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Asymmetric market efficiency of the Eurozone using the MF-DFA: a comparison between global financial crisis and COVID-19 era

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Abstract

Purpose – This research paper aims to explore asymmetric market efficiency of the 13 Euro countries, i.e. Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Portugal, Slovakia, Slovenia and Spain, concerning the period before global financial crisis (GFC), after GFC and period of COVID-19 pandemic.

Design/methodology/approach – Multifractal detrended fluctuation analysis (MF-DFA) is applied to examine the persistence and anti-persistency. It also discusses the random walk behavior hypothesis of these 13 countries non-stationary time series. Additionally, generalized Hurst exponents are applied to estimate the relative efficiency between short- and long-run horizons and small and large fluctuations.

Findings – The current study results suggest that most countries' markets are multifractal and exhibit long-term persistence in the short and long run. Moreover, the results with respect to full sample confirm that Portugal is the most efficient country in short run and Austria is the least efficient country. However, in long run, Austria appeared to be highly efficient, and Slovakia is the least efficient. In the pre-GFC period, Greece is said to be the relatively most efficient market in the short run, whereas Austria is the most efficient market in the long run. In the case of Post-GFC, Netherland and Ireland are the most efficient markets in short and long run, respectively. Lastly, COVID-19 results indicate that Finland's stock market is the most efficient in short run. Whereas, in the long run, the high efficiency is illustrated by Germany. In contrast, the most affected stock market due to COVID-19 is Belgium.

Originality/value – This study will add value to the present knowledge on efficient market hypothesis (EMH) with the MF-DFA approach. Also, with the MF-DFA approach, potential investors will be capable of ranking the stock markets of Eurozone countries based on their efficiency in the period before and after GFC and then specifically in the period of COVID-19.

Keywords Global financial crisis, COVID-19, Efficient market hypothesis, MF-DFA

Paper type Research paper

1. Introduction

The global financial crisis (GFC) and COVID-19 share uncertainty as a significant element after originating in one of the two leading economies (the USA in 2008 and China at the end of 2019). Moreover, both crises severely affect the stock markets, resulting in an economic downturn. Hence, there is a need to consider both situations collectively to analyze the efficiency of stock markets. Therefore, to explore the financial markets' efficiency, a new concept, the efficient market hypothesis (EMH), has been introduced; it has become the investor's favorite device to understand any financial market's quality

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and efficiency. According to Fama (1970), an efficient market (even in its weak form) is if prior information enclosed in price movements is entirely explained in the current prices. Therefore, it is challenging for investors to earn abnormal profits and predict prices based on past statistics. Further, if an efficient market exhibits random walk behavior, the new information is more likely to lessen or exaggerate the prices in an inefficient market, resulting in a severe impact on efficient resource allocation (Ali *et al.*, 2018; Mensi *et al.*, 2017).

The EMH has a significant role in financial literacy in understanding financial markets' behavior and performance. As per the EMH theory presented by "Fama (1970), 1998", any sensible investor can forecast market efficiency with a given market's share price index information. It further stated that if the asset price rapidly shows variation due to the current relevant market information or the asset price is market sensitive, such a market is called a weak-form efficient market. It is not easy for investors to procure abnormal profit in a given situation because of asset price fluctuation, and no one can predict market price and condition. So, the validity of EMH suggests that it is the primary key to predicting such probable gain. There are three significant well-known market situations depending on the market behavior: bear, standard and bull markets. In a stock market, no one can predict the investor's behavior. However, in the other two bear and bull markets, investors' behavior can easily be examined as either aggressive "Greed" or defensive "Fear." In these risky situations, investors can make irrational decisions due to herding behavior, resulting in a variation in stock prices and economic features (Baker and Wurgler, 2006). Many global and regional black swan events have recently distressed the global markets. In discussed techniques, market crashes can occur directly, while the rise in the stock price over a long time confirms asymmetric effects in stock markets (Ni *et al.*, 2015).

Share price indices measure the variation in the stock's value; it states the investor's return on their investment and expresses the variation in the market capitalization. The stock market is a complicated and dynamic structure sensitive to various internal and external variables (Boubaker and Raza, 2017). Exchange institutes and investors are the primary sources of internal influences. Further, external factors that make stock market vulnerable are policies and changes by the governments (Raza and Jawaid, 2014). Also, some crucial events play a major role in affecting stock markets (Mensi *et al.*, 2022). Several researchers have inspected the influence of important events, such as crises, on the stock market's efficiency (Anagnostidis *et al.*, 2016; Mensi *et al.*, 2017; Tiwari *et al.*, 2018). Managi and Okimoto (2013) declared that abrupt "big" shocks, like GFC of 2008, generate structural changes in financial and commodities markets that might result in asymmetric impacts on market efficiency, volatility spillovers and portfolio allocations. Hence, it stimulates the importance of exploring the GFC and COVID-19 effects on the efficiency of these markets. Therefore, in this study, the EMH concept is tested on 13 Eurozone countries with the support of MF-DFA recommended by Kantelhardt *et al.* (2002). The roles of GFC and COVID-19 have been investigated to reflect these countries' stock markets' efficiency by using share price indices data. That is a more flexible and efficient approach than other approaches of analyzing the multifractal (long-term persistent) features of time series having non-stationary properties (Mensi *et al.*, 2017; Bouoiyour *et al.*, 2018).

We have divided the contribution of current study into multiple roles; first of all, this study will add value to the present knowledge on EMH via the estimation of the MF-DFA approach. As the name implies, MF-DFA is based upon the combination of the following two procedures, i.e. "multifractal methods (MF) and detrended fluctuation analysis (DFA)." Mandelbrot *et al.* (1997) considered the MF method a monofractal approach. Conversely, Chen *et al.* (2002) state that DFA is useful in assessing noisy time series and non-stationary long-term correlations, hence, said to detect monofractal scaling technique. Horvatic *et al.* (2011) claim that the MF-DFA approach expands Kantelhardt *et al.* (2002) DFA method. In this way, it assists in exploring stochastic process's multifractal spectrum for a financial time series (Raza *et al.*, 2021). Some other benefits are: "removal of the monofractal and multifractal behavior of the financial data, assessment of volatility's long-run correlations, degree of time-varying efficiency, and predictability of financial series." Furthermore, this method provides a valid multifractal classification of non-stationary multifractal financial time series. Such attributes of MF-DFA are said to be more interesting than other econometrics approaches. In present research, MF-DFA contributes to the information concerning range memory, random walk behavior, degree of persistency and Eurozone's market efficiency. Secondly, the application of the MF-DFA approach will make potential investors capable enough to rank the stock markets of these Eurozone countries based on their efficiency in the following periods: full sample, pre and post-GFC and period of COVID-19. Thirdly, 13 European countries for the analysis have been targeted. However, prior research by Cao *et al.* (2013) is based on a similar approach, but a point of difference is the selected country. Moreover, prior authors employed MFDFA in analyzing Shenzhen and Shanghai stock markets concerning asymmetric multifractal scaling behavior.

2. Literature review

The literature includes various studies which have explored the efficiency of different markets through MF-DFA. For instance, research conducted by (Tiwari *et al.*, 2018) focused on eight developed countries for investigating their efficiency. The authors employed "the MF-DFA approach" and observed that most markets were highly efficient in the long run. Furthermore, Rizvi *et al.* (2014) claimed that progressive markets are highly efficient; hence, less efficient are the Islamic states' markets. Different results were found by Ali *et al.* (2018) that Islamic markets are found to be more efficient than conventional ones after using the MF-DFA method. Arshad *et al.* (2016) selected the "Organization for Islamic Conference (OIC)" countries and explained that complete efficiency is different across the OIC based on the MF-DFA approach. Stakić *et al.* (2016) examined that the stock market is inefficient after using daily return data from 2006 to 2013. Anagnostidis *et al.* (2016) revealed a significant mean-reverting behavior established after the crisis, and markets are near to random walk behavior before crises.

Rizvi and Arshad (2017) claimed that Japanese stock markets were most efficient during the global crisis period. Moreover, Dow Jones Islamic stock index sectors were targeted by Mensi *et al.* (2017) for testing these markets' efficiency and multifractality. For this purpose, the authors employed MF-DFA. The results indicate that in the long term, efficiency is higher and time-varying. Cao *et al.* (2013) targeted China for the examination of stock markets' uptrend and downtrend multifractality. Thus, the authors used asymmetric MF-DFA. The analysis reveals that uptrends have stronger multifractality than downtrends. In the literature, some studies are available that used the same method in the cryptocurrency, gold, green bonds and conventional bond markets. Such as, Al-Yahyaee *et al.* (2018) emphasize Bitcoin, gold, currency (USD index) and world stock markets' long memory and efficiency. Authors found that long memory and multifractality are present in all investigated return series, and these features are more prominent in the Bitcoin market than in other traditional markets. Likewise, green and conventional bond markets' efficiency was studied by (Naeem *et al.*, 2021). The authors divided the analysis into two periods, i.e. pre and during the pandemic of COVID-19. Hence, to meet this goal, the authors employed the approach of MF-DFA.

Literature consists of several studies that inspect the impact of GFC on market efficiency. For instance, the research investigated 15 emerging European stock markets for their efficiency (Smith, 2012). The results exhibit a severe influence of GFC on the stock markets' efficiency. Kumar and Deo (2013) emphasize the effects of GFC (pre and during crisis) on twenty international financial indices using MF-DFA. It was disclosed that some indices hold significant discrepancies in multifractal degrees in both periods. Majumder (2012) in the context of US and BRICS markets, reveals that before the period of GFC, the US market was highly efficient than others but became inefficient after the crisis. Finally, Mensi *et al.* (2017) considered Islamic stock markets to test the effect of GFC. They employed the MF-DFA approach to examine the efficiency of these markets in the short and long run and concluded that after GFC, most of the markets' efficiency was weakened.

Further, Adu *et al.* (2015) targeted the BRICS countries' stock returns and concluded that China and India's stock markets do not depend on the unit of measurement; on the contrary, Brazil and South Africa's market prediction is dependent on the unit of measurement. Sensoy *et al.* (2015) explored that conventional equity markets are found to be highly efficient than Islamic equity markets. GFC and the succeeding Eurozone sovereign debt crisis underline the higher level of dependency among markets and reveal a degree of asymmetry that exists internally and among markets.

3. Methodology

The share price indices data from June 1994 to August 2022 is used to examine the efficiency of the markets of 13 Euro area countries. The research further divided the full sample into pre-GFC post-GFC and COVID-19 periods.

