A SIMILARITY MEASURE OF MULTIVARIATE TIME SERIES IN STOCKS NETWORK ANALYSIS

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To my beloved family, for your love and support.

To my friends, for your wits, intelligence and guidance in life.

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ABSTRACT

Correlation-based network as a model for financial markets, especially stock market, is a complex system has received much attention. There have been a lot of studies which deals with stocks network analysis, where each stock is represented by a univariate time series of its closing price, and then the similarity between two stocks are quantified by using Pearson correlation coefficient (PCC) on the logarithmic returns. However, in daily stock market activity, stock is represented by a multivariate time series during its opening, highest, lowest, and closing prices. The solely used of the information from closing price may cause the loss of information from other prices. In this thesis, all four prices are considered. The notion of multivariate time series similarity among stocks are developed. The use of Escoufier vector correlation (EVC), a multivariate generalization of PCC, is proposed to measure the similarity between stocks. Then the EVC coefficients are used to construct the stocks network in multivariate setting based on minimal spanning tree (MST). In the case study on BURSA MALAYSIA, the topological properties of stocks in EVC-based MST and in PCC-based MST are different. The total path lengths among stocks in the economic sector according to EVC-based MST is generally smaller than according to PCC-based MST. It means that with the approach of EVC-based MST, the stocks are strongly connected with other stocks in the same sector. Moreover, EVC is proposed to define the similarity between economic sectors, where each sector is represented by a multivariate time series of p components and each component is a univariate time series of stock's closing price. To the best of our knowledge, there is no previous studies which deals with the similarity between economic sectors using this approach. The methodology for economic sectors network analysis is formulated in this thesis. The current practice of using Kruskal's or Prim's algorithm is to obtain MST, and then sub-dominant ultrametric (SDU) from the MST. It will consume a lot of time when the number of stocks is large. Therefore to solve this problem, an efficient algorithm is developed based on fuzzy relation approach. A comparison study based on the empirical and simulated data shows that the proposed algorithm is faster. The proposed algorithm provides not only MST and SDU, but also the forest of all MSTs.

ABSTRAK

Jaringan berdasarkan korelasi sebagai sebuah model pasaran kewangan, khususnya pasaran saham, ialah suatu sistem yang kompleks telah mendapat perhatian. Banyak kajian dijalankan berkenaan analisis jaringan saham, dengan setiap saham diwakili oleh siri masa univariat bagi harga penutupnya, dan seterusnya persamaan antara dua saham dikuantifikasikan dengan mengguna pekali korelasi Pearson (PCC) pada pulangan logaritma tersebut. Walau bagaimanapun, dalam aktiviti pasaran saham harian, saham diwakili oleh siri masa multivariat semasa harga pembukaan, tertinggi, terendah, dan penutupnya. Dengan menggunakan maklumat daripada harga penutup sahaja boleh menyebabkan kehilangan maklumat daripada harga-harga lain. Dalam tesis ini, kesemua empat harga dipertimbangkan. Persamaan siri masa multivariat dalam kalangan unit saham dibangunkan. Penggunaan korelasi vektor Escoufier (EVC), iaitu satu generalisasi multivariat bagi PCC, diusulkan untuk mengukur persamaan antara saham. Seterusnya, korelasi EVC digunakan untuk membina jaringan saham dalam latar multivariat berdasarkan pokok perentangan minimum (MST). Dalam kajian kes terhadap BURSA MALAYSIA, sifat topologi saham dalam MST berdasarkan EVC dan MST berdasarkan PCC adalah berbeza. Jumlah panjang laluan kalangan saham dalam sektor ekonomi menurut MST berdasarkan EVC pada umumnya lebih kecil daripada MST berdasarkan PCC. Ini bermakna dengan pendekatan MST berdasarkan EVC, sahamnya amat kuat terhubung dengan saham-saham lain dalam sektor yang sama. Selain itu, EVC juga diusulkan untuk mendefinisikan persamaan antara sektor ekonomi, dengan setiap sektor diwakili oleh siri masa multivariat bagi komponen p dan setiap komponen ialah suatu siri masa univariat bagi harga penutup saham tersebut. Sepanjang pengetahuan kami, tiada kajian terdahulu yang memberi fokus kepada persamaan antara sektor ekonomi menggunakan pendekatan ini. Metodologi analisis jaringan bagi sektor ekonomi diformulasikan di dalam tesis ini. Amalan terkini yang menggunakan algoritma Kruskal atau Prim adalah perlu untuk memperoleh MST, dan kemudian ultrametrik subdominan (SDU) daripada MST. Ini akan memakan masa apabila bilangan saham tersebut besar. Oleh itu untuk menyelesaikan masalah ini, satu algoritma yang cekap dibangunkan berdasarkan pendekatan hubungan kabur. Kajian perbandingan berdasarkan data empirikal dan simulasi menunjukkan bahawa algoritma yang diusulkan lebih laju. Algoritma yang diusulkan menyediakan bukan hanya MST dan SDU, tetepi juga *forest* bagi semua MST.

