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Research paper

Analysis of cyclical behavior in time series of stock market returns

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ABSTRACT

In this paper we have analyzed scaling properties and cyclical behavior of the three types of stock market indexes (SMI) time series: data belonging to stock markets of developed economies, emerging economies, and of the underdeveloped or transitional economies. We have used two techniques of data analysis to obtain and verify our findings: the wavelet transform (WT) spectral analysis to identify cycles in the SMI returns data, and the time-dependent detrended moving average (tdDMA) analysis to investigate local behavior around market cycles and trends. We found cyclical behavior in all SMI data sets that we have analyzed. Moreover, the positions and the boundaries of cyclical intervals that we found seam to be common for all markets in our dataset. We list and illustrate the presence of nine such periods in our SMI data. We report on the possibilities to differentiate between the level of growth of the analyzed markets by way of statistical analysis of the properties of wavelet spectra that characterize particular peak behaviors. Our results show that measures like the relative WT energy content and the relative WT amplitude of the peaks in the small scales region could be used to partially differentiate between market economies. Finally, we propose a way to quantify the level of development of a stock market based on estimation of local complexity of market's SMI series. From the local scaling exponents calculated for our nine peak regions we have defined what we named the Development Index, which proved, at least in the case of our dataset, to be suitable to rank the SMI series that we have analyzed in three distinct groups.

1. Introduction

This paper seeks to investigate the appearance of periodic and non-periodic cycles in the time series of stock market returns, and the contribution of cyclic behavior to the market efficiency and the distribution of stock indexes returns. Cycles in the economic data have been studied extensively [1], resulting in a number of stylized facts that characterize some cyclical or seasonal effects to financial time series [2]. The study of cycles in economic data dates back to the early 1930s [3]. Various

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techniques to measure seasonality have been widely applied, combining ideas from mathematics, physics, economics and social sciences. These efforts have resulted in research findings of, among other, intraday trading effects [4], weekend and/or three-day effects [5], intramonth effects [6], quarterly and annual cycles [7], and various multi-year cyclical variations in stock market index returns [3,8]. A consensus of opinion on the nature, character, or the importance (to the overall market data behavior) of cyclic effects, however, has not been reached.

Financial markets belong to a class of human-made systems exhibiting complex organization and dynamics, and similarity in behavior [9]. Complex systems have a large number of mutually interacting parts that operate simultaneously at different scales, are often open to their environment, and self-organize their internal structure and dynamics, thus producing various forms of large-scale collective behaviors. The outputs of such systems, time series of records of their activity, display co-existence of collectivity and noise [10]; the complexity of systems is reflected in datasets that exhibit a wealth of dynamic features, including trends and cycles on various scales [1,3]. The tools to study such systems therefore cannot be analytical, but rather must be adapted to enable accurate quantification of their long-range order. In this sense, we have chosen to contribute to the debate about the existence, types, and importance of cycles in stock market data in two ways: by way of applying wavelet spectral analysis [11] to study market returns data, and through the use of Hurst exponent estimation methods [12] to study local behavior around market cycles and trends. The utility of our methods to estimate the scaling of financial time series has recently been confirmed [13] in an extensive overview of scientific time series data and analysis methods.

Firstly, we utilized wavelets to study cyclical consistency in time series of stock market indexes (SMIs). Wavelet analysis is appropriate for such a task; it was originally introduced to study complex signals [14]. We use wavelet-based spectral analysis, which estimates the spectral characteristics of a time-series as a function of time [15], revealing how the different periodic components of a particular time-series evolve over time. It enables us to compare stock market index time series wavelet spectra from different economies, and to examine the similarities in contributions of cycles at various characteristic frequencies to the total energy spectrum. With this tool we can attempt to address the question of whether the complexity of a financial market is specifically limited to the statistical behavior of each SMI time series or parts of an SMI's series complexity can be attributed to the overall world market [16].

We use the Hurst exponent estimation formalism, in a form of time-dependent detrended moving average analysis, to test the local character of cycles at various characteristic frequencies of SMI time series from different economies. In recent years, the application of the Hurst-exponent-based analyses has led many researchers to conclude that financial time series possess multi-scaling properties [17–19]. In addition, these methods have allowed for the examination of local scaling around a given instance of time, so that the complex dynamical properties of various time series can be analyzed locally rather than globally [20]. In this paper, we aim to compare the local scaling of each cycle across stock markets and to find ways to classify various markets according to their cyclical behavior.

We choose to analyze three types of SMI time series: data belonging to stock markets of developed economies, emerging economies, and of the underdeveloped or transitional economies. Previous and recent work by our group and others has demonstrated that SMI series exhibit scaling properties connected to the level of growth and/or maturity of the economy the stock market is embedded in [17,21]. It has also been demonstrated that in emerging or transitional markets stock indexes do not fully represent the underlying economies [17], therefore we wanted to tailor our SMI study with this in mind and differentiate between underdeveloped (transitional) economies, emerging economies, and developed economies.

Our study is structured as follows. In Section 2 we give a brief overview of the methodological background: the general framework of the wavelet transform (WT) spectral analysis and an introduction to the detrended moving average (DMA) method and its time-dependent variation (tdDMA). In Section 3 we present our dataset and the results of the usage of the WT framework to study the appearance and consistency of cycles across stock markets. In addition, in this section we present the results of investigation of statistical effects of the observed cyclical behavior on the WT spectral behavior of our SMI data. In Section 4 we list the results of the use of tdDMA on our SMI data and develop a quantitative indicator (that we have dubbed the 'Development Index'), which may help classify the level of development of a particular market according to the markets' local cyclical behavior. We end our paper with a list of conclusions and a few suggestions for future work in Section 5.

2. Methodological background

In this paper we use the wavelet transform power spectrum and the time-dependent detrending moving average approaches for data analysis.

The wavelet transform (WT) was introduced [22–24] in order to circumvent the Heisenberg uncertainty principle problem in classical signal analysis and achieve good signal localization in both time and frequency that a classical Fourier transform approach lacks. Namely, in WT the window of examination length is adjusted to the frequency analyzed: slow events are examined with a long window, whilst a shorter window is used for fast events. In this way an adequate time resolution for high frequencies and a good frequency resolution for low frequencies is achieved in a single transform [11].