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# A novel integrated measure for energy market efficiency

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**Abstract**

This paper formulates a novel integrated measure for energy market efficiency, by investigating different perspectives of the market performance. Different from most existing models focusing on certain one perspective, the integrated measure especially takes all aspects into consideration, including self-similarity (or system memorability or long-term persistence) in terms of fractality, attractor properties in phase-space in terms of chaos, and disorder state of data dynamics in terms of entropy. In the proposed method, the most popular data analysis techniques of multi-fractal detrended fluctuation analysis, correlation dimension and sample entropy are respectively conducted on the market return data to capture the corresponding features; and then, the entropy weight method is used to generate the final integrated index. For illustration and verification, the proposed measure is applied to two typical energy markets, i.e., crude oil and carbon markets. Some interesting results can be found that the crude oil market (a comparatively mature and competitive market) can be shown more efficient than carbon market (an emerging market). Furthermore, the novel method can also offer much more information about the corresponding contribution of each aspect to the total efficiency.

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*Keywords*: Energy market; Efficiency; Complexity test; Fractality; Chaos; Entropy;

## 1. Introduction

Confronted with the double problems of energy shortage and environment deterioration, the energy market has played an increasingly predominant role in global economic system; and an efficient energy market can effectively help guarantee a sustainable economic development [1]. In particular, an energy market is said to be efficient if the relevant information to the fundamental price generation is completely processed by the capital market price mechanism, thus the energy market efficiency accentuates the informational efficiency of energy markets [2]. An achievement of the ideal efficient energy market, enabling efficient allocation of resources, thus ensures the rapid economic development.

According to the existing literature, the market efficiency is measured by some complexity testing methods, the more complex the market, the more efficient the market is. Based on different features, the complexity measurements for time series data can be divided into three main groups, i.e., fractality [3] (mono- or multi-

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fractality) for self-similarity (or system memorability or long-term persistence), chaos [4] (via attractor invariants or diagram descriptions) for attractor properties in phase-space, and entropy [5] (structural or behavioral entropy) for disorder state of the nonlinear system. In particular, a weaker self-similarity, a more complex structure of attractor, and a higher-leveled disorder state of system consistently indicate that the observed time series data are at a higher-level of complexity.

The main contribution of this paper is to formulate a novel integrated measure for energy market efficiency, including crude oil and carbon markets. The remainder of this paper is organized as follows: Section 2 describes the framework of efficiency measure scheme and details the concrete approaches. For illustration purpose, the two energy markets are analyzed by the proposed method, and the empirical results are discussed in Section 3. Section 4 draws some concluding remarks and outlines the future researches.

## 2. Methodology formulation

In the first step, the complexity of series is analyzed from different perspectives. MF-DFA, a competitive fractality analysis method, is implemented to measure the long-term dependence of the time series. Correlation dimension, a most popular used fractal dimension index, is adopted to analyze the attractor in phase space. SampEn, a robust entropy method, is used to measure the disorder state of the dynamic system. In the second step, entropy weight method, an effective weight calculation method is applied to determine the weight of each index so as to get the final complexity index.

### *2.1. Multi-fractal detrended fluctuation analysis(MF-DFA)*

The MF-DFA was proposed by Kantelhardt et al. (2002) [6] for the multi-fractal characterization of non-stationary time series, which is based on a generalization of the detrended fluctuation analysis (DFA). It can show the local characterization by time-varying parameters thus more specific information can be extracted from the series. According to the final power-law correlation between the fluctuation function and the scale:

$$F_q(s) \sim s^{h(q)} \tag{1}$$

The generalized Hurst exponents $h(q)$ can be calculated by the least square method. The generalized Hurst exponents $h(q)$ far from the disordered level 0.5 and higher the multi-fractality present a strong system memorability, i.e., the target data system is at a low-level complexity.

### *2.2. Correlation dimension*

For time series data, the chaos property is tested based on the phase-space reconstruction, by investigating the attractor in phase space. Among the various strange attractor invariants, the correlation dimension [7] may be the most frequently used. Consider a time series, the reconstructed phase space is given by

$$X_t = \{x_t, x_{t+\tau}, ..., x_{t+(m-1)\tau}\} \ t = 1, 2, ..., N-(m-1)\tau \tag{2}$$

where $\tau$ is an appropriate time delay and $m$ is an embedding dimension. Then based on the correlation integral, the correlation dimension is defined as:

$$D^m = \lim_{r\to 0} \frac{\log C^m(r)}{\log r} \tag{3}$$

The higher the value of the correlation dimension consistently shows a more complex structure that the system might take, and the tested data system accordingly demonstrates a higher-leveled complexity.

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