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CHAPTER 1

INTRODUCTION

The aim of this chapter is to introduce the significance of this research. In Section 1.1, the background of the problem is discussed followed by the problem statement in Section 1.2. After that, the objectives of the study are presented in Section 1.3. In Section 1.4, the scope of the study is presented. The organization of the thesis is delivered in Section 1.5. Finally, the research framework in Section 1.6 closed this chapter.

1.1 Background of the Problem

The existence of interrelationships among stocks is a well-known fact. This phenomenon as can be seen from the stock price of a company is not only influenced by company fundamental itself but also the news released from the other listed companies. Meanwhile, the economic factors presented in financial markets drive the prices of several stocks. Stocks are highly transmitting behavior or information with the stocks in the same economic sector. Understanding the interrelationships among stocks and assessing the relative importance of stocks are essential in asset allocation, portfolio selection and risk management. The interrelationships can be expressed by measuring the similarities among the stocks.

The similarity between stocks is customarily quantified by using Pearson correlation coefficient (PCC) on the time series of logarithmic closing price returns. For studying the correlations of stocks, the analysis based on network model has been proposed by Mantegna (1999). The correlation structure among stocks summarized in a symmetric matrix is conceptualized as a network. A network is defined by a set of nodes connected by a set of edges; nodes represent the stocks and edges represent the interrelationships among stocks. The network is usually large with n stocks are connected by $n(n-1)/2$ edges. Since the stocks network is complex and difficult to analyze, Mantegna (1999) introduced a filtering process based on minimal spanning tree (MST) to extract the most important information contained therein and provides a simple representation of the network.

The MST method provides a simple way to study the correlations of stocks. The topological structure of stocks generated by MST is useful for studying the topological properties such as the relative importance of each stock in the investigated portfolio. It is useful for recognizing the specific characteristic of stocks with their relative positions in the network. The previous studies have shown that the individual stocks tend to gather with the stocks in the same economic sector. In the current practice of stocks network analysis, sub-dominant ultrametric (SDU) is obtained from MST and then presented in the form of an indexed hierarchical tree (HT). MST is used to study the topological properties of stocks and the corresponding SDU to understand the taxonomic structure of stocks. The important roles of MST and SDU can be found in many studies of stock market, currency market, commodity market, and automotive industry. The studies showed that the MST provides meaningful economic explanation. Most of previous studies of stocks network analysis are focused on the United States (US) market, such as New York Stock Exchange (NYSE).

According to the business activities of companies in the market, stocks are classified into specific economic sectors. Therefore, each economic sector is composed by a number of homogenous stocks. Generally, the numbers of stocks in two different economic sectors are not necessary the same. Understanding the topological properties of economic sectors is as important as understanding the topological properties of stocks. In order to construct the economic sectors network, the similarities between economic sectors are quantified. A few studies work on the economic sectors network analysis. In the existing studies, the similarity between economic sectors is defined as PCC between the logarithmic returns of economic sector indices and then with the analysis based on MST.

In current practice, there are four steps for conducting stocks network analysis. The first step is to define the similarities between stocks considering their corresponding time series of prices. In the existing studies, each stock is typically represented by a univariate time series of its closing price. Then, the similarity between stocks is quantified by PCC between time series of logarithmic closing price returns. The second step is to transform the correlation coefficient matrix into distance matrix. The third step is to analyze the corresponding network based on MST method and then followed by constructing the SDU from MST in the last step.