3.1 Multifractal detrended fluctuation analysis

The two most used methods in the literature are MF-DFA and MF-DCC, but MF-DFA is the most effective and better approach (Shahzad *et al.*, 2017). To detect the scaling behavior that has multifractal features in non-stationary time series, MF-DFA is a better technique. In addition, this method delivers evidence on the long-term memory, level of persistency and efficiency of stock markets. Previously rescaled range analysis "R/S" was used to analyze the long-range correlation behavior of non-stationary time series. However, MF-DFA is a better tool than rescaled range analysis because it avoids the miscalculation of correlation. Furthermore, to analyze the persistence, anti-persistency in the series (mean-reverting process) and random walk behavior, MF-DFA is a better method.

The MF-DFA approach developed by Kantelhardt *et al.* (2002) is applied to examine Eurozone countries' market efficiency. MF-DFA is comprised of five steps as follows.

Let "$\{X_{t,} t = 1, \ldots, N\}$" be a time series.

Step1. Define the profile

$$Y_k \equiv \sum^{k} t = 1[x_i - \overline{x}], k = 1, \ldots, N, \tag{1}$$

Where $\overline{x}$ represents the average of the entire time series.

Step2. Divide the profile "y_i" into "$Ns \equiv f(N/s)$" non-overlapping segment windows of equal length *s*.

Step 3. Compute the local trend for each of the two N's by the least-squares fit of the series and calculate variance:

$$F^2(s,v) = \frac{1}{s}\sum^{s} i = 1\{y[(v-1)s+i] - y_v(i)\}^2 \quad (2)$$

For "v = 1,2, ...,N_s," and

$$F^2(s,v) = \frac{1}{s}\sum^{s} i = 1\{y[N-(v-N_s)s+i] - y_v(i)\}^2 \quad (3)$$

For v = N_s +1, . . .,2N_s.

Step 4. The "*q*th" order fluctuation function "$F_q(s)$" is determined by averaging all segments.

$$F_q(S) = \left\{\frac{1}{2N_s}\sum^{2Ns} v = 1\left[F^2(s,v)\right]^{\frac{q}{2}}\right\}^{\frac{1}{q}} \quad (4)$$

Step 5. Define the scaling behavior of fluctuation functions by analyzing log-log plots "Fq(s)" versus s for each level of "q."

If there is a correlation between the series "xi" in the long term, then "Fq(s)" increases for large values of s, according to power law:

$$F_q(S) \sim S^{h(q)} \quad (5)$$

In general, "h(q)" the exponent describes the criteria for whether the time series is monofractal or multifractal; if "h(q)" is not dependent on q, time series is monfractal otherwise multifractal when "h(q)" is dependent on "q," meaning that the small variation "(q < 0)" and large variation "(q > 0)" of scaling behavior is different. Where "h(q)" is a generalized Hurst exponent, when in the case of stationary series, "h (2)" is the same as the well-known Hurst exponent(H). To examine the correlation in the time series, the scaling exponent "h (2)" is used when "h (2) = 0.5". It explains that series are not correlated and follow a random walk process when "0.5< h (2) <1" indicates long-term persistence series (long-memory), and "0< h (2) >0.5" shows anti-persistence series (mean-reverting process).

4. Empirical results

4.1 Preliminary analysis

Descriptive statistics are explained in Table 1. The results depict that the Jarque-Bera time series of all countries is not normally distributed, indicating the properties of high-pitched peaks and fat-tailed distributions. Furthermore, Augmented Dickey and Fuller's (1979) analysis indicates that all series are stationary at a 1% level of significance. Skewness and Kurtosis results of all series show asymmetry and leptokurtic series.

4.2 Multifractal detrended fluctuation analysis (MF-DFA)

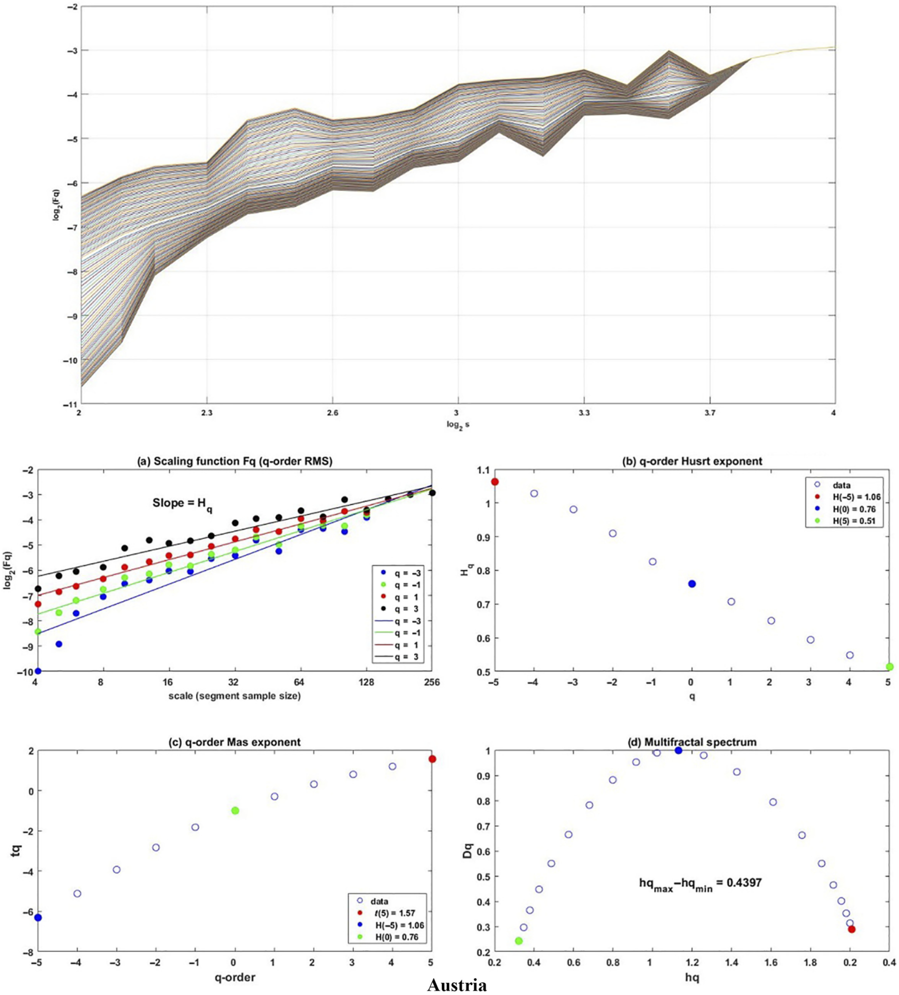
The share price indices' fractal properties are explained by a log-log plot on the length scale and the order of fluctuation effect. A scaling range is vital to decide a linear behavior, as it axes on both lower and upper limits. The current study scaling behavior of the given share price indices is exhibited in Figure 1(a–m). It is clear from these figures that the local slope of these 13 countries' plots changes with crossover time scale (logs*) = 3.3 in the case of overall

Table 1. Descriptive statistics and results of unit root test

	Mean		Maximum	Minimum	Std. Dev	Skewness	Kurtosis	J-B	ADF test
Austria	0.0014	0.0043	0.0672	−0.1731	0.0217	−2.1641	16.9880	2751.45***	−11.19***
Belgium	0.0015	0.0043	0.0477	−0.1182	0.0179	−1.2951	8.9892	546.42***	−11.00***
Finland	0.0024	0.0051	0.1136	−0.1113	0.0277	−0.3689	5.0740	62.18***	−11.35***
France	0.0017	0.0045	0.0478	−0.0878	0.0191	−0.9573	5.4128	121.75***	−11.43***
Germany	0.0016	0.0046	0.0566	−0.1016	0.0208	−1.0672	5.9614	171.01***	−11.27***
Greece	0.0000	0.0007	0.1315	−0.1341	0.0331	−0.0357	4.2883	21.36***	−11.15***
Ireland	0.0019	0.0051	0.0625	−0.1381	0.0218	−1.4515	8.9053	555.68***	−11.11***
Italy	0.0008	0.0023	0.0730	−0.0985	0.0227	−0.5205	5.1158	71.35***	−11.62***
Netherland	0.0016	0.0051	0.0550	−0.1323	0.0202	−1.5389	9.6807	694.34***	−11.73***
Portugal	0.0019	0.0025	0.0584	−0.0959	0.0205	−0.5324	4.9175	61.73***	−13.83***
Slovakia	0.0004	0.0001	0.0897	−0.1418	0.0221	−0.3858	9.8899	616.84***	−15.22***
Slovenia	0.0068	0.0017	1.6809	−0.0898	0.0988	15.8637	269.3924	923.92***	−23.12***
Spain	0.0015	0.0025	0.0595	−0.0761	0.0210	−0.4700	4.1566	28.50***	−11.30***

Note(s): J-B = Jarque-Bera test of Normality, ADF = augmented Dickey and Fuller (1979) test and KPSS = Kwiatkowski *et al.* (1992) test of stationary. *** denotes the rejection of null hypothesis at the 1%"

