ABSTRACT
OF THESIS ENTITLED
STATISTICAL MECHANICS OF COMPLEX
SYSTEMS: CORRELATION, NETWORKS
AND MULTIFRACTALITY IN FINANCIAL
TIME SERIES

SUBMITTED TO THE UNIVERSITY OF DELHI
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

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Abstract

The financial markets are complex systems in which various approaches and concepts from the world of physics have been used to investigate the deterministic mechanisms in trends of prices in financial markets. The crisis (downs) and booms (ups) in the financial markets are some of the most important phenomena that have focussed our attention towards the study of financial time series. The study of financial crisis and finding the organizational changes of clusters during a financial crisis is useful and interesting as similar changes may occur during other crisis, leading to innovative ways of prevention and control. Thus in the presented thesis, we apply three methods namely random matrix theory (RMT), complex network analysis, and multifractal analysis to the financial time series.

In the Random matrix theory (RMT) approach we investigate the cross-correlation in 20 global financial indices. The results are compared before and during the financial crisis of 2008. We find that the RMT analysis of correlation matrices of global financial indices provides information about the formation of cluster in financial indices. The largest eigenvalue deviating from the RMT prediction represents the collective information (hidden in the empirical correlation matrix) about the correlation between different financial indices and depends on the market conditions. We find that first few largest eigenvalues deviate significantly from the RMT prediction and these deviation changes during the financial crisis of 2008. We find that components of eigenvector corresponding to the second largest eigenvalue are associated with the formation of clusters (organization) in global financial markets in the positive and negative directions. The components of these two clusters switch in opposite directions during the financial crisis of 2008. We analyze the distribution of eigenvector components corresponding to the largest eigenvalue of empirical correlation matrix of global financial indices.
We find that all components of eigenvector are distributed in the positive direction only. This shows a deviation from the prediction of RMT (for the random correlation matrix the components are distributed in both positive and negative directions). Next we compute the inverse participation ratio (IPR) which allows us to compute the inverse of the number of eigenvector components that contribute significantly to each eigenvector. The value of IPR for the empirical correlation matrix before (during) the crisis is found to be 0.056 (0.055) which is close to 0.05(1/20), the value we would expect when all components contribute significantly. For random correlation matrix the value of IPR is found to be 0.193. Thus we find that the empirical correlation matrix contains important information about the interactions (in terms of price changes) between the global financial indices.

Complex network technique is another powerful tool that helps us to find a clearer cluster structure in global financial indices. The correlation threshold and hierarchical clustering methods are important techniques to construct and analyze the complex network which enable us to study their network properties. The changes in the structure of network are used to analyze deviations in the characteristics of network. Thus to obtain a clearer structure of interaction between global financial indices, we construct financial correlation networks of indices at different thresholds (in the range 0 to 0.9) before and during the financial crisis of 2008. The Fruchterman-Reingold layout is used to find clusters in all these networks. The interesting feature of reorganization of financial indices is found during the crisis of 2008 in the global financial networks. At a threshold of 0.6, before the crisis, financial indices corresponding to the Americas, Europe, and Asia-Pacific form separate clusters. On the other hand, during the crisis at the same threshold, the American and European indices combine together to form a strongly linked cluster while the Asia-Pacific indices form a separate weakly
linked cluster. If the value of the threshold is further increased to 0.9 then the European indices (France, Germany, and the United Kingdom) are found to be the most tightly linked indices. Using the hierarchical method for drawing the minimum spanning tree we find that the structure of the MST of financial indices is more star like before the crisis and changes to become more chainlike during the crisis. To support our findings the average linkage hierarchical clustering algorithm is used to find a clearer cluster structure in the network of financial indices. The cophenetic correlation coefficients are found to increase significantly, which indicate that the hierarchy increases during the financial crisis. These results show that there is substantial change in the structure of organization in financial indices during a financial crisis.

More recently multifractal theory has been applied to the field of finance. We extend this study by detecting the long range correlations and multifractality in financial time series. The Hurst exponents are estimated for BSE, NSE, and S&P500 indices over time windows of 25 days, for most of the time Hurst exponents are found to be greater than 0.5 for BSE and NSE indices. This shows that BSE and NSE indices are not random and indicate the persistence behavior. Hurst exponents tends to fluctuate around 0.5 for the S&P 500 index. This analysis indicate that the Indian financial market (BSE and NSE index) is an emerging market while the US market (S&P 500) is a mature market. We investigate the effect of 9/11 crash in financial markets, a change in the value of Hurst exponent is observed near the 9/11 crash. A large dip in the value of Hurst exponent for BSE index is observed as compare to the S&P 500 index. We also investigate the effect of global financial crisis of 2008 on Hurst exponents for 20 global financial indices. Hurst exponents for most of the financial indices increases during the period of crisis as compared to the period before crisis. We study multifractal properties in financial time series of the India (BSE and NSE indices) and US (S&P 500 index).
On the basis of the non-linearity of multifractal scaling exponents and singularity spectrum, we prove that the time series of India and US both exhibit multifractality. Further the multifractality is confirmed in 20 global financial time series. To investigate the source of multifractality, we shuffle these financial time series. We generate surrogate series from original financial series to quantify the influence of fat-tail distribution. We find that the BSE, NSE, and US S&P 500 indices exhibit multifractality due to the contribution of broad probability density function and long-range correlation. The strength of multifractality, Hurst exponent, and volatility of the BSE and S&P 500 index over time windows of two years, are compared from 1997 to 2007. On average we find that the higher value of Hurst exponent leads to higher average volatility and higher average strength of multifractality. We also compare multifractal degrees of 20 global financial times series before and during the financial crisis of 2008.

Finally, we fit the Binomial multifractal model (BMFM) to these financial markets. By comparing multifractal results for the binomial multifractal series with those for financial time series, we find that financial markets have less multifractal strength as compared to the Binomial multifractal series.