In terms of computation, in the literature, there are two algorithms commonly applied to construct the MST, namely Kruskal's algorithm and Prim's algorithm. These algorithms are directly applied on the distance matrix to obtain the MST and then the SDU from the MST. The Kruskal's algorithm is mathematically appealing and simple. Based on the frequency of algorithms applied in the literature, it is clear that researchers prefer to use Kruskal's algorithm than Prim's algorithm. This maybe because of the former is easier to formulate than the latter. The search for efficient ways to construct the MST and SDU is one of the most important problems in the modern financial industry. This study proposes an efficient algorithm.

1.2 Statement of the Problem

In the existing studies, PCC is customarily used to calculate the similarity between stocks. The current stocks network analysis is based on the PCCs between the logarithmic closing price returns. The use of only information from closing price in the analysis might cause losing of information from other variables in the system.

This is because, in daily stock market activity, the price information for each stock is recorded in opening, highest, lowest, and closing prices. Thus, stock is a multivariate time series of those four prices and not a univariate time series of closing price only. The use of those four prices provides more information than the information from closing price only. It could help to understand the market better. In order to have a comprehensive stocks network analysis, we have to take into account the information of all four prices. To the best of our knowledge, so far, there is no study attempt to construct such stocks network.

Although there are a lot of studies in stocks network analysis, a few studies in the economic sectors network analysis have been conducted. As the importance of analyzing the topological properties of stocks, the topological properties of economic sectors are crucial for investment activities. If each stock is represented by a univariate time series of its closing price, then each economic sector can be considered as a multivariate time series of several closing prices each of which represents a stock in that sector. In practice, the numbers of stocks in two different economic sectors are not necessary the same. Based on this idea, the similarity between economic sectors is the similarity between two multivariate time series which might be of different dimensions. To the best of our knowledge, there is no study dealing with the notion of economic sectors network in multivariate setting.

In order to analyze the topological properties of stocks, the MST issued from Kruskal’s algorithm or Prim’s algorithm is used. The algorithm is directly applied on the distance matrix to obtain the MST. Therefore, the size of the distance matrix or, equivalently, the size of the correlation matrix influences the performance of the algorithm in constructing the MST. The performance of the algorithm becomes slower and slower when the number of stocks gets larger and larger. This is one of the fundamental problems in stocks network analysis as the number of stocks that involved in the analysis is always large. In this thesis, a faster algorithm is presented.

1.3 Objectives of the Study

The objectives of this research are:

i. To define the similarity between multivariate time series of stocks' opening, highest, lowest, and closing prices by using Escoufier's operator.

ii. To develop a filtering process for stocks network analysis in multivariate setting.

iii. To formulate a methodology for economic sectors network analysis.

iv. To develop an efficient algorithm having faster computational running time than Kruskal's algorithm and Prim's algorithm.

1.4 Scope of the Study

The scope of this research can be divided into three aspects.

1. Theoretical aspect. This aspect covers:

   i. The use of Escoufier's operator to define Escoufier vector correlation (EVC) that can be used to quantify the similarity between two multivariate time series of different dimensions. We propose the use of EVC to measure the similarity between stocks, each of which is represented by a multivariate time series of its opening, highest, lowest, and closing prices. Then, construct stocks network in multivariate setting based on MST. We also introduce the use of EVC in economic sectors network analysis when each stock is represented by a univariate time series of its closing price.

   ii. Prove that EVC is a multivariate generalization of PCC.

   iii. Develop an efficient algorithm based on the combination of fuzzy relation theory and the properties of forest of all MSTs.

2. Computational aspect.

   Empirical and simulated networks are conducted to show that, in terms of the running time, the proposed algorithm has higher computational efficiency than Kruskal's algorithm and Prim's algorithm.

3. Practical aspect.

   It covers the applications in real stock markets to show the advantages of the methods developed in points 1 and 2 for (i) stocks network analysis, and (ii) economic sectors network analysis.