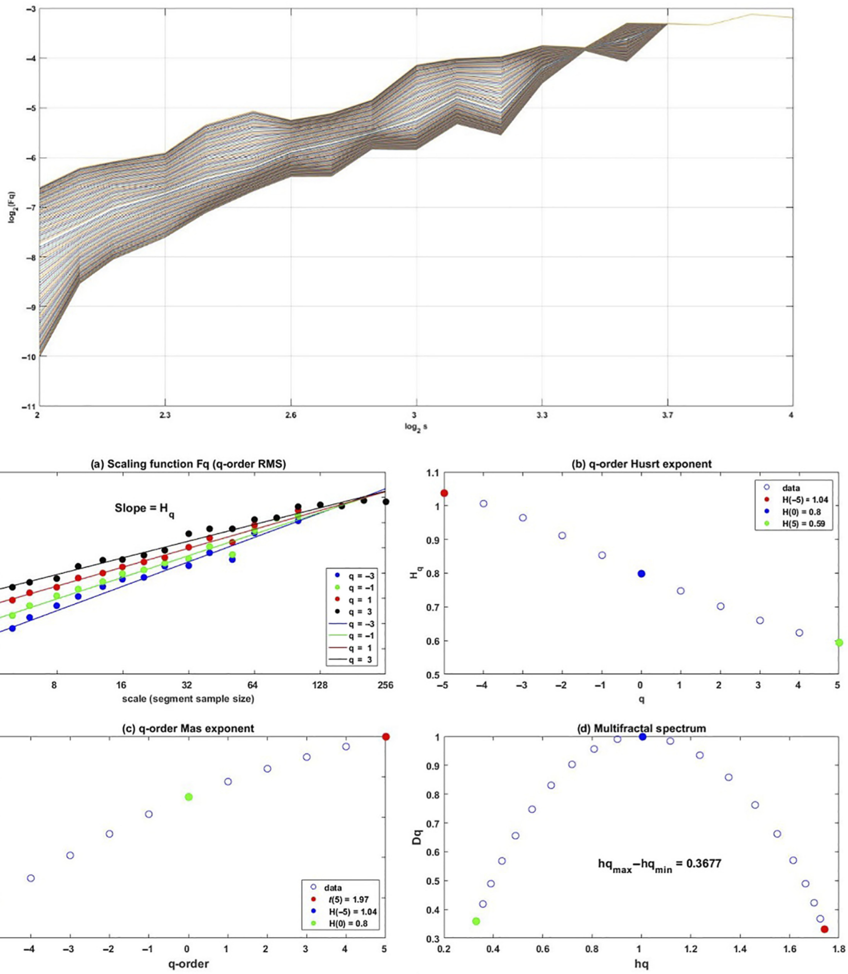
Source(s): Authors' Estimation, Table 1 by authors



Austria
(a)

Figure 1.
(a–m) Scaling behavior of the given share price indices

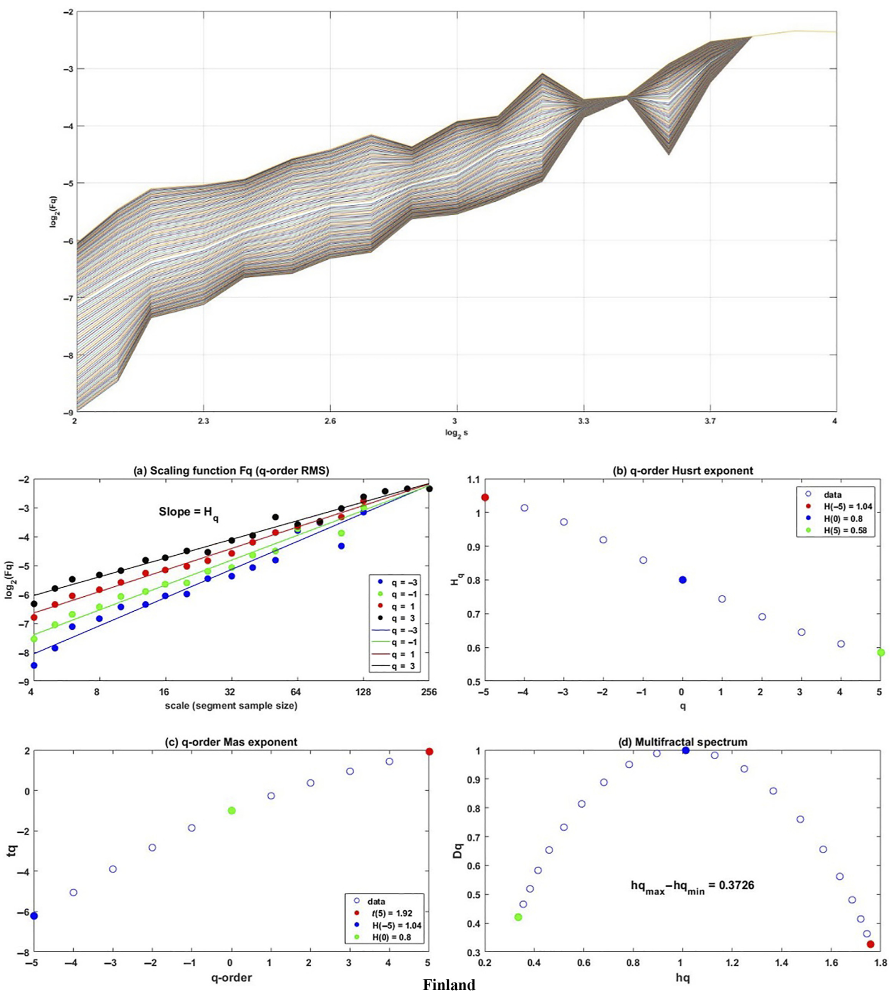
(*continued*)



Belgium

(b)

Figure 1. (*continued*)

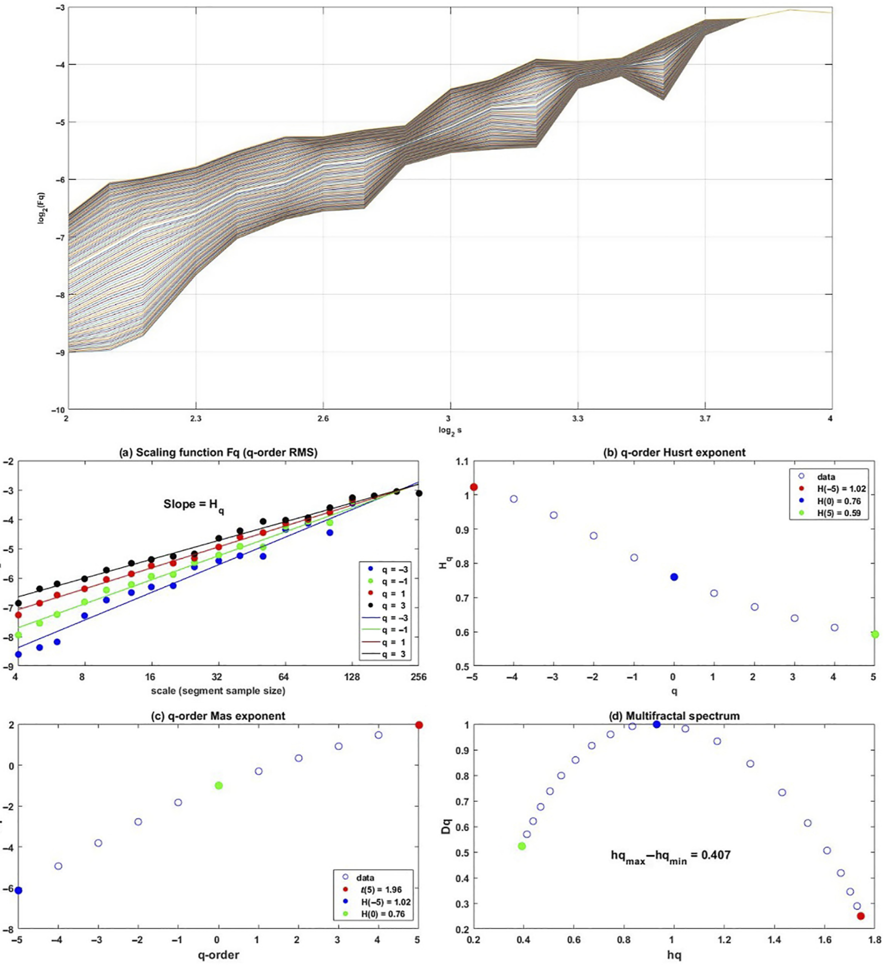


Finland

(c)

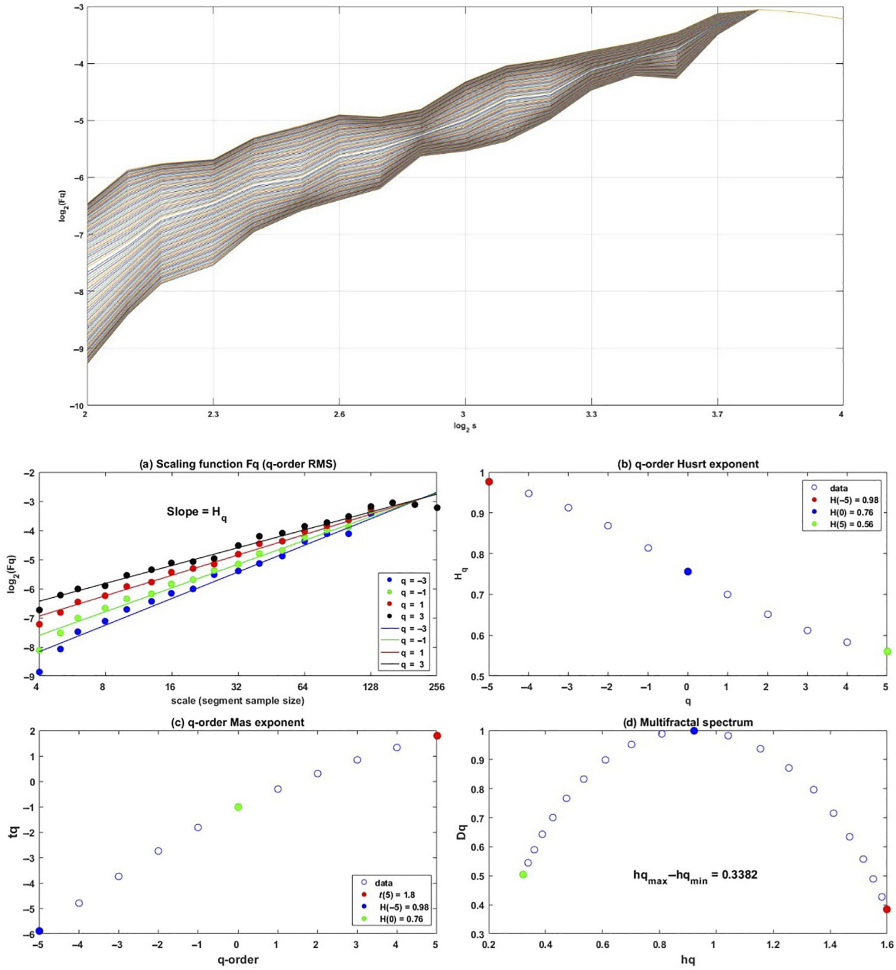
Figure 1.

