dominate in the global stock markets.

Finally, we present a theoretical analysis of the sensitivity of various centrality and centralisation measures on the level of decentralisation in the network structure. A star topology is generally used as a benchmark for comparing the level of centralisation of an empirical network. Comparing stock market network with star topology does not give us any visual clue to which generic decentralised network structure the empirical network under study closely resembles to. Therefore, analytic expressions for centrality and centralisation measures based on degree, betweenness, closeness, and eigenvector centrality are derived for network topologies with varying levels of decentralisation. Pair-wise cross-correlations between these centralisation measures and the variances in node centrality corresponding to the four centrality measures for all the types of networks have been analysed. Findings reveal that these centrality and centralisation measures are

highly sensitive to the degree of decentralisation in the network. The analytical expressions would be useful in approximating the values of these centrality and centralisation measures for similar decentralised structures.

Overall findings and contributions of the study presented in this dissertation can be summarised as follows. We have extended the concepts of social network analysis to be used for the analysis of financial markets and for identifying dominant stocks and stock indices from the global stock markets. We have also developed methods to capture changes in the network structure and detect anomalous behaviour in its evolutionary pattern indicating occurrence of some unusual or extreme event. The stock markets from different regions show their own characteristic evolutionary patterns. The study provides empirical evidence for the existence of global trend in the comovement of stock markets at the onset of financial crisis during the year 2008. Such market behaviour points to synchronisation of investors' response at the onset of financial crisis. Stock indices from European region emerge as dominant indices in the emergent network of stock indices and the network structure becomes more decentralised after the collapse of Lehman Brothers in year 2008. Stocks from Europe and the US emerge as dominant stocks and Financials, Industrials, Materials, and Consumer Discretionary emerge as dominant economic sectors. The study also reveals the dominant influence of geographical proximity over economic sectors of the stocks in determining the emergent interdependence structure. Further, we did some analytical study on the sensitivity of various centrality and centralisation measures with an aim at understanding the level of decentralisation in the global stock market network structure. The study would facilitate further research on evaluating impact of policy decisions on financial markets, detecting anomalous behaviour of the stock market and developing early warning systems for financial crises. The methodologies developed in this dissertation are generic and can be used to analyse the dynamic behaviour of other complex systems as well that can be modeled as networks.