To illustrate the advantages of the proposed stocks network analysis and economic sectors network analysis, we perform empirical studies for Malaysian and US stock markets. The data from BURSA MALAYSIA and NYSE are used in this study. For BURSA MALAYSIA case study, we analyze the data of 50 most capitalized stocks during the time period from January 2, 2007 until September 26, 2011. The data of opening, highest, lowest, and closing prices were downloaded from http://www.klse.info/downloads. For NYSE case study, we analyze the data of 1515 stocks continuously traded at NYSE from December 16, 2004 until November 21, 2014. The data of four prices were downloaded from http://www.nasdaq.com/.

To illustrate the advantages of the proposed algorithm in finding an MST and corresponding SDU, a comparison study based on empirical data from stock markets and simulated data are presented in this study. The considered stock markets are Singapore Stock Exchange (SGX), BURSA MALAYSIA, NYSE, and Shanghai and Shenzen Stock Exchange (SHSZ). The number of stocks in SGX, BURSA MALAYSIA, NYSE and SHSZ are 28, 90, 100, and 300, respectively. The data were collected during the period of January 2, 2008 until December 31, 2010, of January 2, 2007 until December 31, 2009, of November 18, 2010 until March 28, 2012, and of July 28, 2011 until June 1, 2012, respectively. The data were downloaded from Yahoo Finance.

1.5 Organization of the Thesis

This thesis is organized into seven chapters. Chapter 1 is the Introduction. The research background, problem statement, objectives, and scopes of this research are given in this chapter.

In Chapter 2 the literature review about the similarity measures on univariate and multivariate time series are presented. The importance of correlation-based network analysis in stock market and the centrality measures used in network analysis are presented.

The methodologies of this research are given in Chapter 3 which is divided into four sections. In the first section the standard practice of stocks network construction proposed by Mantegna (1999) is recalled. The second section is about defining the similarity between stocks in multivariate setting by using Escoufier's operator and then with the stocks network construction. Based on the EVC defined from Escoufier operator, the construction of economic sectors network in multivariate setting is developed in the third section. In the last section, an efficient algorithm is developed based on the properties of SDU from fuzzy relation viewpoint, uniqueness theorem and properties of forest of all MSTs in Djauhari (2012).

In Chapter 4, as a case study, the topological properties of 50 stocks traded at BURSA MALAYSIA are analyzed based on PCC-based MST and EVC-based MST. The stocks are classified according to their economic sector classifications defined in BURSA MALAYSIA. Then, the economic sectors network based on EVC is presented. The topological structures of inter and intra economic sectors are presented and discussed.