(*continued*)



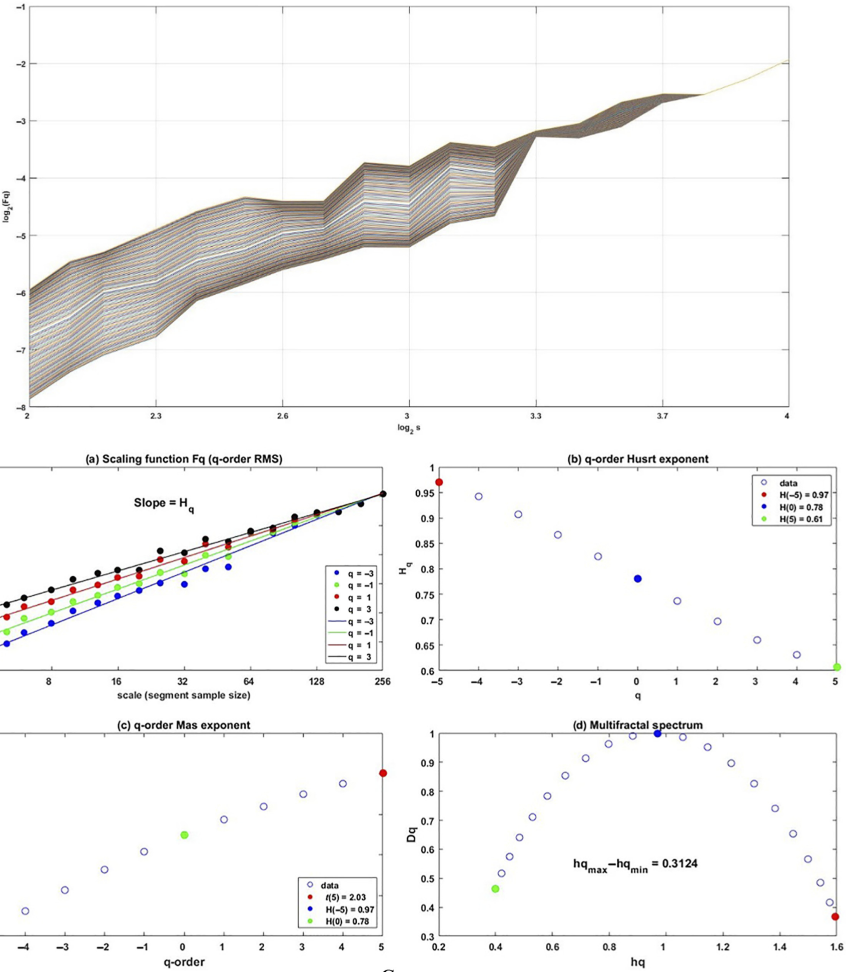
France
(d)

Figure 1. (*continued*)



Germany
(e)

Figure 1.
(*continued*)

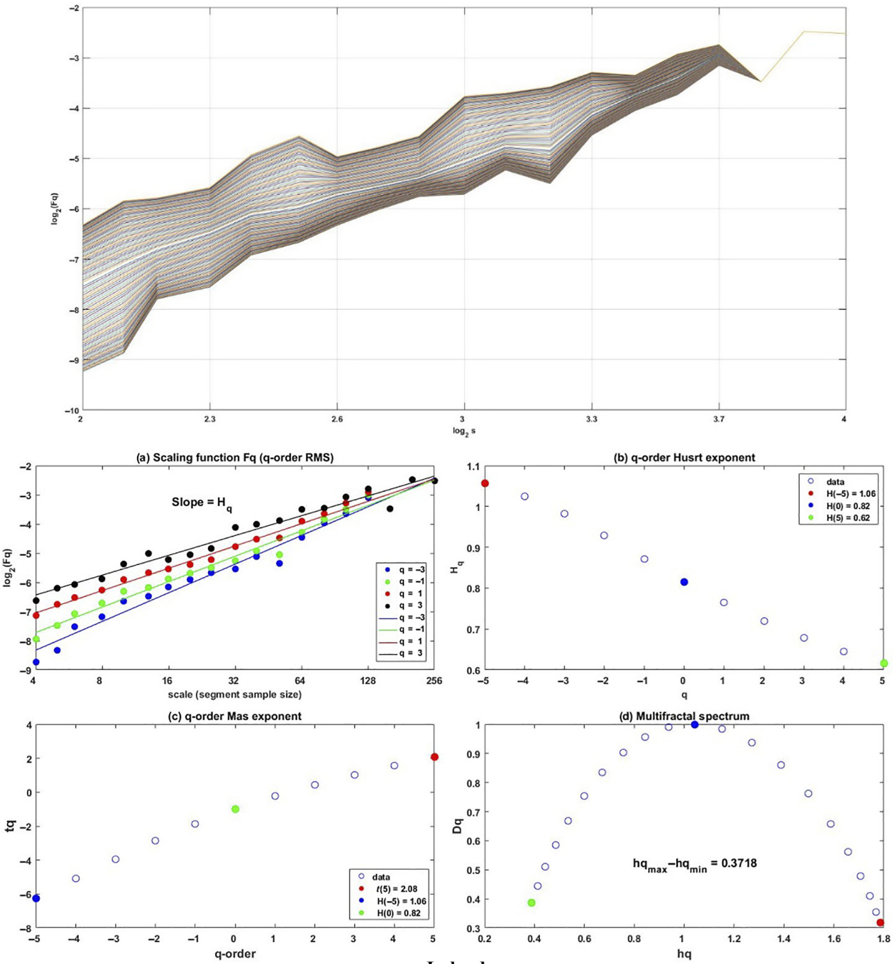


Greece

(f)

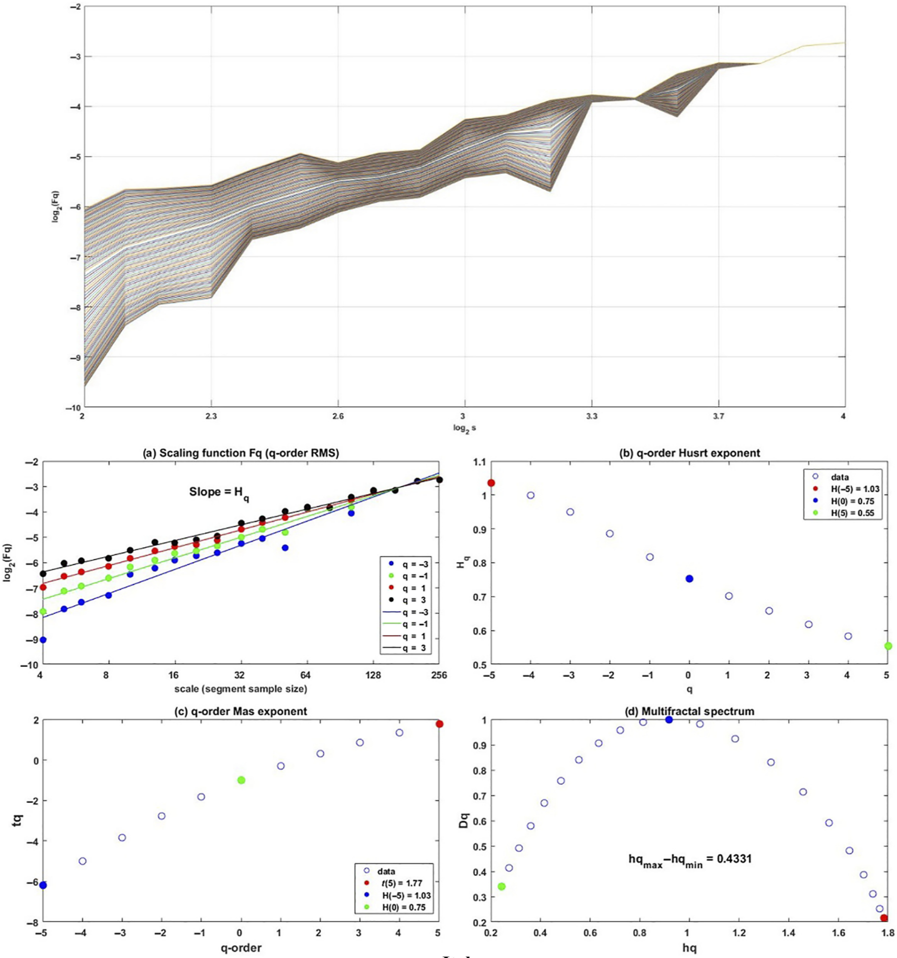
Figure 1.

(*continued*)



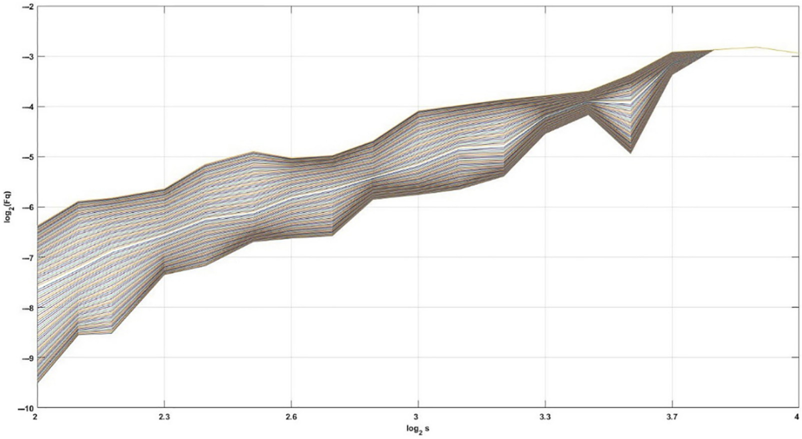
Ireland
(g)

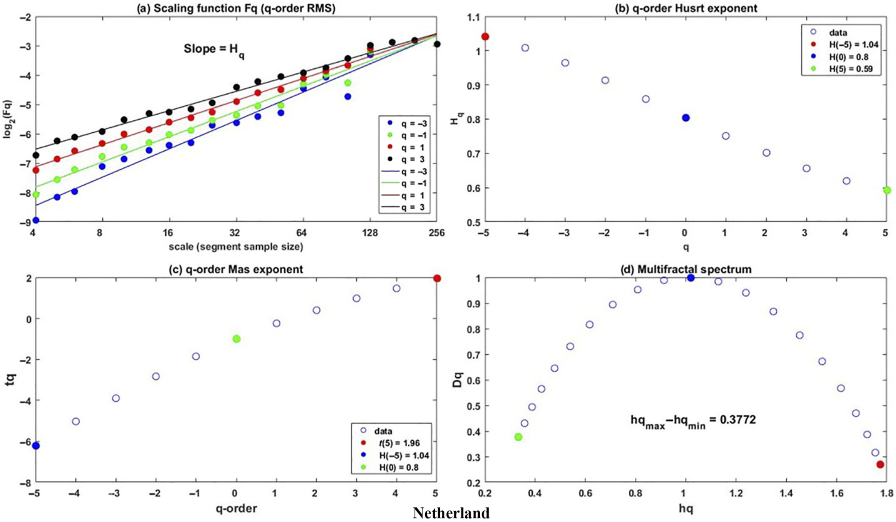
Figure 1. (*continued*)



