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Network analysis of a financial market based on genuine correlation and threshold method

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ABSTRACT

A financial market is an example of an adaptive complex network consisting of many interacting units. This network reflects market's behavior. In this paper, we use Random Matrix Theory (RMT) notion for specifying the largest eigenvector of correlation matrix as the market mode of stock network. For a better risk management, we clean the correlation matrix by removing the market mode from data and then construct this matrix based on the residuals. We show that this technique has an important effect on correlation coefficient distribution by applying it for Dow Jones Industrial Average (DJIA). To study the topological structure of a network we apply the removing market mode technique and the threshold method to Tehran Stock Exchange (TSE) as an example. We show that this network follows a power-law model in certain intervals. We also show the behavior of clustering coefficients and component numbers of this network for different thresholds. These outputs are useful for both theoretical and practical purposes such as asset allocation and risk management.

1. Introduction

In real world, a large number of systems can be described by complex networks [1,2]. After innovative works on complex networks [3,4], extensive empirical research has been carried out on topology characteristics of actual networks in different domains. All of these networks have both small-world and scale-free topological properties [2–9]. Based on market efficiency theory, there is no systemic way to exploit opportunities in the stock market superior gains. Operational efficiency is based on rationality of investors, incompleteness of information and heterogeneity of interpretation and decision rules. These differences have led to consider the stock exchange as a complex adaptive system to understand its behavior [10–12].

In essence, a financial market can be represented as a network where nodes represent financial entities such as stocks and the edges connecting them represent the correlations between their returns [13–18]. Mantegna was the first [13] who constructed networks of DJIA (Dow Jones Industrial Average) and S&P 500 (Standard and Poors 500) indexes based on stock price correlations. Onnela et al. [15] constructed the asset graph NYSE stocks (New York stock exchange) and studied its different topological properties. Tumminello et al. [16,17] investigated the planar maximally filtered graphs of the 300 most capitalized stocks of NYSE and its topological properties. Boginski et al. [18] constructed a stock market graph based on daily fluctuation of 6546 financial instruments in the US stock markets and found some of their properties. Wei-Qiang Huang et al. [9] investigated the topological properties of Chinese stock market. Several other studies on network topology of other emerging and mature markets have been carried out [19–21]. The study on such topological properties can help to understand correlation patterns among stocks. Thus it can be a guide for risk management.

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In the field of Econophysics, there is an interest for studying the correlation matrices. many methods were proposed in order to investigate cross-correlations between either pairs of simultaneously recorded time series [22,23] or among a large number of them [24,25]. Random matrix theory is one of these methods [26–30]. RMT was developed by many researchers [29–37] in order to explain the statistics of the energy levels of complex quantum systems [27,38]. Recently, it has also been applied to studies of economic and financial data. Allowing us to compute the effect of uncertainty in the estimation of the correlation matrix makes RMT useful in financial applications. Therefore, it can be applied very effectively in portfolio management [31–36]. It is pointed that originally RMT was introduced in order to zero-lag cross-correlations in collective modes of empirical time series. however, recently, besides zero-lag cross-correlations, the time-lag RMT (TLRMT) was applied in finance and other disciplines [39,40].

RMT was introduced to sort out genuine correlations among stocks from spurious ones [36,41,42]. In each correlation matrix, the largest eigenvalue, develops an energy gap that separates it from the other eigenvalues. This specific eigenvalue is associated with a strongly delocalized eigenvector and is related to a collective evolution of a large group of stocks that usually determine the evolution of market global index and we call this eigenvector the market mode. From this perspective, the magnitude of the largest eigenvalue reflects how collective is the evolution of an analyzed market and it is used as an indicator for increase in cross-correlation of financial markets. Podobnik et al. [39] found for the members of S&P 500 index that the largest singular value of cross-correlation matrix versus time exhibits pronounced peaks in times of crisis. Also, some other researchers [43,44] by analyzing different markets found that there are peaks in times of market shocks and recessions for the largest eigenvalues of the asset correlation matrices.

In this paper, according to trading data of TSE as an emerging market [45] and DJIA as a mature one, we use Random Matrix Approach for removing the market mode from correlation matrices. Because of cleaning the correlation matrix from invaluable information, this technique is useful for a better risk management. In the next section, we construct a corresponding stock correlation network with a correlation threshold method. For showing the importance of our proposed technique, we tested this for DJIA index and found an important change in the mean of correlation coefficient distribution with respect to the situation where we have market mode. Then, we analyze the topological properties of this network. Different from other network construction arithmetic, the correlation threshold method is suitable for studying relationships between network characteristics and correlation threshold [9]. The organization of the paper is as follows. In Section 2, we describe how to construct the network. In Section 3, we present our data set in detail and the empirical results. Finally, in Section 4, we draw out our conclusions.

2. Cross-correlation matrix

In order to quantify correlations, we calculate the price change (return) of stocks $i = 1, \ldots, N$ over a time scale Δt

$$G_i(t) = \ln S_i(t) - \ln S_i(t - \Delta t), \tag{1}$$

where $S_i(t)$ denotes the price of stocks i at time t. we define a normalized return in order to standardize the different stock volatilities.

$$g_i(t) = \frac{G_i(t) - \langle G_i \rangle}{\sigma_i}, \tag{2}$$

where $\sigma_i = \sqrt{\langle G_i^2 \rangle - \langle G_i \rangle^2}$ is the standard deviation of G_i and $\langle\rangle$ denotes a time average over the period studied. Then, We compute the equal-time cross-correlation matrix C with elements [27,38]

$$C_{ij} = \langle g_i(t) g_j(t) \rangle. \tag{3}$$

The elements C_{ij} are restricted to the interval $[-1, 1]$, where $C_{ij} = 1$ defines perfect correlation, and $C_{ij} = -1$ corresponding to perfect anti-correlation. $C_{ij} = 0$ corresponds to uncorrelated pairs of stocks. Also, C is a symmetric matrix where $C_{ij} = C_{ji}$ [27,28].

We analyze Tehran Stock Exchange database that covers all transactions of securities of Tehran Stock Exchange. We extract from this database time series of 325 stock prices of Tehran Stock market, on the starting date April 1, 2005. We analyze daily change of this database over a period of 1291 consecutive trading days in 2005–2010.

3. Removing market effect from cross-correlation matrix

An important area of risk management is the estimation of correlations between the price movements of different assets in portfolios. So, studying the correlation matrices is an important topic of risk management. Applying RMT methods on correlation matrices shows that most of the eigenvalues of correlation matrices agree with RMT predictions, suggesting a considerable degree of randomness in the measured cross-correlations [27,28]. So, there is no information in this part. Also, as stated before, Application of RMT in the investigation of financial correlation matrices leads to the immediate observation that the largest eigenvalue is more greater than the other eigenvalues (in this research the largest eigenvalue of TSE correlation matrix is about 2 times greater than the previous largest eigenvalue and 65 times greater than the smallest eigenvalue) and based on Principle Component Analysis (PCA), it represents the maximum variance of the system [27–34].