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Comparing emerging and mature markets during times of crises: A non-extensive statistical approach

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HIGHLIGHTS

- Results show the measure of deviation from Gaussianity proving a good index for detecting crises by nonextensive entropy approach.
- To measure the value of crises the non Gaussianity has been studied in various time scales.
- Response of emerging markets to global events is delayed compared to mature markets.

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ABSTRACT

One of the important issues in finance and economics for both scholars and practitioners is to describe the behavior of markets, especially during times of crises. In this paper, we analyze the behavior of some mature and emerging markets with a Tsallis entropy framework that is a non-extensive statistical approach based on non-linear dynamics. During the past decade, this technique has been successfully applied to a considerable number of complex systems such as stock markets in order to describe the non-Gaussian behavior of these systems. In this approach, there is a parameter q, which is a measure of deviation from Gaussianity, that has proved to be a good index for detecting crises. We investigate the behavior of this parameter in different time scales for the market indices. It could be seen that the specified pattern for q differs for mature markets with regard to emerging markets. The findings show the robustness of the stated approach in order to follow the market conditions over time. It is obvious that, in times of crises, q is much greater than in other times. In addition, the response of emerging markets to global events is delayed compared to that of mature markets, and tends to a Gaussian profile on increasing the scale. This approach could be very useful in application to risk and portfolio management in order to detect crises by following the parameter q in different time scales.

1. Introduction

The distribution of financial returns is one of the most fundamental concepts in finance for analysis and assessment of portfolios [1]. It was shown that the probability distributions of financial returns have power-law tails,and this fact cannot be described by normal probability distributions [2–4].

These non-Gaussian behaviors have been shown clearly during extreme events such as market crashes and crises [5,6]. So, the question is which is the best probability density function to describe the returns of financial markets. Some researchers

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have tried to answer this question for purposes such as financial risk estimation [7–9]. One method for solving this problem is through an entropic view [10]. In the real world, most systems with irreversible processes tend to move toward a state of high probability with maximum entropy, and this maximizing minimizes the amount of prior information built into the distribution [11,12]. Based on the Boltzmann–Gibbs (Shannon) framework, the specific probability distribution that maximizes the entropy is the Gaussian distribution [13,14]. So, regarding the previous statements, the Boltzmann–Gibbs framework needs to change to a new approach such that, by maximizing the entropy, it can consider the higher moments and fat tails of the distributions [15–17]. One of the methods that consider the tails of distributions is the Tsallis approach, which is a non-extensive entropy that has been used in different disciplines [18–21]. The Tsallis framework is a generalized form of entropy such that, by maximizing it, q-Gaussian probability distributions are obtained [15–17]. It was shown that this type of distribution can explain the behavior of real financial systems and their fat tails very well [22–27]. Much research has been done for evaluating the Tsallis approach for describing the non-Gaussian behavior of financial markets and subjects related to this phenomenon [1,22,24,25,27–29]. In this paper, we use this technique on some of the market indices for extracting the notion of a crisis and also for analyzing the behavior of emerging and mature markets during crises.

We have used different databases, covering securities from the Tehran stock exchange (TSE), Shanghai Stock Exchange (SSE), Korean Stock Exchange (KS11), Dow Jones Industrial Average (DJIA30), Standard and Poor's 500 (SPX), and Nasdaq Composite (NDX100) indices. We analyzed the daily change of the SPX, DJIA30, and NZX100 indices from 1 January 1980 until 1 January 2010; the time series for the TSE is from 1 January 1996 until 1 January 2010, that for the SSE is from 1 January 2001 until 1 January 2010, and that for the KS11 is from 1 January 1999 until 1 January 2010. The paper is organized as follows. In Section 2, we explain our methods and present a statistical framework for the Tsallis approach. Section 3 presents our findings, and then in Section 4 we present our conclusions.

2. Methods

One of the best methods for describing the coupled and non-linear dynamics of stock markets is the concept of entropy [28,32,33,30,31]. This concept is used as a measure of disorder and uncertainty [34]. One of the basic entropy measures is the Shannon information framework. The continuous type of the entropy in this framework is [1]

$$S_s = -\int P(x)\ln P(x)\mathrm{d}x. \tag{1}$$

This kind of entropy measure is additive, which means that, if two states X and Y are independent of each other, $P(X\bigcup Y) = P(X)\cdot P(Y)$, then $S_s(X\bigcup Y) = S_s(X) + S_s(Y)$ [1]. This approach does not consider systems that entail long-range interactions and multi-fractal structures. The Boltzmann–Gibbs statistics is useful for describing the behavior of systems under significant short spatial/temporal interactions [35], but in this research we consider the Tsallis approach, which is based on more parameters such as multi-fractality and long-range correlations in the probability density functions of the systems. Since Havrda, Charvat, and Daroczy developed this method with Tsallis, it is named Havrda–Charvat–Daroczy–Tsallis entropy [28].

2.1. Tsallis entropy

Tsallis entropy is a generalized form of Gaussian distribution that is named q-Gaussian; it can describe the fat-tail behavior of financial time series [22–28,23].

The parameter q that is the essential feature of q-Gaussian distributions indicates long-range correlations among states of a system [1]; therefore it can be considered as a long-memory parameter.

Tsallis entropy ($q =$ entropy) is a generalized form of entropy, which is defined as [1]:

$$S_q = \frac{1-\int [P(x)]^q \mathrm{d}x}{q-1}, \tag{2}$$

where q is a measure of non-additivity, meaning that $S_q(X\bigcup Y) = S_q(X) + S_q(Y) - (1-q)S_q(Y)S_q(X)$. High values of q are typical of systems with long-range correlations [1]".

Applying the maximum entropy principle for the Tsallis framework, constrained by

$$\int P(x)\mathrm{d}x = 1, \qquad \frac{\int x^2 P(x)^q \mathrm{d}x}{\int P(y)^q \mathrm{d}y} = \sigma^2, \tag{3}$$

leads to the following q-Gaussian probability density function (PDF):

$$P(x) = \frac{\exp_q(-\beta_q x^2)}{\int \exp_q(-\beta_q x^2)\mathrm{d}x} \propto \frac{1}{Z}[1 + (1-q)(-\beta_q x^2)]^{\frac{1}{1-q}}, \tag{4}$$

where β_q and Z are functions of q. $\exp_q(x)$ is a q-exponential function, defined by

$$\exp_q(x) = \begin{cases} [1+(1-q)x]^{\frac{1}{1-q}} & \text{if } 1+(1-q)x > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$