Italy
(h)

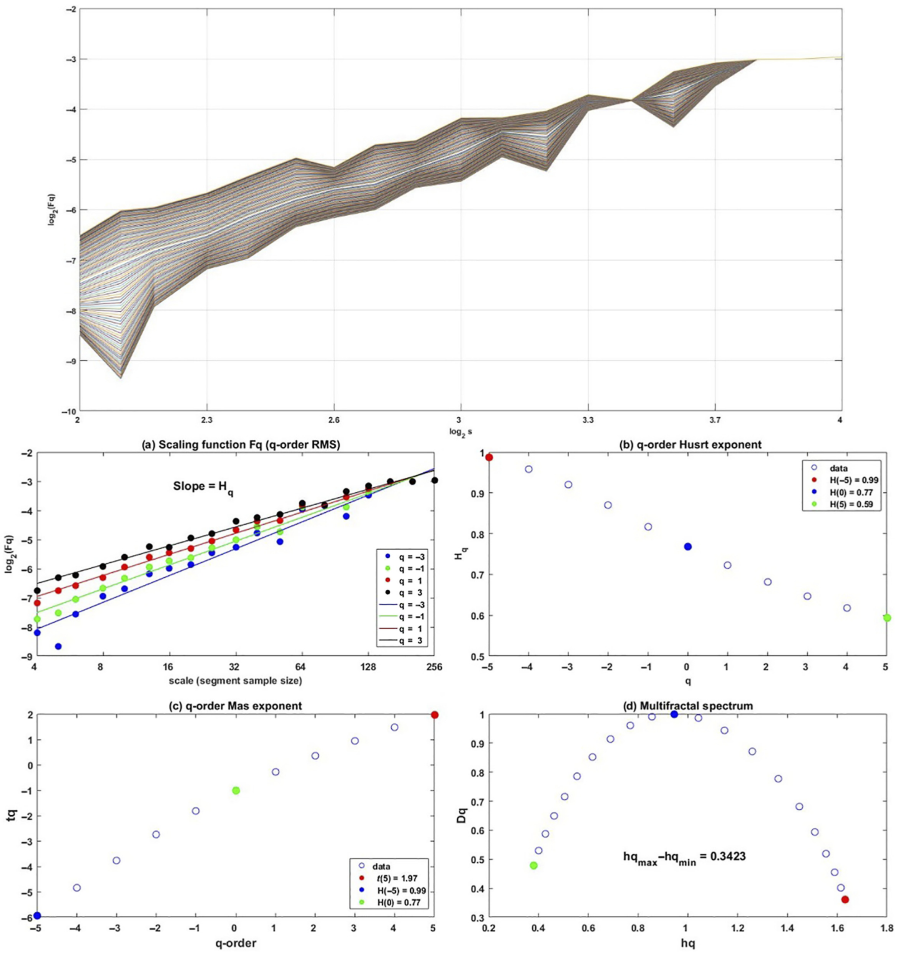
Figure 1. (*continued*)





Netherland
(i)

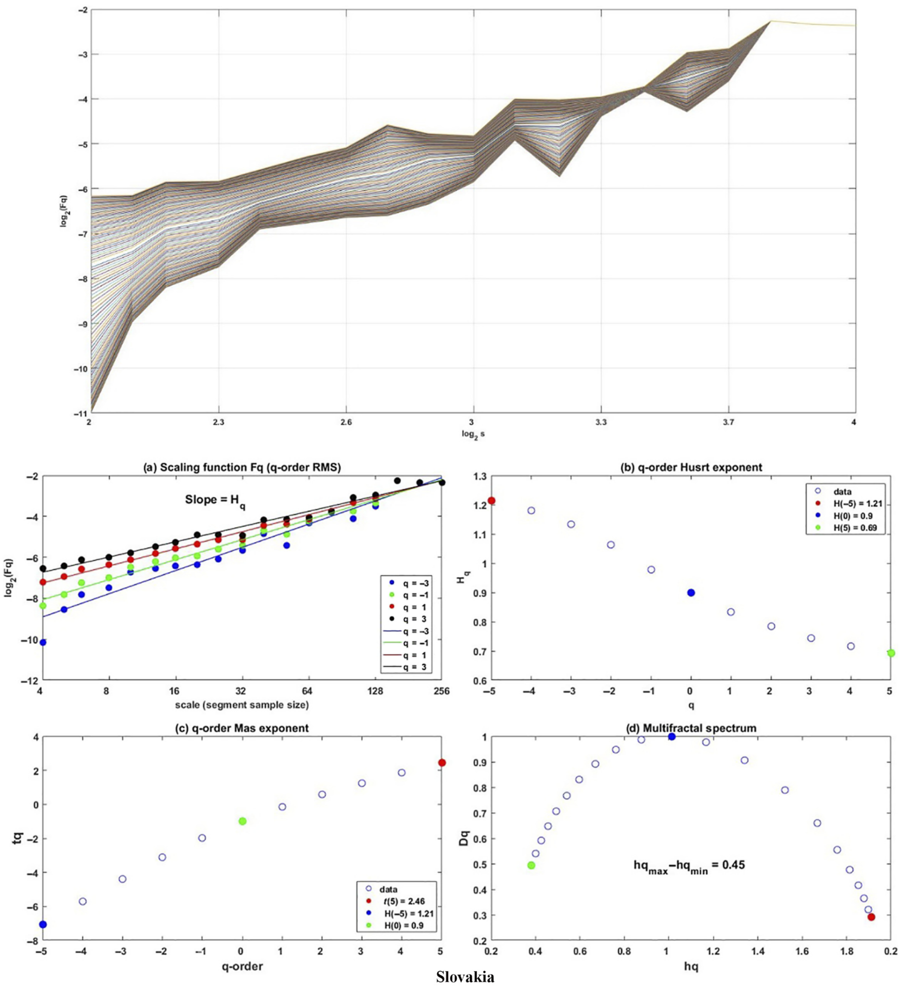
(*continued*) **Figure 1.**



Portugal
(j)

Figure 1.

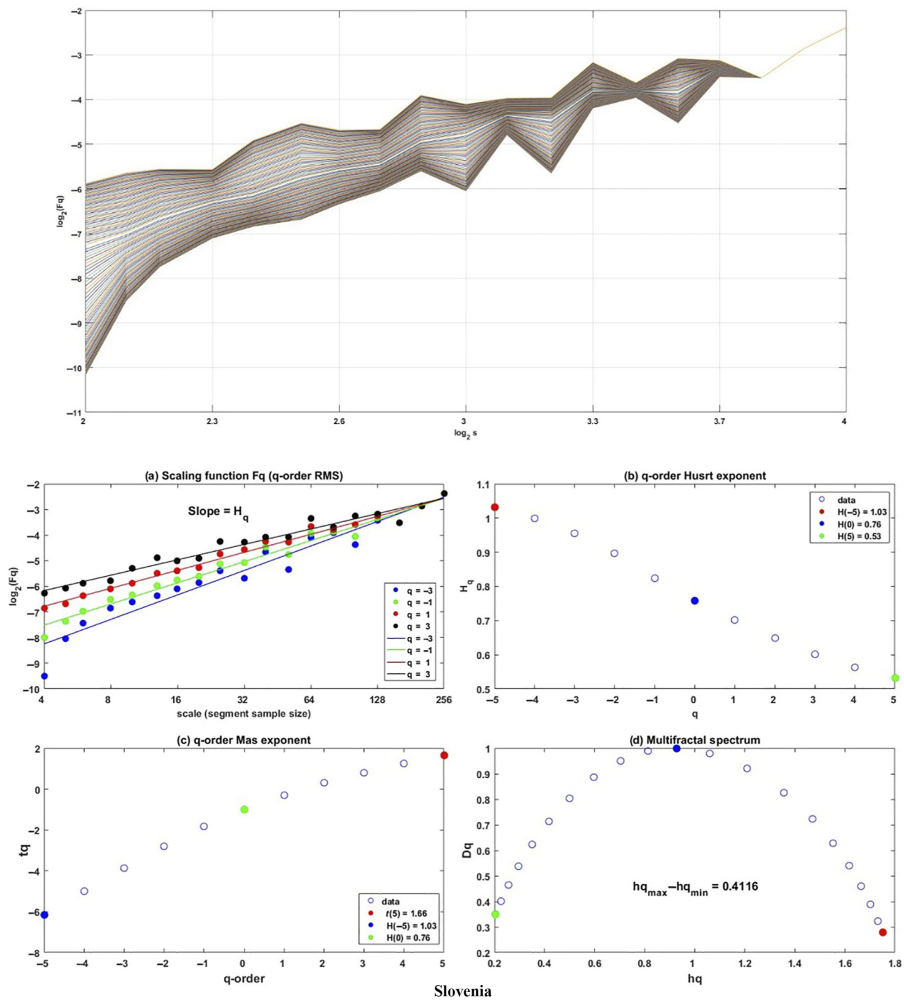
(*continued*)



Slovakia
(k)

