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Multifractal spectrum analysis of nonlinear dynamical mechanisms in China's agricultural futures markets

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ABSTRACT

Based on Partition Function and Multifractal Spectrum Analysis, we investigated the nonlinear dynamical mechanisms in China's agricultural futures markets, namely, Dalian Commodity Exchange (DCE for short) and Zhengzhou Commodity Exchange (ZCE for short), where nearly all agricultural futures contracts are traded in the two markets. Firstly, we found nontrivial multifractal spectra, which are the empirical evidence of the existence of multifractal features, in 4 representative futures markets in China, that is, Hard Winter wheat (HW for short) and Strong Gluten wheat (SG for short) futures markets from ZCE and Soy Meal (SM for short) futures and Soy Bean No.1 (SB for short) futures markets from DCE. Secondly, by shuffling the original time series, we destroyed the underlying nonlinear temporal correlation; thus, we identified that long-range correlation mechanism constitutes major contributions in the formation in the multifractals of the markets. Thirdly, by tracking the evolution of left- and right-half spectra, we found that there exist critical points, between which there are different behaviors, in the left-half spectra for large price fluctuations; but for the right-hand spectra for small price fluctuations, the width of those increases slowly as the delay t increases in the long run. Finally, the dynamics of large fluctuations is significantly different from that of the small ones, which implies that there exist different underlying mechanisms in the formation of multifractality in the markets. Our main contributions focus on that we not only provided empirical evidence of the existence of multifractal features in China agricultural commodity futures markets; but also we pioneered in investigating the sources of the multifractality in China's agricultural futures markets in current literature; furthermore, we investigated the nonlinear dynamical mechanisms based on spectrum analysis, which offers us insights into the underlying dynamical mechanisms in China's agricultural futures markets.

1. Introduction

In recent years, econophysics [1] became a hot issue and provided the methods and theories originated from multidisciplinary fields such as statistical physics, nonlinear sciences, complex sciences, etc., to explain the complex behaviors and mechanisms behind the economic (or financial) phenomena.

The study of commodity prices is largely based on the main stream literature of financial markets, whose fundamental assumption is that returns of stock prices follow a normal distribution and price behavior obeys 'random-walk' hypothesis (RWH), which was first introduced by Bachelier in 1900 [2], since then it has been adopted as the essence of many asset pricing models. However, some important results in econophysics suggest that returns in financial markets have fundamentally different properties that contradict or reject RWH. These ubiquitous properties identified are: fat tails [3],

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long-term correlation [4], volatility clustering [5], fractals/multifractals [6,7], chaos [8], etc. Nowadays, RWH has been widely criticized in the financial literature as this hypothesis failed to explain the market phenomena.

After investigating the prices of cotton, wheat, stock and so on, Mandelbrot provided earliest empirical evidence that agricultural commodity spot prices do not obey RWH by means of fractal geometry [9,10]. Since then, fractal geometry has been widely applied in finance and market research domains. Peters introduced the fractal theory into the capital market research, and gave empirical evidence of the mono-fractal features in the markets by means of R/S analysis [11,12]. As Mono-fractals cannot describe the multi-scale and subtle structures of fractals in complex systems, many measures are applied to investigate the multifractality, such as height–height correlation function [13], multifractal detrended fluctuation analysis (MF-DFA) [14–23], the partition function method [24–26], etc. Empirical evidence shows that many financial markets are multifractal, such as the cases in LIBOR interest rates [27], in Japanese stock market [28], in Latin-American market indices [29], and in equity returns for European transition markets [30]. For other instances, Owicimka et al. investigated the different multifractal properties between the time series of logarithmic price increments and the inter-trade intervals of time by high-frequency tick-by-tick data, and found that the multifractals come from the long-range correlations as well as the non-Gaussian distributions of the fluctuations [16]; Norouzzadeh et al. found the multifractal properties and scaling behaviors of the exchange rate variations of the Iranian rial against the US dollar, and found that the contributions of two major sources of multifractality are fat-tailed probability distributions and nonlinear temporal correlations [18]; Kumar and Deo studied the multifractal properties of the logarithmic returns of the Indian financial indices, and found that the multifractality is due to the contributions of long-range correlations as well as the broad probability density function [23]. Similar results are found in commodity markets. Alvarez-Ramirez et al. investigated the multifractal features of international crude oil prices and their dynamical features [7]; Matia et al. analyzed daily price of 29 commodities and 2449 stocks and found that the price fluctuations for commodities had a significantly broader multifractal spectrum than for stocks, and both of the multifractal properties can be attributed mainly to the broad probability distribution of price fluctuations and secondly to their temporal organization [15]; Lim et al. investigated the multifractal properties of price increments in the cases of derivative and spot markets, and found that multifractality due to a fat-tailed distribution is significant [19].

In agricultural future markets domain, Corazza et al. studied six main US agricultural futures and found the existence of mono-fractals [31]; Chatrath et al. studied four futures as the representatives of US agricultural futures and found low-dimensional chaotic structures in the markets [32]. As for China's markets, many scholars investigated the multifractal features in Shenzhen and Shanghai stock markets [21,24,25], while few empirical evidence in current literature can offer the answer to the problem whether China's agricultural futures markets are multifractal or not.

Since nearly all agricultural futures markets are listed in two China's exchanges, namely, Zhengzhou Commodity Exchange (ZCE) and Dalian Commodity Exchange (DCE), we chose Hard Winter wheat (HW), Strong Gluten wheat (SG) futures, Soy Meal (SM) futures and Soy Bean No. 1 (SB) futures, the 4 influential and representative futures markets in China, to get the overview of China agricultural futures markets. we identified the multifractal features in Chinese agricultural markets by means of partition function and multifractal spectrum analyses, and proposed plausible explanations of the underlying multifractality formation by shuffling procedure, by which the underlying long-range correlation is destroyed; furthermore, we tracked qualitatively the evolution of left- and right-half spectra to investigate the different impacts of the large fluctuations and small fluctuations on price dynamics as the time delay increasing. Understanding those different impacts will help us to get better insights into the underlying dynamical mechanisms in China's agricultural futures markets.

We contribute to current literature in the following: firstly, we provided empirical evidence of the existence of multifractal features in China's agricultural futures markets, which is seldom discussed in current agricultural economics literature; secondly, we proposed the explanation of the dynamical formation of the multifractality in the markets; thirdly, we furthered our study to investigate the nonlinear dynamical mechanisms based on spectrum analysis to get better understanding on the underlying dynamical mechanisms in those markets.

2. Theoretical background

2.1. Model

To keep our description as self-contained as possible, let us review briefly the model [24–26].

Let us suppose $T(i)$ $(i = 1, 2, \ldots, L)$ to be a time series, where L is the length of the time series. Let us define its t-returns

$$r(i) = \log\left(T(i+t)/T(i)\right) \quad (1 \le t \le 250). \tag{1}$$

Then we divide it into N parts with equal size s. We assume the length of the whole time series as unit length 1, then each part is δ $(\delta = 1/N)$. For the jth part, we define the mass probability $P_j(\delta)$

$$P_j(\delta) = \frac{\sum_{i=1}^{s} |r((j-1)s+i)|}{\sum_{i=1}^{L} |r(i)|}. \tag{2}$$