Available online at www.sciencedirect.com

SCIENCE DIRECT®

ELSEVIER

Physica A 363 (2006) 377–382

PHYSICA A

www.elsevier.com/locate/physa

Microscopic spin model for the dynamics of the return distribution of the Korean stock market index

Jae-Suk Yang*, Seungbyung Chae, Woo-Sung Jung, Hie-Tae Moon

Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Republic of Korea

Received 16 November 2005; received in revised form 15 December 2005
Available online 23 January 2006

Abstract

In this paper, we studied the dynamics of the log-return distribution of the Korean Composition Stock Price Index (KOSPI) from 1992 to 2004. Based on the microscopic spin model, we found that while the index during the late 1990s showed a power-law distribution, the distribution in the early 2000s was exponential. This change in distribution shape was caused by the duration and velocity, among other parameters, of the information that flowed into the market.

Keywords: Econophysics; Emerging market; Log return; Power-law distribution; Exponential distribution

1. Introduction

Interdisciplinary research is now routinely carried out, with econophysics being one of the most active interdisciplinary fields [1–5]. Many research papers on mature markets have already been published. However, since emerging markets show different characteristics to those of mature markets, they represent an active field for econophysicists. The Korean market, one of the foremost emerging markets, has already been studied by physicists [4,5]. We concentrate on the particular properties of the Korean market through the return distribution.

It is broadly assumed that the distribution of price changes takes the form of a Gaussian distribution, and that all information is applied to the market immediately by the efficient market hypothesis (EMH) [6]. Using the EMH, the trading profit with arbitrage cannot be obtained from the superiority of information. The price changes in an efficient market cannot be predicted and change randomly. This is suited to classical economics theory. However, experimental proofs reveal that Gaussian distributions of price changes do not exist in real markets [7,8].

Mandelbrot determined empirically that the tail part of the distribution is wider and the center of the distribution is sharper and higher than a Gaussian distribution by examining price changes of cotton; this distribution of price changes is termed the Lévy stable distribution [7]. Fama also found a Lévy stable distribution for the New York Stock Exchange (NYSE) [8]. After Mandelbrot's study, the distribution of price

*Corresponding author. Fax: +82 42 869 2510.
E-mail address: yang@kaist.ac.kr (J.-S. Yang).

0378-4371/$ - see front matter
doi:10.1016/j.physa.2005.12.039

changes was identified as non-Gaussian by many researchers [9–12]. It was reported that distributions in mature markets have a power-law tail, while those in emerging markets have an exponential tail [13,14].

Silva et al. [11] and Vicente et al. [12] reported that the distributions of price changes vary with time lag. Price changes have a power-law distribution for a short time lag, and an exponential distribution when the time lag is long. Moreover, for a very long time lag, the distribution becomes Gaussian. Transition problem of the tail behavior was solved analytically by Dragulescu and Yakovenko [15] using a stochastic model [16].

Financial markets are adaptive evolving systems, so the distributions of price changes are also different for various periods and countries. Especially, the Korean stock market has different properties compared with other countries, and the distribution of price changes is not stable and changes with time.

In this paper, we study the characteristics of the Korean stock market using probability distribution functions (PDFs) of the Korean Composition Stock Price Index (KOSPI) and investigate why phenomena different to other countries occur. We also carry out a simulation using the microscopic spin model to explain these differences.

2. Empirical data and analysis

We use the KOSPI data for the period from 1992 to 2004, and observe the PDFs of the KOSPI price changes for a time window of 1 year. We use only intra-day returns to exclude discontinuous jumps between the previous day's close and the next day's open price due to overnight effects. The price change log return is defined by

$$S(t) \equiv \ln Y(t + \Delta t) - \ln Y(t), \tag{1}$$

where $Y(t)$ is the price at time t and Δt is the time lag.

Fig. 1a shows the log return distribution for the KOSPI. The distribution for an 1-min time lag represents a power-law distribution, that for 10 min is exponential, and that for 30 min is also exponential but close to Gaussian. These results are in accordance with previous reports [11,12].

In the Korean stock market, the log return distribution for an 1-min time lag shows some peculiar phenomena. Fig. 1b shows the PDFs of the KOSPI log return from 1998 to 2002, while Fig. 1c is a graph of the tail index, power-law exponent of tail part of the log return distribution, as a function of time from 1993 to 2004. The shape of the distribution in 1998 ($\diamond$) in Fig. 1b is close to a Lévy distribution and the tail part shows a power-law distribution. However, the tail index of the PDFs increases over the years and the shape of tail part changes to exponential with increasing time. This phenomenon can be confirmed in Fig. 1c. As well the tail index in the early 1990s is approximately 2.0, increases from the mid-1990s to the early 2000s, finally changes to an exponential tail. Although a discontinuity in the increasing trend occurred during the 1997 Asian financial crisis, the tail index continued to increase thereafter.

In Fig. 2a, the decay time for the autocorrelation function of log return is continuously decreasing, while the tail index abruptly varied around the time of the 1997 Asian financial crisis. This suggests that the decay time is related to the increasing trend of the tail index, regardless of the Asian financial crisis. Thus, we investigated the relation between the decay time for the autocorrelation function of log return and the tail index of the log return distribution to identify why this phenomenon has happened. Fig. 2b shows the relation between the tail index and the decay time. The decay time of the autocorrelation function is inversely proportional to the tail index by a factor of 4.

The decay time of the autocorrelation function decreases as the log return distribution of the KOSPI changes from a power-law to an exponential distribution (Fig. 2). This decrease in decay time means that the duration of information in the market is diminished compared with the past, that is, past information decreases more rapidly when the decay time is shorter. Information and communication technology such as high-speed internet connections and electronic trading systems were not fully utilized in the past, so it took a longer time to deliver information to the market. Moreover, the information flow was small because social structures in the past were relatively simpler. For this reason, much more information flows into the market for a specific time interval now compared with the past. Therefore, the time scale of the past differs from the current scale. The amount of information and its velocity in reaching the market for 1 min now may be the same as that for 2 or 3 min or more in the past.