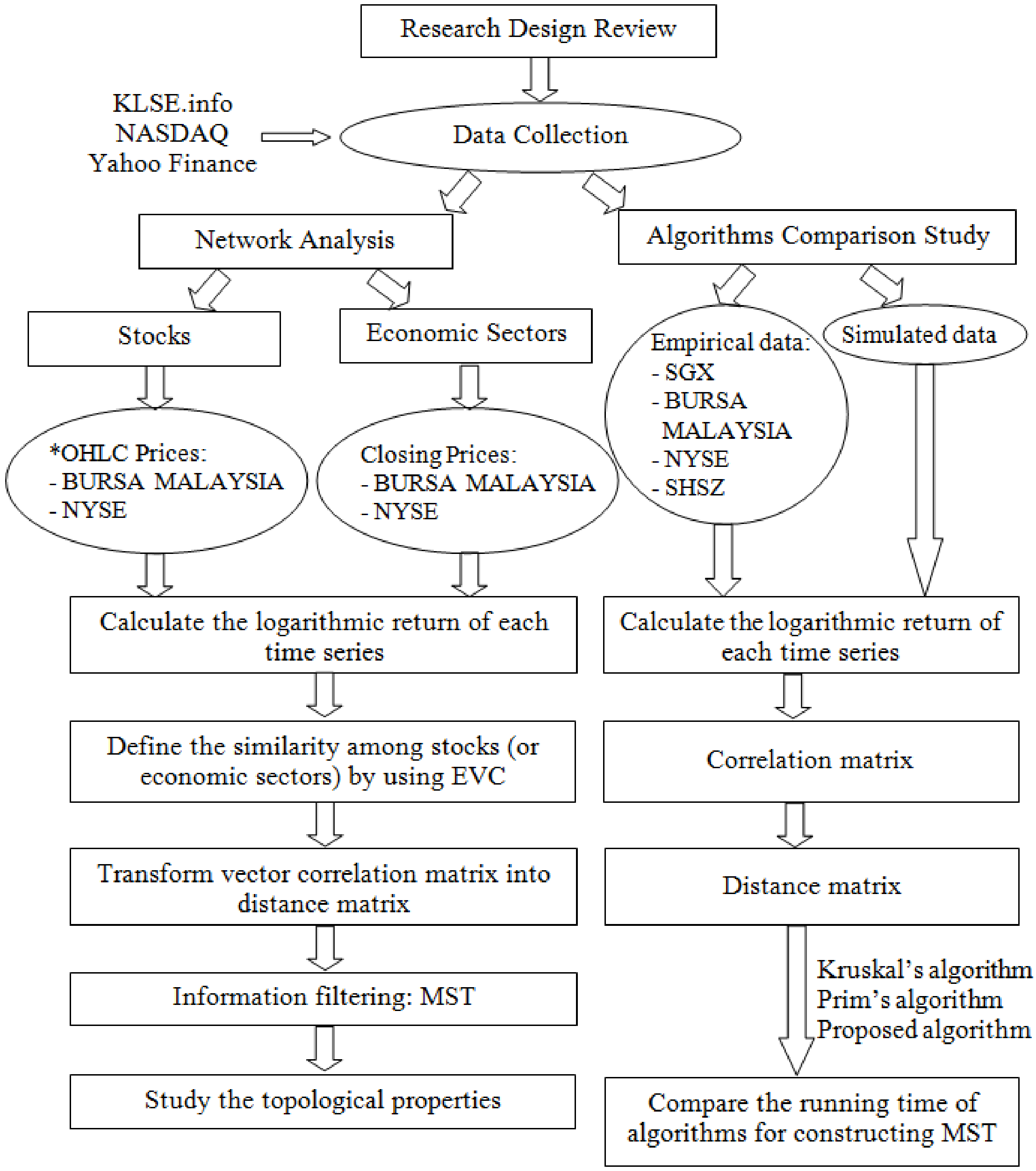
In Chapter 5, the case study of NYSE involving 1515 stocks that continuously traded in market are analyzed based on EVC-based MST. The topological properties of those stocks are analyzed. According to Standard Industrial Classification (SIC) system, the stocks are classified into 63 SICs. These 63 SICs are again classified into nine main industry sectors. The EVC-based SICs network is presented. The topological structures of inter and intra SICs are presented and discussed.

In Chapter 6, an illustrative example on how the proposed algorithm works is given. In order to show the advantage of the proposed algorithm, its running time is compared to Kruskal's algorithm and also to Prim's algorithm. For that purpose, four empirical data and four simulated data are used. For each data set, the running time of each of those algorithms are reported.

Finally, conclusion and recommendations for future research in the Chapter 7 which consists of some conclusions, contributions of the study and future research directions will close the presentation of this thesis.

1.6 Research Framework

To facilitate the readers, the flow chart presented in Figure 1.1 gives the summary of the research framework. The left-hand side of the figure depicts the steps of conducting the stocks network analysis and economic sectors network analysis of the stock markets, i.e., BURSA MALAYSIA and NYSE in Chapters 4 and 5, respectively. The right-hand side shows the steps of conducting the comparison study between algorithms in Chapter 6.



*OHLC is the abbreviation formed from opening, highest, lowest and closing.