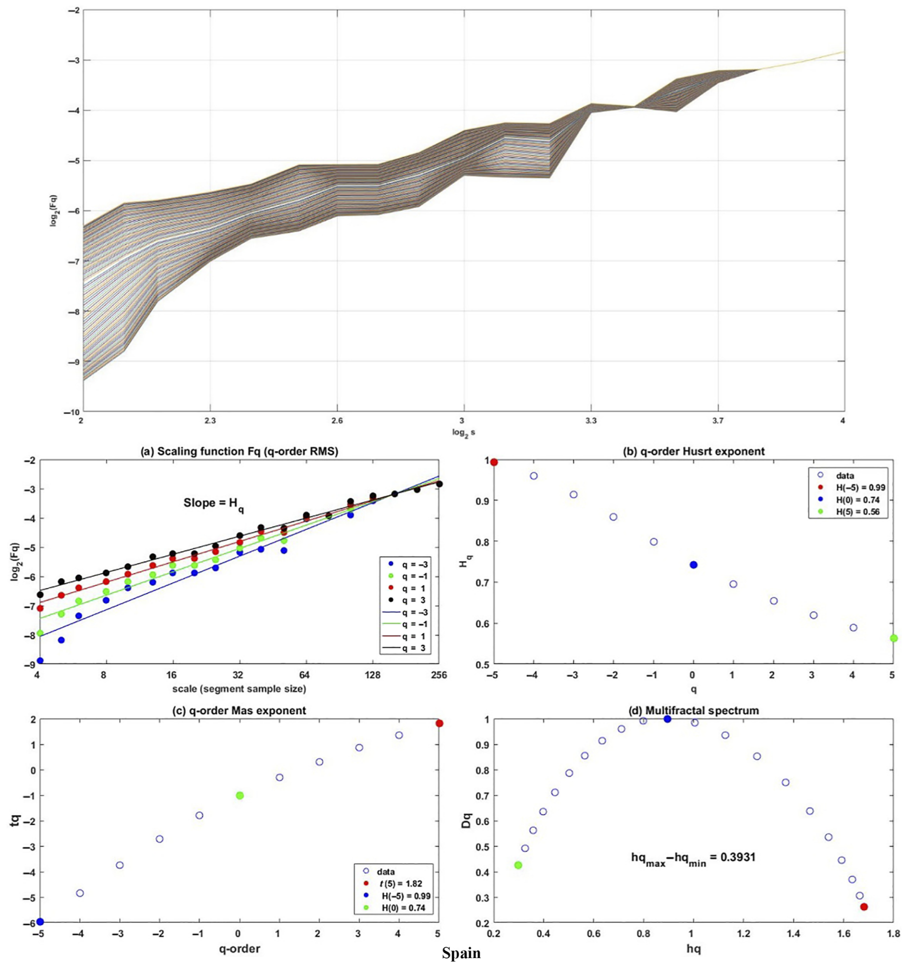
(*continued*)

Figure 1.



Slovenia
(l)

Figure 1. (*continued*)



Spain
(m)

Source(s): Autors' Estimation, Figure 1 (a-m) by authors

Figure 1.

data of all 13 countries, but in this study, we are also analyzing the effect of the GFC, in case of before GFC the crossover time scale for all countries is logs* = 3.9 except in case of Austria, Belgium, France and Germany where crossover time scale logs* = 3.7, but after GFC the crossover time scale for all countries is same that is logs* = 3.3. The crossover point varies at a different time of scale because of the unlike properties of time series. This is the case of two different time scales of stock markets one is the short-run component when s* < s, and the other is the case of the long-run component when s* > s; the MF-DFA approach is used to stud these two-time scales of the stock market of selected 13 Eurozone countries. The q-order Hurst exponent graphs of all 13 countries exhibit proof of multifractality in the time series of these selected countries as h(q) vary with the variation in (q), and there is a decreasing trend in the case of this sample size. The multifractal spectrum graph shows the large arc for the multifractal time series and the small for the monofractal time series. This graph also calculates the amplitude of the fractal spectrum as it is the difference between hq_{maxi} and $hq_{mini;}$ in our case, Slovakia has the most massive multifractal strength (0.45), and Greece the least multifractal strength (0.31).

4.2.1 Discussion of full sample results. Output Table 2 represents the slopes of generalized Hurst exponents h(q). The upper bound for q is 5, and the lower bound for q is −5 for large fluctuations $q > 0$ and small fluctuations $q < 0$. Moreover, h(q) is not constant and dependent on q, showing that all 13 countries' share price indices have multifractal properties. h(q) explains the scaling behavior of these countries with small and large fluctuations. Further, h(q) for $q < 0$ is higher than h(q) for $q > 0$. This scaling behavior is explained by the stock markets of these 13 countries, estimating long-memory features better in short-term fluctuations than in long-term fluctuations. All h(q) is more significant than 0.5 in both small and large fluctuation, i.e. "$q < 0$ ($q > 0$)," which shows long-term persistence in stock markets of all selected countries. At $q = -5$, Austria is the most constant stock market in the short run, with the series' highest h(q) value (4.021). Greece, in the long run, is chiefly the persistent market with the highest h(q) value (1.019) of the series, and as the h(q) value in both cases exceeds 0.5, both countries are showing more substantial long-term persistence in the short run. To predict the long-term or large fluctuation, we focused on $q = 2$, clearly showing deviation from random walk behavior as all h(q) values are different from 0.5; the same is the case; in the long run, all countries series show long-term persistence as all h(q) are more significant than 0.5. The results of prior literature (Mensi *et al.*, 2019) and (Sensoy and Tabak, 2015) depict similar results. According to Sensoy and Tabak (2015), the literary discourse on random walk behavior has shown negative autocorrelations in the long term. Consequently, in the long run, stock market returns are mean-reverting. Further, in previous studies, it has been found that all series exhibit multifractality; hence, if we compare short and long fluctuations, it is revealed that multifractality is more prominent in short fluctuations than long. It is concluded that investors can predict their future returns based on MF-DFA results, as in our study, most of the countries' markets are presenting long-term persistence. It implies that these markets will be positive in the future if, currently, their returns are complimentary. However, it is also dependent on countries' economic conditions.

4.2.2 Discussion of GFC and COVID-19 results. In Table 3 at $q = -5$, all countries show long-term persistence in the short and long run. Austria has the largest (q) value, the most persistent in the short run, and Portugal has the highest h(q) value, the most persistent in the long run. However, in case of large fluctuation when $q = 2$, all countries have long term persistence except Austria and Slovenia; both countries are mean-reverting or anti-persistence in the long term as $h(q) < 0.5$, which shows that future returns of these two markets are capable of returning to a long-term mean. In the case of Austria and Slovenia, their market scaling behavior is anti-persistence. These results align with past studies' results (Smith, 2012; Sensoy and Tabak, 2015). The findings of Smith (2012) claimed that in the case of the following stock markets "Croatian, Hungarian, Polish, Portuguese, Slovakian, and UK," GFC is highly linked with return predictability. Moreover, the following stock markets "Greece, Latvia, Romania, Russia, and Turkey" observe a minor influence of crisis on weak-form efficiency. Authors also claim that the efficiency of "Croatia, Estonia, Slovenia, and Portugal markets" has deteriorated badly because of the crisis.

Table 4 portrays that at $q = -5$ in the short-term fluctuation, Slovakia is the most persistent country in both the short and long run. At $q = 2$ in the case of long-term fluctuation, most of the countries are showing long term persistency having $h(q) > 0.5$ except Belgium, Finland, France, Germany, Ireland and Italy. While the Netherlands is showing short-term persistence in both the short and long run as h(q) is less than 0.5, these countries' market returns will be negative in the future if it is currently positive. Only two countries' markets show anti-persistent or malicious autocorrelation behavior; after the GFC, seven countries' markets exhibit anti-persistent autocorrelation. These markets' anti-persistent behavior

Table 2. Generalized Hurst exponents of full sample for short and long term components from −5 to 5

Country	Austria		Belgium		Finland		France		Germany		Greece		Ireland	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	4.021	0.738	3.043	0.969	2.678	0.902	1.985	0.924	1.939	0.899	1.676	1.019	2.608	0.990
−4	3.896	0.726	2.823	0.957	2.471	0.889	1.881	0.903	2.003	0.881	1.604	0.993	2.468	0.968
−3	3.602	0.715	2.486	0.942	2.166	0.873	1.741	0.878	2.035	0.860	1.515	0.960	2.236	0.944
−2	2.965	0.704	2.016	0.924	1.763	0.853	1.563	0.849	1.945	0.833	1.401	0.918	1.900	0.915
−1	2.018	0.697	1.520	0.899	1.382	0.826	1.355	0.816	1.676	0.801	1.265	0.867	1.513	0.884
0	1.384	0.687	1.163	0.864	1.181	0.786	1.158	0.778	1.338	0.761	1.132	0.808	1.181	0.846
1	1.115	0.652	0.964	0.815	1.144	0.738	1.036	0.738	1.112	0.716	1.039	0.747	0.971	0.800
2	0.983	0.574	0.868	0.753	1.187	0.693	0.991	0.698	1.016	0.671	0.997	0.689	0.878	0.740
3	0.912	0.484	0.831	0.686	1.251	0.655	0.982	0.662	0.978	0.631	0.993	0.638	0.856	0.674
4	0.872	0.411	0.826	0.627	1.307	0.626	0.982	0.631	0.955	0.599	1.008	0.596	0.862	0.617
5	0.848	0.361	0.834	0.579	1.349	0.603	0.982	0.605	0.937	0.572	1.030	0.562	0.873	0.572

Country	Italy		Netherland		Portugal		Slovakia		Slovenia		Spain	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	2.984	0.947	2.494	0.965	1.754	0.967	3.699	1.076	3.532	0.917	2.913	0.896
−4	2.819	0.923	2.336	0.945	1.685	0.944	3.469	1.054	3.356	0.892	2.789	0.875
−3	2.558	0.894	2.122	0.923	1.572	0.917	3.073	1.026	3.036	0.864	2.567	0.851
−2	2.147	0.859	1.839	0.898	1.399	0.882	2.384	0.990	2.457	0.833	2.190	0.824
−1	1.600	0.817	1.498	0.869	1.199	0.841	1.614	0.947	1.631	0.799	1.698	0.793
0	1.168	0.771	1.198	0.830	1.031	0.794	1.272	0.898	1.061	0.756	1.283	0.758
1	0.970	0.723	1.032	0.779	0.918	0.744	1.109	0.850	0.838	0.699	1.050	0.718
2	0.875	0.675	0.972	0.716	0.864	0.694	0.968	0.808	0.731	0.632	0.939	0.677
3	0.795	0.631	0.944	0.654	0.854	0.649	0.848	0.773	0.646	0.572	0.883	0.639
4	0.715	0.593	0.912	0.602	0.868	0.611	0.759	0.744	0.569	0.527	0.851	0.606
5	0.644	0.560	0.875	0.560	0.891	0.580	0.699	0.721	0.501	0.495	0.832	0.578

Source(s): Authors' Estimation, Table 2 by authors

Table 3. Generalized Hurst exponents of before the GFC sample for short and long term components from −5 to 5

