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A method for detection of abrupt changes in the financial market combining wavelet decomposition and correlation graphs

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ABSTRACT

The objective of this work is to propose a new methodology to detect the imminence of abrupt changes in the stock market by combining a numerical indicator based on the wavelet decomposition technique with a measure of the interdependency of the markets using graph theory. While the indicator based on wavelet decomposition is based on a single time series, an approach based on network representation can provide information on the interdependency of the various markets. More specifically, the stock market indices are associated with nodes of a network and the correlation between pairs of nodes with links. Results from the theory of graphs can then be used to indicate numerically the connectivity of this network. Experimentations with a variety of financial time series shows that the connectivity varies as trends of the financial time series varies. Combining the indicator based on the wavelet decomposition with the proposed measure of the connectivity of the network, it was possible to refine the authors previous results in terms of detecting abrupt changes in the stock market. In order to illustrate the methodology a case study involving twelve stock market indices was presented.

1. Introduction

The financial crisis of 2008 has raised issues such as contagion and herding effects. For instance, the recent debt crisis in Greece provoked a significant impact on other European nations, showing that the financial systems should be viewed as network structures. The idea in this work is to exploit some known results on graph theory to model networks and use them to improve a method proposed by the authors in a previous article, in order to provide more accurate indication of occurrence of abrupt changes in the stock market. In the graph structure adopted here, the vertices represent financial agents, while the links are related to the correlations of their price history.

The Graph Theory has been used in a variety of fields to represent complex networks, such as those in the fields of biology and ecology [1,2]. For instance, Haldane [3] notes that some simple ecosystems such savannas and rainforests could be quite robust to attacks, while complex systems such as tropical forests could exhibit fragilities against plagues. In the same line, Haldane [3] points out that in financial systems, complexity does not mean robustness and the 2008 crisis has shown itself to be neither self-regulating nor self-repairing. In a later work Haldane and May [4] concluded that the topology of a financial network has fundamental implications on the dynamics of its systemic risk.

Onnela et al. [5a,6] conjectured, by applying graph theory to the study of financial systems, that it is possible estimate the information content of market networks. In the case of Black Monday of 1987, Onnela et al. [5b] observed that the normalized tree length decreased during the crash in the stock market (trees are graphs with a special structure). It is possible find others

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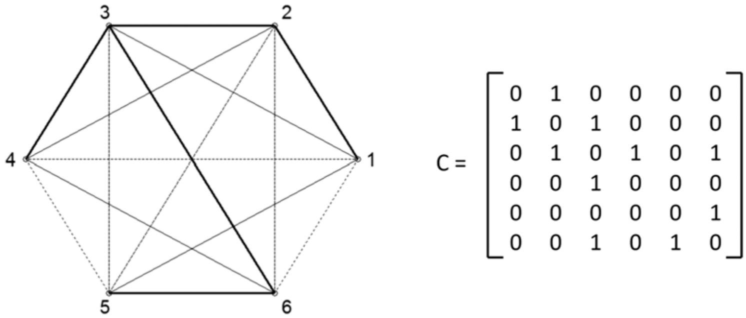

Fig. 1. An undirected graph and its adjacency matrix.

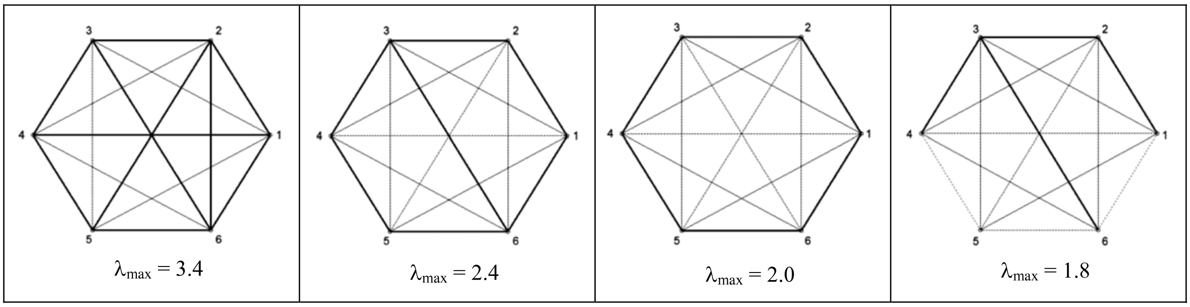

Fig. 2. Illustration of the value of the λ_{max} as a measure of the multiplicity of links. One can note that λ_{max} decreases as links are eliminated, reducing the connectivity of the network.

works following the same subject on networks in literature such as Allen and Gale [7], Watts [8], Stumpf and Wiuf [9] and Vitali et al. [10].

The graph theory has also been used to characterize price returns in stock portfolios, such as in Ref. [11]. They present an important example related to the terrorist attacks of September 11th, 2001, when the network structure was severely affected, leading to a liquidity crisis. In some cases, a node in network competes with other nodes, the full system can even become unstable [12]. The robustness of a networked system against attacks can also be studied using graph theory. In Ref. [13] random and intentional attacks are considered. Nier et al. [14] investigated how systemic risk is affected by the structure of the financial system. Wang et al. [15] developed a modified time lag random theory in order to quantify the time-lag cross-correlations among multiple time series. They obtained short-range cross-correlations between returns, and long-range cross-correlations between their magnitudes to the daily data for 48 financial indices. Podobnik et al. [16] reported large peaks in singular eigenvalues during market shocks and economic crises.

On the other hand, several articles dealing with crashes in the stock market point out that high frequency components are usually observed in the quotation data prior to their occurrence [17–20,21a,b,22–24]. These high frequency components represent fast changes of prices when the market is stressed. One approach to quantify the relevance of these high frequency components is to build an index based on a wavelet [25,26].

In this work, the information derived from the application of the graph theory to financial networks is used to improve the detection accuracy of the wavelet based index proposed previously by the authors' wavelet [25,26].

2. Networks and graph theory

This section is devoted to the review of some known facts of Graph Theory. A graph $G(S, L)$ is defined by a set S of nodes, $S = \{n_1, \ldots, n_N\}$ and a set L of links. Each link is an ordered pair of nodes, i.e. (n_i, n_j) represents a link between n_i and n_j [12]. When no possibility of confusion exists, a graph is denoted simply G. In order to represent a graph in a convenient way, the concept of adjacency matrix C is introduced. The entry c_{ij} of C is set to 1 if a link exists from n_i to n_j. Otherwise $c_{ij} = 0$. In the present work, the concept of correlation is used to represent links. Therefore $c_{ij} = c_{ji}$ and C is symmetric. Thus, the graph is of undirected type. Fig. 1 shows an example graph and its corresponding adjacency matrix. Solid lines indicate that the link is present ($c_{ij} = 1$), while light dashed lines represent the absence of a link.

Now, it is known that if G is an undirected graph, then the eigenvalues of its adjacency matrix C are real and the maximum eigenvalue λ_{max} is non-negative. Moreover, the modules of all other eigenvalues do not exceed λ_{max}. If H is a sub-graph of G, i.e., $H(S', L')$ is such that $S' \subset S$ and $L' \subset L$, then

$$\lambda_{max}(C') \leq \lambda_{max}(C) \quad (1)$$