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# Multifractal features of EUA and CER futures markets by using multifractal detrended fluctuation analysis based on empirical model decomposition

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ABSTRACT

Basing on daily price data of carbon emission rights in futures markets of Certified Emission Reduction (CER) and European Union Allowances (EUA), we analyze the multiscale characteristics of the markets by using empirical mode decomposition (EMD) and multifractal detrended fluctuation analysis (MFDFA) based on EMD. The complexity of the daily returns of CER and EUA futures markets changes with multiple time scales and multilayered features. The two markets also exhibit clear multifractal characteristics and long-range correlation. We employ shuffle and surrogate approaches to analyze the origins of multifractality. The long-range correlations and fat-tail distributions significantly contribute to multifractality. Furthermore, we analyze the influence of high returns on multifractality by using threshold method. The multifractality of the two futures markets is related to the presence of high values of returns in the price series.



## 1. Introduction

The massive $CO_2$ emissions from fossil fuel consumption and their influence on climate change have become a major ecological and political issue worldwide. The "Kyoto Protocol," which was established in February 2005, aims to limit the total global $CO_2$ and other greenhouse gas emissions. In the same year, the European Climate Exchange (ECX) futures were listed on the carbon dioxide emission futures to assist the buyers and the sellers who are engaged in the emissions trading for risk management. European Union Emissions Trading Scheme (EU ETS) is the largest carbon market worldwide in terms of market value and trading volume according to [1]. The two major instruments traded in the EU ETS are Certified Emission Reduction (CER) credits since 2007 and the European Union Allowances (EUA) since 2005. As participants in futures markets function as hedgers and speculators, the market may be considered a place for transferring price risks. Therefore, the prices of EU ETS, CER, and EUA futures markets are analyzed in this study.

The relationship between EU ETS spot and futures prices has been empirically analyzed. The earliest time-series analysis of spot market prices conducted by [2]; they reveal that the market fundamentals model is unsuitable for EUA and recommend the use of generalized autoregressive conditional heteroscedasticity (GARCH) model to simulate the price. Current studies are difficult to compare because they cover different time periods and use different approaches. Empirical methodologies are grouped into structured [3] and econometric models [4–23]. Structured

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models used to outline carbon markets, and analyze carbon price movements from the perspective of supply–demand equilibrium [3].

Econometric models include linear models, such as Auto-Regressive and Moving Average Model (ARMA) and vector autoregression (VAR). VAR model is used [4] to analyze the relationship of EUA and CER prices; the results show that these prices significantly affect each other and are cointegrated. Granger-causality tests and identifies futures markets as the leader of the long-run price discovery process to analyze short-run dynamics [5,6]. Moreover, strong bidirectional causality exists between emissions and foreign direct investments with a multivariate Granger-causality test [7]. And unit root and cointegration models are utilized to determine the existence of long-term links and the causal relationship among prices [8–10]. But the central results reject the existence of a long-run relationship between the EU allowance spot and futures prices. However, autoregressive conditional heteroscedasticity (ARCH) and GARCH models to provide an in-depth analysis of the effects of inherent heteroskedastic dynamics on emission allowance returns can be found in [11]. Since then, the high-frequency EUA price dynamics are captured by a fractionally integrated asymmetric power GARCH process is discovered in [12]. Threshold GARCH and Markov switching-autoregressive-GARCH models are employed by Benz and Trück [13] to analyze the relationship between relevant markets and emission allowance futures prices of the EU ETS. In addition to the use of econometric method to study the linear relationship between each other, scholars have recently began studying the asymmetric effects besides using econometric method to study the linear relationship between relevant markets and emission allowance futures prices. VAR and switching transition regression-exponential GARCH models are applied by Arouri et al. [14] to determine the asymmetric and nonlinear effects on returns and volatility of the spot and futures prices in Phase II of the EU emission allowances. The empirical results show that the spot and futures returns of carbon prices are asymmetrically and nonlinearly related.

For nonlinear models, rescaled range analysis ($R/S$) and modified $R/S$ model are used by Feng et al. [15] and reveal that carbon market is a biased random walk characterized by fractals. Empirical mode decomposition (EMD) is proposed by Huang et al. [16], an analytical approach to assess nonlinear and non-stationary time series and decompose time or price series into several independent intrinsic mode functions (IMFs) and one residue. Since then, EMD is adopted for analysis of spot and futures prices, as well as for forecasting and cross-correlation analysis [17–19]. In the present study, we use EMD to analyze the multiscale and multifractality of EUA and CER futures market prices.

Although structured models are used to understand the characteristics of carbon markets, actual application is difficult because constructing an appropriate demand and supply model is complicated under the dynamic and changeable market context. Econometric methods perform well for short term or price-series analysis and forecasting but cannot satisfactorily explain the intrinsic driving force of carbon price changes. The accuracy of $R/S$ analysis is significantly reduced if the sample data sequence is short term or non-stationary. Detrended fluctuation analysis (DFA) is proposed by Peng et al. [20] to address the limitation of $R/S$ analysis. And the detrended fluctuation method "grafting" to a multifractal field and establish multifractal DFA (MFDFA) [21].

In the recent years, an increasing number of researchers, including [22–24], have used DFA or MFDFA to analyze the multifractality of stock markets; although this approach can effectively describe the multifractal and long-term memory characteristics of non-stationary time-series method, it also presents some limitations. For time-series analysis, MFDFA requires detrended processing, in which polynomial fitting is commonly used. Nonetheless, polynomial selection exhibits a variable mode ranging from 1 to $k$ order. Moreover, segmentation of the entire sequence after partition is intermittent because of MFDFA formation. This phenomenon leads to intermittent polynomial fitting adjacent segmentation on the interval, thus introducing new errors of the pseudo wave and causing deviation of the wave function, resulting in distortion of the scaling exponents.

Our work has three objectives. First, we apply EMD and MFDFA-EMD method to investigate whether the daily returns in the selected EUA and CER futures markets are characterized by multiscales and multifractality. Second, we investigate the origins of multifractality of the market prices of EUA and CER futures by using shuffle and surrogate approaches. Finally, we analyze the influence of high returns on multifractality through threshold method.

The paper is organized as follows. Section 2 explains the data and methodology used throughout the paper. Section 3 presents and discusses the empirical results. We conclude the article in Section 4.

## 2. Data and methodology

### 2.1. Data

For futures market, we use daily price series provided by the ECX, which accounts for about 90% of the total daily futures market transaction volume. The EU ETS for carbon emission trading products are artificially divided into three separate stages. The first and pilot period lasted from 2005 to 2007, and the second or relatively "mature period" ranged from 2008 to 2012. The third period is from 2013 to 2020.

We select the settlement prices of EUA and CER futures provided by the ECX from March 14, 2008 to December 31, 2012 as sample data with a total of 1231 samples. We select the annual contract expires in December because the largest trading volume is obtained when the futures contract expires in December. EUA futures market prices (EUAF) and CER futures market prices (CERF) sample data units are in euros per ton of carbon dioxide equivalent. Data are derived from the Wind database.

Future prices and returns of CER and EUA are illustrated in Fig. 1 (a) and (b), respectively. The trend of EUAF and CERF index is identical, but the overall tendency of EUA futures price is slightly higher than that of CER as shown in Fig. 1(a). Moreover, in October 2012 EUA