Country Order of q	Austria Short-term	Austria Long-term	Belgium Short-term	Belgium Long-term	Finland Short-term	Finland Long-term	France Short-term	France Long-term	Germany Short-term	Germany Long-term	Greece Short-term	Greece Long-term	Ireland Short-term	Ireland Long-term
−5	3.202	0.753	1.509	0.782	1.647	0.999	1.143	0.951	1.319	0.917	0.894	0.863	1.720	0.878
−4	3.006	0.736	1.488	0.775	1.537	0.955	1.104	0.928	1.359	0.900	0.883	0.852	1.668	0.854
−3	2.682	0.717	1.438	0.767	1.378	0.894	1.063	0.898	1.395	0.879	0.874	0.841	1.572	0.823
−2	2.171	0.693	1.344	0.757	1.172	0.818	1.022	0.861	1.386	0.851	0.863	0.826	1.407	0.786
−1	1.589	0.663	1.206	0.742	0.984	0.743	0.977	0.819	1.276	0.811	0.844	0.801	1.181	0.742
0	1.224	0.620	1.066	0.718	0.887	0.694	0.929	0.774	1.094	0.759	0.822	0.759	0.973	0.690
1	0.989	0.563	0.958	0.683	0.846	0.672	0.892	0.730	0.958	0.701	0.803	0.701	0.820	0.632
2	0.778	0.494	0.882	0.639	0.813	0.656	0.865	0.691	0.888	0.650	0.793	0.642	0.712	0.571
3	0.602	0.424	0.831	0.594	0.782	0.638	0.844	0.659	0.845	0.609	0.794	0.593	0.633	0.511
4	0.483	0.363	0.797	0.555	0.755	0.617	0.828	0.635	0.810	0.579	0.799	0.556	0.572	0.459
5	0.412	0.315	0.775	0.523	0.734	0.598	0.815	0.616	0.782	0.557	0.801	0.528	0.521	0.417

Country Order of q	Italy Short-term	Italy Long-term	Netherland Short-term	Netherland Long-term	Portugal Short-term	Portugal Long-term	Slovakia Short-term	Slovakia Long-term	Slovenia Short-term	Slovenia Long-term	Spain Short-term	Spain Long-term
−5	1.628	0.986	2.002	0.828	1.816	1.010	1.445	1.004	2.368	0.837	2.089	0.829
−4	1.566	0.965	1.870	0.823	1.750	0.994	1.407	0.959	2.257	0.809	1.956	0.799
−3	1.473	0.941	1.685	0.815	1.623	0.975	1.350	0.902	2.070	0.776	1.768	0.766
−2	1.335	0.914	1.447	0.801	1.396	0.950	1.265	0.840	1.734	0.737	1.515	0.734
−1	1.136	0.882	1.192	0.777	1.119	0.914	1.149	0.787	1.203	0.687	1.221	0.704
0	0.920	0.843	0.989	0.740	0.917	0.863	1.020	0.748	0.802	0.620	0.962	0.675
1	0.765	0.795	0.861	0.692	0.779	0.797	0.899	0.722	0.666	0.537	0.779	0.644
2	0.654	0.742	0.778	0.643	0.687	0.723	0.791	0.701	0.617	0.448	0.640	0.608
3	0.562	0.691	0.721	0.603	0.627	0.656	0.696	0.681	0.580	0.368	0.520	0.571
4	0.487	0.648	0.684	0.571	0.587	0.602	0.619	0.660	0.541	0.306	0.417	0.536
5	0.427	0.613	0.657	0.546	0.559	0.560	0.560	0.640	0.504	0.260	0.334	0.505

Source(s): Authors' Estimation, Table 3 by authors

Table 4. Generalized Hurst exponents of after the GFC sample for short and long term components from −5 to 5

Country	Austria		Belgium		Finland		France		Germany		Greece		Ireland	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	3.530	0.855	2.695	0.723	2.455	0.689	1.657	0.741	2.075	0.775	1.464	0.850	1.971	0.686
−4	3.418	0.837	2.582	0.706	2.246	0.673	1.565	0.722	1.935	0.751	1.479	0.837	1.867	0.665
−3	3.207	0.814	2.376	0.685	1.944	0.653	1.444	0.695	1.740	0.721	1.502	0.821	1.711	0.639
−2	2.757	0.787	2.000	0.657	1.550	0.628	1.296	0.659	1.478	0.679	1.502	0.802	1.489	0.605
−1	1.929	0.752	1.452	0.621	1.175	0.597	1.139	0.610	1.177	0.623	1.416	0.777	1.223	0.563
0	1.256	0.704	0.996	0.576	0.936	0.562	0.993	0.550	0.926	0.549	1.259	0.747	0.970	0.509
1	1.006	0.638	0.739	0.523	0.785	0.524	0.855	0.487	0.768	0.468	1.121	0.713	0.762	0.442
2	0.910	0.562	0.583	0.466	0.639	0.487	0.723	0.432	0.669	0.392	1.037	0.675	0.600	0.364
3	0.872	0.490	0.469	0.412	0.483	0.455	0.605	0.388	0.595	0.333	1.004	0.639	0.477	0.289
4	0.866	0.432	0.377	0.367	0.339	0.427	0.509	0.356	0.539	0.289	1.004	0.607	0.386	0.225
5	0.875	0.389	0.302	0.331	0.221	0.405	0.434	0.332	0.497	0.257	1.023	0.580	0.316	0.176

Country	Italy		Netherland		Portugal		Slovakia		Slovenia		Spain	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	3.143	0.847	1.478	0.803	1.395	0.840	4.064	1.049	2.655	0.818	3.000	0.908
−4	2.962	0.818	1.405	0.778	1.329	0.818	3.832	1.025	2.497	0.808	2.834	0.878
−3	2.649	0.781	1.299	0.746	1.245	0.792	3.443	0.993	2.218	0.795	2.559	0.840
−2	2.124	0.733	1.147	0.705	1.152	0.760	2.778	0.952	1.769	0.780	2.127	0.793
−1	1.497	0.675	0.961	0.652	1.068	0.723	1.910	0.900	1.255	0.757	1.600	0.736
0	1.097	0.608	0.780	0.586	0.998	0.681	1.263	0.837	0.938	0.712	1.188	0.673
1	0.874	0.538	0.613	0.515	0.930	0.636	0.829	0.768	0.829	0.628	0.957	0.610
2	0.663	0.471	0.432	0.450	0.854	0.592	0.552	0.701	0.808	0.508	0.827	0.552
3	0.426	0.415	0.246	0.399	0.777	0.552	0.401	0.642	0.785	0.394	0.735	0.502
4	0.205	0.370	0.083	0.361	0.707	0.519	0.320	0.595	0.746	0.307	0.661	0.461
5	0.031	0.335	−0.047	0.333	0.650	0.491	0.271	0.559	0.707	0.247	0.602	0.427

Source(s): Authors' Estimation, Table 4 by authors

makes it easier for investors to predict the stock return and earn the abnormal profit (Tiwari *et al.*, 2017). A study by Hasan and Mohammad (2015) revealed that during the post-crisis era, a decline was observed in multifractality indices of all markets, with the exception of the Malaysian market. Another research by Anagnostidis *et al.* (2016) claimed that after GFC, anti-persistent behavior had been observed in Spain and France's stock price movements. Also, scholars observed improvement in the post-crisis period instead of the availability of significant mean-reverting patterns. In contrast, across the sample period, Germany, Netherlands, Greece and Italy were considered to be weak-form efficient.

The outcomes of the COVID-19 period are illustrated in Table 5. We identified that at q = −5, Belgium has the largest (q) value, the most persistent in the short and long run. Nevertheless, at q = 2 in the case of long-term fluctuation, most of the countries are showing long term persistency having h(q) > 0.5 except Austria, Belgium and Ireland, presenting short-term persistence in the long run. While France is showing short-term persistence in the short run as h(q) is less than 0.5, these countries' market returns will be negative in the future if it is currently positive. Hence, results confirm that in COVID-19 period, the stocks of Belgium and France are most fluctuating. The results are in line with the findings of Abuzayed *et al.* (2021) and Khattak *et al.* (2021). The prior studies also claim that in the times of COVID-19, Belgium, the UK and France are the most incremental systemic risk receivers. Hence, the stock markets are adversely exposed to the emergence of the deadly coronavirus. Due to COVID-19, the GDP of Belgium declined by 6.3% in 2020. The economic failure because of COVID-19 outbreak is the greatest yearly GDP decline ever observed in Belgium after Second World War. This is significantly larger than the drop observed during the GFC. At that time, GDP declined by a "mere" 2% in 2009 after having risen by 0.4% in 2008. Further, Sami and Abdallah (2021) claims that stock market returns are highly volatile. Also, as per the statistics, the most crucial stock of France, i.e. CAC 40, witnessed a fall of 37% from its highest value. In a nutshell, the stock markets of Belgium and France witnessed a downturn.

4.2.3 Ranking efficient markets. The next step in MF-DFA is to rank the efficient markets based on the market deficiency measure (MDM) score .

Table 6 illustrates country's rank based on the efficiency of the market both in the short run and in the long run. The most efficient market has an MDM value equal to zero, while the less efficient market has a higher MDM value (Mensi *et al.*, 2017). According to the MDM ranking, Portugal is the most efficient market, with the lowest MDM value (1.277), and Austria, with the highest MDM value (2.3838), is the most inefficient market in the short and long run. Austria is the most efficient market after having the lowest MDM value (0.5689), and Slovakia is the most inefficient market in the long run, with the highest MDM value (0.899).

According to the given output of MDM ranking before the GFC of 2007–2008, Greece is the most efficient market with the lowest MDM value (0.847) in the short run. On the other hand, Austria is the most efficient market in the long run after having the lowest MDM value (0.5499). In GFC, the Netherlands is the most efficient market having the lowest MDM value (0.744), and Ireland is the most efficient market in the long run based on MDM value (0.4452). Simultaneously, Austria and Slovakia are the most inefficient markets before and after GFC, both in the short and long run. In COVID-19, Finland is the most efficient market as MDM value is (1.3071) in the short run. The second most efficient is Germany (1.4245). Conversely, in long run, the most efficient market is Germany (0.5512) which is followed by Austria with an MDM value of (0.5783). However, in the short run, Belgium (4.4943) and France (2.8755) are appeared to be the least efficient. Likewise, the least efficiency is exhibited by Belgium (1.5974) in long run. Also, the results depict that the stock markets of Belgium and France are highly fluctuating, making markets inefficient in the short and long run. Finally, we suggest that the investors should invest in the markets with the lowest MDM value to earn abnormal profit as these stock returns are predictable.

