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Comparing asymmetric price efficiency in regional ESG markets before and during COVID-19

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\textbf{ABSTRACT}

The ever-emerging environmental, social, and governance (ESG) concerns have received significant attention of policymakers, governments, regulation bodies, and investors. Considering the markets volatilities due to economic and financial uncertainties that can drive the informational price inefficiencies across the markets, this study compares the asymmetric price efficiency of regional ESG markets by using an asymmetric multifractal detrended fluctuation analysis before and during COVID-19 crisis. We then examine whether global factors influence the asymmetric efficiency of regional ESG markets. Our findings reveal that COVID-19 outbreak reduced the efficiency of regional ESG markets, except for Europe, which sustained its efficiency even during the pandemic. Moreover, global factors drive the efficiency of regional ESG markets significantly before and during COVID-19. A major implication of our findings stems from the fact that a contagion reduces the efficiency of the markets while stable economic conditions make those markets informationally efficient.

\section{1. Introduction}

The tremendous growth of environmental, social, and governance (ESG) stocks over the last few decades has brought to the attention of policymakers, regulation bodies, and investors to carefully evaluate the fruitful benefits of ESG investments. During the COVID-19 pandemic, socially responsible investments outperformed other conventional stocks (Whieldon and Clark, 2021), thereby attracting the attention of investors, portfolio managers, the media, and regulators. ESG adoption has increased dramatically in recent years because investors consider these three nonfinancial factors (environmental, social, and governance) crucial when assessing risks and investment opportunities (Pastor et al., 2020). During 2016–2018, the ESG assets increased from $22.8 to $30.6 trillion. Accordingly, Bloomberg predicts that the value of ESG assets will increase from $37.8 trillion in 2021 to $53 trillion in 2025 (Diab and Adams, 2021). In 2018, Europe, the United States, and Japan held the largest share of ESG assets (Umar et al., 2020). Furthermore, the public and governments emphasize a pollution-free environment, societal friendly policies, and firm transparency. ESG addresses the following issues: (a) environmental concerns, such as using renewable energy and reducing waste and greenhouse emissions; (b) social concerns, such as customer satisfaction, labor standards, workplace safety regulations, human rights, and illegal child labor; and (c) governance dynamics that include the rules describing the responsibilities, rights, and expectations of various firms’ stakeholders. Further, ESG-based socially responsible investments provide higher returns with lower risks, particularly during times of crisis and turmoil (Naeem and Karim, 2021; Naeem and Karim, 2021; Naeem et al., 2022; Riedl and Smeets, 2021).
ESG-based firms provide sustainable growth, which is necessary for ethical and sustainable long-term investors.

The “efficient market hypothesis” (EMH) claims that market prices reflect all available information with no arbitrage opportunities and forecast the prices by using historical data (Fama, 1965, 1970). Efficient ESG markets are not forecastable and do not provide the opportunities of abnormal profits to the investors. However, markets are considered inefficient because of several anomalies in markets. In contrast to the EMH, the “multifractal hypothesis” asserts that markets are inefficient with a pronounced forecasting ability of financial markets (Peters, 1994). Multifractality in financial refers to an inefficient market, that is, if we detect multifractality in any ESG market, then it is predictable and provides arbitrage opportunities to investors. High-profit seeker investors are always looking for inefficient markets to earn abnormal profits. Therefore, studying ESG market efficiency can provide investors with useful information on forecasting power, arbitrage opportunities, and portfolio risk management in ESG markets. The detection of multifractality in markets becomes crucial in substantial uncertainty and loses crisis episodes. Therefore, we must explore those markets that provide evidence of multifractality, and thus, investors can obtain maximum profits from these markets by forecasting these markets during crises.

Using the asymmetric multifractal analysis, this study compares the efficiency of four regional ESG markets, namely, the Americas, Europe, Asia, and the Pacific, before and during the COVID-19 pandemic. Regional ESG markets differ based on financial performance (Verheyden et al., 2016), ESG scores (Alessandrini and Jondeau, 2020), implementation of reporting standards (Karim et al., 2020a; 2020b; Karim et al., 2021a; 2021b; Giese et al., 2016), stage of economic development (McWilliams et al., 2006), regulatory pressure (Weber, 2014), and level of awareness (Peiró-Signes, 2013). These differences across regional markets motivate us to investigate whether a difference exists in market efficiency between regional ESG markets. Fewer studies have been conducted to assess the effectiveness of various types of socially responsible investments (green bonds, emissions trading scheme (ETS), and clean energy stocks), particularly during the COVID-19 pandemic. Naeem et al., (2021) compare the efficiency of conventional and green bonds during and before the COVID-19 pandemic.1 This study provides evidence of asymmetric multifractality in both markets. Further, they report the green bond market as highly efficient during the COVID-19 pandemic, whereas the conventional bond markets are highly efficient in the pre-COVID-19 period. They suggest green bonds as an effective diversifier for other assets, particularly during the pandemic. Meanwhile, Fan et al. (2019) investigate the multifractality in China’s carbon emission trading markets (ETS) and provide evidence of multifractality in the short and long terms. They further discover that the level of efficiency in the Chinese ETS market increases over time. Lee et al. (2020) investigate the asymmetric efficiency of EU carbon markets and found evidence of time-varying asymmetric efficiency. They further find that the efficiency level is directly proportional to the level of maturity in EU carbon markets. Shahzad et al. (2020) investigate the asymmetric efficiency of clean energy stocks in the global, European, and US markets and find evidence of time-varying efficiency in these markets. The US clean energy stocks are more efficient in downturns, whereas the global and European markets are highly efficient in upturns. It is clear from the preceding studies that none of them has focused on examining the efficiency of ESG stock markets in crisis or noncrisis episodes; therefore, we fill this literature gap.