Figure 1.1 Summary of research framework

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APPENDIX A

PUBLICATIONS

I. Journal Publications

1. Gan, S. L. and Djauhari, M. A. (2012). Stock Network Analysis in Kuala Lumpur Stock Exchange. *Malaysian Journal of Fundamental & Applied Sciences*. 8(2), 60-66. **(Indexed in Google Scholar)**
2. Gan, S. L. and Djauhari, M. A. (2012). An Overall Centrality Measure: The Case of U.S Stock Market. *International Journal of Basic & Applied Sciences IJBAS-IJENS*. 12(6), 99-103 **(Indexed in Google Scholar with I.F: 0.9878)**
3. Djauhari, M. A. and Gan, S. L. (2013). Minimal Spanning Tree Problem in Stock Networks Analysis: An Efficient Algorithm. *Physica A: Statistical Mechanics and its Applications*. 392(2), 2226-2234. **(Indexed in SCOPUS with I.F: 1.722)**
4. Djauhari, M. A. and Gan, S. L. (2013). Network Topology Property of English Dialects: A Robust Filter Approach. *American Journal of Applied Sciences*. 10(7), 646-653. **(Indexed in SCOPUS)**
5. Djauhari, M. A. and Gan, S. L. (2014). Dynamics of Correlation Structure in Stock Market. *Entropy*. 16(1), 455-470. **(Indexed in SCOPUS with I.F: 1.564)**
6. Djauhari, M. A. and Gan, S. L. (2015). Optimality Problem of Network Topology in Stocks Market Analysis. *Physica A: Statistical Mechanics and its Applications*. 419, 108-114. **(Indexed in SCOPUS with I.F: 1.722)**
7. Djauhari, M. A. and Gan, S. L. (2015). Bursa Malaysia Stocks Market Analysis: A Review. *ASM Science Journal*. 8(2), 150. **(Indexed in SCOPUS)**
8. Gan, S. L. and Djauhari, M. A. (2015). New York Stock Exchange Performance: Evidence from the Forest of Multidimensional Minimum

Spanning Trees. *Journal of Statistical Mechanics: Theory and Experiment.* 2015, P12005. **(Indexed in SCOPUS with I.F: 2.404)**

9. Djauhari, M. A. and Gan, S. L. (2014). Network Topology of Economic Sectors. *Physica A: Statistical Mechanics and its Applications*. **(Revised version is under review) (Indexed in SCOPUS with I.F: 1.722)**

II. International and National Conference Proceedings

1. Gan, S. L. and Djauhari, M. A. (2012). Network Topology of Indonesian Stock Market. *Proceedings of IEEE International Conference on Cloud Computing and Social Networking*. 26-27 April 2012. Bandung, Indonesia, 1-4. **(Indexed in SCOPUS)**
2. Gan, S. L. and Djauhari, M. A. (2012). Filtering Network Topology in Stock Market. *Proceedings of the 1st ISM International Statistical Conference*. 4-6 September 2012. Johor Bahru, Malaysia, 155-162.
3. Gan, S. L. and Djauhari, M. A. (2012). Sub-Dominant Ultrametric Hierarchical Structures of NYSE 100 Stocks. *Proceedings ICSSBE 2012 International Conference on Statistics in Science, Business and Engineering*. 10-12 September 2012. Langkawi, Malaysia, 429-433. **(Indexed in SCOPUS)**
4. Gan, S. L. and Djauhari, M. A. (2013). Multidimensional Stock Network Analysis: An Escoufier's RV Coefficient Approach. *Proceedings ICMSS 2013 International Conference on Mathematical Sciences and Statistics*. 5-7 February 2013. Kuala Lumpur, Malaysia, 550-555. **(Indexed in SCOPUS)**
5. Gan, S. L., Djauhari, M. A. and Ismail, Z. (2014). Economic Sectors Network at Kuala Lumpur Stock Exchange. *ISI-RSC 2014 International Statistical Institute Regional Statistics Conference 2014*. 16-19 November 2014. Kuala Lumpur, Malaysia.
6. Gan, S. L., Djauhari, M. A. and Ismail, Z. (2014). Monitoring Correlation Structures Stability in Foreign Exchange Market. *IEEE 2014 International Conference on Industrial Engineering and Engineering Management*. 9-12 December 2014. Selangor, Malaysia, 848-852. **(Indexed in SCOPUS)**

III. Book Chapters

1. Djauhari, M. A. and Gan, S. L. (2014). *Book Chapters: Statistics in Scientific Investigation III Financial Network Analysis.* Chapter 2: A Robust Filtered Network Analysis of Malaysian Stocks Market, pp. 20-41. **(In press)**