Table 5. Generalized Hurst exponents of during COVID-19 sample for short and long term components from −5 to 5

Country Order of q	Austria Short-term	Austria Long-term	Belgium Short-term	Belgium Long-term	Finland Short-term	Finland Long-term	France Short-term	France Long-term	Germany Short-term	Germany Long-term	Greece Short-term	Greece Long-term	Ireland Short-term	Ireland Long-term
−5	4.187	0.581	8.977	3.33	4.775	1.253	5.501	1.168	1.483	0.915	2.756	0.476	2.362	1.072
−4	4.111	0.463	8.791	3.218	4.673	1.189	5.398	1.136	1.491	0.911	2.707	0.493	2.351	1.069
−3	3.971	0.317	8.446	3.024	4.497	1.086	5.152	1.099	1.536	0.928	2.618	0.55	2.338	1.044
−2	3.698	0.163	7.701	2.684	4.138	0.92	4.465	1.059	1.686	0.989	2.404	0.74	2.314	0.97
−1	3.153	0.044	5.862	2.135	3.38	0.803	2.784	1.016	2.068	1.112	1.806	1.216	2.241	0.822
0	2.234	0.012	3.04	1.43	2.441	1.01	0.981	0.966	2.454	1.199	1.034	1.497	2.049	0.626
1	1.310	0.091	1.429	0.787	1.887	0.957	0.432	0.905	2.272	1.038	0.959	1.118	1.706	0.471
2	0.758	0.256	0.684	0.356	1.563	0.577	0.401	0.833	1.882	0.688	1.02	0.855	1.309	0.384
3	0.459	0.448	0.351	0.212	1.33	0.23	0.39	0.753	1.572	0.387	1.025	0.797	0.988	0.304
4	0.283	0.62	0.198	0.123	1.158	0.122	0.353	0.675	1.358	0.191	1.008	0.826	0.764	0.217
5	0.170	0.751	0.118	0.103	1.033	0.092	0.312	0.603	1.211	0.069	0.967	0.88	0.613	0.137

Country Order of q	Italy Short-term	Italy Long-term	Netherland Short-term	Netherland Long-term	Portugal Short-term	Portugal Long-term	Slovakia Short-term	Slovakia Long-term	Slovenia Short-term	Slovenia Long-term	Spain Short-term	Spain Long-term
−5	4.051	1.378	3.447	1.498	3.006	1.315	3.811	2.107	3.657	2.624	3.45	2.107
−4	3.904	1.347	3.351	1.457	2.912	1.289	3.68	2.055	3.536	2.62	3.32	2.055
−3	3.682	1.322	3.207	1.411	2.779	1.275	3.484	1.993	3.358	2.607	3.122	1.993
−2	3.332	1.321	2.978	1.37	2.6	1.296	3.2	1.934	3.107	2.574	2.805	1.934
−1	2.79	1.339	2.6	1.33	2.381	1.344	2.841	1.874	2.792	2.473	2.311	1.874
0	2.084	1.271	2.047	1.214	2.132	1.3	2.494	1.737	2.477	2.195	1.696	1.737
1	1.377	1.03	1.419	0.953	1.862	1.071	2.225	1.466	2.212	1.711	1.14	1.466
2	0.818	0.694	0.878	0.615	1.601	0.736	2.031	1.127	2.004	1.195	0.731	1.127
3	0.457	0.397	0.509	0.326	1.388	0.435	1.89	0.832	1.844	0.806	0.463	0.832
4	0.252	0.189	0.288	0.13	1.235	0.22	1.789	0.619	1.727	0.548	0.305	0.619
5	0.14	0.052	0.159	0.006	1.13	0.077	1.718	0.476	1.643	0.377	0.213	0.476

Source(s): Authors' Estimation, Table 5 by authors

Ranking	Short-term Country	MDM	Ranking	Long-term Country	MDM
Full sample period					
1	Portugal	1.277	1	Austria	0.5689
2	Greece	1.306	2	Slovenia	0.710
3	France	1.4314	3	Germany	0.7399
4	Germany	1.4789	4	Spain	0.740
5	Netherland	1.624	5	Finland	0.7572
6	Ireland	1.6649	6	Italy	0.758
7	Italy	1.767	7	France	0.7668
8	Spain	1.820	8	Netherland	0.774
9	Belgium	1.8248	9	Portugal	0.778
10	Finland	1.8892	10	Belgium	0.792
11	Slovenia	1.962	11	Ireland	0.7924
12	Slovakia	2.114	12	Greece	0.7944
13	Austria	2.3838	13	Slovakia	0.899
Before the GFC					
1	Greece	0.847	1	Austria	0.5499
2	France	0.966	2	Slovenia	0.557
3	Slovakia	1.013	3	Ireland	0.6562
4	Italy	1.027	4	Belgium	0.6648
5	Germany	1.0845	5	Spain	0.667
6	Ireland	1.1195	6	Netherland	0.697
7	Belgium	1.1428	7	Greece	0.7042
8	Finland	1.1461	8	Germany	0.7399
9	Portugal	1.168	9	France	0.7812
10	Spain	1.186	10	Finland	0.786
11	Netherland	1.277	11	Portugal	0.798
12	Slovenia	1.399	12	Italy	0.807
13	Austria	1.7444	13	Slovakia	0.896
After the GFC					
1	Netherland	0.744	1	Ireland	0.4452
2	Portugal	1.018	2	Germany	0.5202
3	France	1.0369	3	Belgium	0.5366
4	Ireland	1.1264	4	France	0.5389
5	Germany	1.2372	5	Finland	0.55
6	Greece	1.2414	6	Slovenia	0.558
7	Finland	1.2926	7	Netherland	0.569
8	Belgium	1.4796	8	Italy	0.594
9	Italy	1.584	9	Austria	0.6345
10	Slovenia	1.622	10	Portugal	0.669
11	Spain	1.748	11	Spain	0.669
12	Slovakia	2.076	12	Greece	0.7222
13	Austria	2.1421	13	Slovakia	0.810
COVID-19 period					
1	Finland	1.3071	1	Germany	0.5512
2	Germany	1.4245	2	Austria	0.5783
3	Ireland	1.5578	3	Finland	0.6053
4	Spain	1.8123	4	Ireland	0.6429
5	Netherland	1.8193	5	Greece	0.6665
6	Greece	1.8539	6	Portugal	0.7545

(*continued*)

Table 6.
MF-DFA rankings for short and long-term components

Ranking	Short-term Country	MDM	Ranking	Long-term Country	MDM
7	Portugal	2.0736	7	Italy	0.768
8	Italy	2.0779	8	Netherland	0.7937
9	Austria	2.1968	9	France	0.9052
10	Slovenia	2.6314	10	Spain	1.3369
11	Slovakia	2.7348	11	Slovakia	1.3369
12	France	2.8755	12	Slovenia	1.5838
13	Belgium	4.4943	13	Belgium	1.5974

Source(s): Authors' Estimation, Table 6 by authors

Table 6.

5. Conclusion

This research explores asymmetric market efficiency of the 13 Euro countries concerning the period before GFC, after GFC and the period of COVID-19 by employing MF-DFA. Further, it aims to explore the efficiency of markets based on MDM scores. The findings suggest that efficiency in these markets varies over time. It implies that all markets possess multifractal properties. These markets are not deteriorating efficiently over time, and all markets reject the hypothesis of random walk behavior. Further, developed economies' market behavior is more toward stability, but emerging economies' behavior is less stable. This study's implication is for investors to earn abnormal profits and help predict the future returns of anti-persistent markets. It will assist these countries' economies in the implementation of relevant regulations on stock markets. It is crucial to have in-depth knowledge about stock indices, and in which particular sector the development of speculative bubbles is more likely to appear. Eurozone markets play a major role in crisis; hence, a comprehensive understanding of their behavior is necessary. More importantly, it is suggested that policymakers should start enforcing laws and legislation to improve the efficiency of these markets and strengthen local and international investors' confidence in them.

The results indicate that only two countries' markets show anti-persistent or negative autocorrelation behavior; after GFC, seven countries' markets exhibit anti-persistent autocorrelation. These markets' anti-persistent behavior provides ease to investors to predict the stock return and earn abnormal profit. Based on the MDM ranking, it is concluded that Portugal is the most attractive market and Austria is the least attractive market in terms of future return in the short run. However, Austria is the most favorable market for investors in the long run, and Slovakia is the least efficient market.

According to the results of the before-GFC period, Greece is the most favorable market, and again Austria is the least significant market for future returns in the short run. Whereas, in the long run, Austria is the most efficient market for investors in terms of their efficiency, and Slovakia is the least preferred market for investors before the GFC of 2007–2008. After GFC, the MDM ranking tells a different story, as the Netherlands is the most significant market in the short run, and Ireland is the most efficient in the long run from an investing point of view. However, Austria and Slovakia are still the least efficient markets in the short and long run, consistently before and after the financial crisis.

During the period of COVID-19, the discovered results are surprising and different from the full sample and GFC pre and post-periods. As per the outcomes of Generalized Hurst exponents during COVID-19 sample for short and long term components and market efficiency, the most fluctuating stocks are of Belgium and France in long and short run. Most importantly, Belgium's stock markets appear to be highly fluctuating, hence, making the market least efficient in short and long run. Moreover, France is also the second least efficient market in short run. Conversely, the most efficient market in the times of COVID-19 is Finland

and Germany in the short and long run, respectively. The reason for the sudden change in the results is the robust role of COVID-19.

These vibrant market conditions of 13 countries can be defined in bear markets, such as markets with low growth opportunities and bull markets having high growth opportunities, and regular markets with stable conditions. These market conditions are persistent. Our study results can divide these 13 countries into different segments, as we have incorporated the crucial role of the GFC and COVID-19 in the stock markets of 13 Eurozone countries. Countries showing long-term persistence can be viewed as regular markets or bull markets, and countries showing anti-persistent behavior can be viewed as bear markets. However, again, it also depends on the country's economic condition, and the occurrence of any black swan event that may alter the condition, such as an outbreak of coronavirus, has affected the global markets adversely. Although it started in China gradually, unfortunately, it has spread worldwide and upset the world economy.

6. Future recommendations

We recommend the scholars: (1) to conduct a comparative study by considering the data of different economies. For instance, comparison between China–USA, BRICS countries, developed-developing economies, European-Asian countries and Islamic countries. It will provide a novel idea of how different economies respond to GFC and COVID-19 with respect to EMH and MF-DFA. (2) We considered the overall stock markets of Eurozones; however, each market responds differently during crises like GFC and COVID-19. Hence, it is suggested to consider a specific stock market for in-depth analysis—for instance, the health, hospitality, tourism and telecommunication sectors.

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