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Long memory in international financial markets trends and short movements during 2008 financial crisis based on variational mode decomposition and detrended fluctuation analysis

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HIGHLIGHTS

- International Stock markets are analyzed by variational mode de composition.
- Trend and shorts variations in price and return series are characterized.
- Detrended fluctuation analysis and R/S analysis are used to estimate Hurst exponent of each mode.
- For all markets and before, during, and after 2008 financial crisis, it is found that price and return trends are persistent, whilst their short variations are anti-persistent.

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ABSTRACT

The purpose of this study is to investigate long-range dependence in trend and short variation of stock market price and return series before, during, and after 2008 financial crisis. Variational mode decomposition (VMD), a newly introduced technique for signal processing, is adopted to decompose stock market data into a finite set of modes so as to obtain long term trends and short term movements of stock market data. Then, the detrended fluctuation analysis (DFA) and range scale (R/S) analysis are used to estimate Hurst exponent in each variational mode obtained from VMD. For both price and return series, the empirical results from twelve international stock markets show evidence that long term trends are persistent, whilst short term variations are anti-persistent before, during, and after 2008 financial crisis.

1. Introduction

In a long memory process, past observation tends to be correlated with future one and this correlation is used to decay slowly. In the recent decade, there has been a significant body of research that considered the application of Hurst analysis to examine long memory in different types of data; including turbulent flow [1–4], biomedical images [5–8], rainfall time series [9–11], wind power and velocity [12–15], and financial data [16–21]. Investigating long memory in financial data is of great importance in financial industry. For instance, stock price may be predicted by exploring the autocorrelation structure in its time series. Therefore, fractal analysis is suitable to examine the underlying structural dynamics of a given stock price time series. Based on fractal analysis results, several studies have provided evidence of long memory in stock markets [16,22–25].

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Detrended fluctuation analysis (DFA) proposed by Peng et al. [26] is one of the methods extensively used to detect long memory in time series [7,19,27,28]. In particular, DFA detects long-range power-law correlations in seemingly non-stationary signals. In this study, DFA is used to investigate long memory dynamics in trends and short variations of international stock markets before, during, and after 2008 financial crisis. Indeed, the aim of this study is to examine long and short term structural dynamics of stock market. A self-adaptive technique would be appropriate to obtain stock market trend and short variations. The variational mode decomposition (VMD) [29] which is a new advanced multiresolution technique is chosen to analyze stock market data for decomposition purpose.

In the VMD framework [29], the original time series is decomposed into a set of sub-signals called modes; where each mode is compact around a center pulsation and has a limited bandwidth. In addition, each mode is updated by Wiener filtering in Fourier domain; and, each center frequency is updated as the center of gravity of the mode's power spectrum. The Lagrangian multiplier is used to enforce exact signal reconstruction and is updated as dual ascent [29].

Concretely, the underlying signal is decomposed from low-frequency to high-frequency modes. The first low-frequency mode captures the low-frequency oscillation of the baseline, whilst the highest frequency mode contains the most noise [29]. In this study, we assume that first low-frequency modes capture signal trend and that high-frequency modes capture its noisy short variations. The advantage of estimating fractal in VMD domain is to obtain a fractal estimate in each mode scale. That is, this approach offers a scale-by-scale decomposition of time series dynamics, which allows analyzing a process long memory over a range of different scales which are adaptively determined. Therefore, one could examine the behavior of long memory in high and low frequency variational modes obtained by VMD. In particular, we aim to find in which frequency scale of data the long memory is concentrated. It should be noticed that the discrete wavelet transform could be used for time series decomposition in this study. However, it is avoided for the following reasons. First, it is not adaptive as the VMD technique. Second, it requires a pre-determined wavelet function and scale of decomposition. Third, the number of observations to be analyzed by DFA, for instance, is reduced in the wavelet scheme as the number of scales increases. For instance, the number of observations used to characterize trend (approximation coefficients) in a given time series decreases with level of decomposition. Certainly, this reduction in number of observations negatively affects the estimated Hurst coefficient as it is estimated by ordinary linear regression.

The R/S analysis [30,31] is a popular approach for investigating long memory in time series. However, it assumes that the underlying data is stationary and as it is based on max and min functions it is sensitive to outliers. Contrary to R/S statistic, the DFA is suitable for nonstationary data and it is less sensitive to outliers since max and min functions are not involved in the computation process. In addition, detrending is essential to analyze time series because it prevents it from being correlated if correlations are not present [32], and reveals a genuine correlation functional dependence when correlations exist [32]. Recall that the authors in Ref. [32] introduced the detrended cross-correlation analysis (DCCA) to study long-term memory between two time series; with the purpose to accurately quantify power-law cross-correlations between two different time series in the presence of highly nonstationary sinusoidal and polynomial overlying trends. For all reasons cited previously, the DFA is used to estimate Hurst exponent in each mode function that represents certain short/long variations in the underlying data. The popular R/S analysis is adopted for comparison purpose; whilst, DCCA [32] is not considered in this study since stock market time series are individually and separately analyzed in this study. In other words, the analysis of cross-correlations is out of scope in this study.

In summary, the contribution of the current study follows. We enrich previous works found in the literature related to investigation of long-memory in stock markets in relation to financial crisis [33–40] by proposing a methodology that combines VMD and DFA to investigate long-range dependence in trend and short variation of stock market price and return series before, during, and after an international financial crisis. The proposed methodology is applied to the most recent financial crisis; namely the 2008 international financial crisis.

The remainder of this paper is divided into the following sections: in Section 2, the methods are presented; namely the VMD, R/S analysis, and DFA. In Section 3, empirical results are presented. Finally, conclusion is provided in Section 4.

2. Methods

The investigation of long memory in trends and short variations of international stock market prices is carried out in two stages. In the first stage, stock market price series are analyzed by using variational mode decomposition to obtain its low to high-frequency variational modes. As mentioned in the Introduction, low and high frequency variational modes capture respectively time series trend and short variations. To investigate long-memory in stock price trends and short variations, the detrended fluctuation analysis is applied to each obtained variational mode to estimate Hurst exponent which is used to measure long memory in price trend and short variations. The standard R/S analysis is adopted for comparison purpose.

2.1. Variational mode decomposition

The purpose of the VMD is to decompose an input signal into k discrete number of sub-signals (modes), where each mode has limited bandwidth in spectral domain [29]. Thus, each mode k is required to be mostly compact around a center pulsation ω_k determined along with the decomposition [29]. The VMD algorithm to assess the bandwidth of a one dimension signal is as follows [29]: (1) for each mode u_k, compute the associated analytic signal by means of the Hilbert transform to obtain