Our research makes several contributions. First, we compare the asymmetric efficiency of four regional ESG markets: the Americas, Europe, Asia, and the Pacific. The asymmetric efficiency approach assumes that market efficiency varies under upward and downward market trends. In general, investors react differently to the bearish and bullish market news (Li et al., 2017). Moreover, investors assign higher weightage to less-than-comparable profit, thereby indicating that investors are more sensitive to negative than positive news (Ding et al., 2004). Therefore, examining asymmetric rather than symmetric efficiency is more appropriate. The findings assist investors and portfolio managers in developing an effective investment strategy for bullish and bearish market conditions.

Second, we estimate the price efficiency of ESG markets over two sub-sample periods, including before and during the COVID-19 pandemic. Several studies have been conducted to investigate the asymmetric efficiency of various markets (oil, gold, and cryptocurrency) other than ESG during and before the COVID-19 sample periods (Mensi et al., 2020; Kakinaka and Umeno, 2021). Because of lockdowns, social distancing, and fear of death, the COVID-19 pandemic adversely affects numerous financial markets (Karim et al., 2022a, 2022b; Yousaf et al., 2021; Menzi et al., 2021a, 2021b; Karim, 2021a; 2021b; Umar et al., 2020; Akhtaruzzaman et al., 2021a; Zhu et al., 2021; George et al., 2021; Fiti et al., 2021; Yousaf et al., 2021). However, the performance of the ESG market during the COVID-19 pandemic demonstrated that these markets were resilient to the crisis. During the COVID-19, investors and the general public became more aware of environmental concerns, thereby resulting in a greater demand for ESG stocks (Albuquerque et al., 2020). Ferriani and Natoli (2020) discover that during the initial phase of the COVID-19, investors prefer low ESG risk-based portfolios, with environmental risk remaining the top concern in making portfolio decisions. Moreover, Akhtaruzzaman et al. (2021b) reported the higher level of connectedness between media coverage and ESG indices during the COVID-19. According to Albuquerque et al. (2020), the higher ES-score-based stocks provide higher returns with lower risk than lower ES-score-based stocks during COVID-19. Because ESG stocks behave differently during and before the COVID-19 pandemic, examining the efficiency of ESG in both periods is useful. It provides investors with insightful information on investment strategies and risk management during the COVID-19 pandemic. Third, we used multiple regression to estimate the impact of global factors on time-varying efficiency for ESG markets and reported phenomenal findings of implied volatilities driving ESG market efficiency in upward, downward, and overall trends. The global factors include the implied volatilities of the stock (VIX), oil (O_V), gold (GVZ), currency (EVZ), and treasury (BOND) markets. The current study examines their impact on the asymmetric efficiency of ESG markets to evaluate whether these factors and uncertainties have a significant impact on ESG efficiency (Kim et al., 2021; Kumar et al., 2021). Finally, it calculates the multifractality at various time scales (Naeem and Karim, 2021).

In this study, the multifractal scaling behavior is examined separately during upward and downward trends in ESG markets by using the asymmetric multifractal detrended fluctuation analysis (A-MF-DFA) approach. The findings revealed that multifractality in regional ESG markets varies for upward and downward trends. The multifractal properties are pronounced during downward market trends. Moreover, the dynamic analysis identifies time-varying characteristics in regional ESG markets. In comparison, the European ESG market has a higher efficiency than the other regions. Excluding Europe, the COVID-19 outbreak reduced the efficiency of regional markets. The higher efficiency in the European ESG market suggests the greater potential of ESG investment to act as a potential diversifier during uncertain economic conditions, thereby revealing effective implications for investors, portfolio managers, and policymakers. Furthermore, global factors have a substantial impact on the efficiency of regional ESG markets, thereby inciting the interest of regulators, ESG markets, and financial market participants. We found a significant relationship between stock volatility

1 Naeem et al. (2021) only focus on exploring the efficiency of green and conventional bond markets in pre and post COVID-19 phases, whereas the current study focuses on examining the asymmetric efficiency of ESG regional stock markets in pre and post COVID-19 phases. Moreover, the present study examines the impact of global factors on the dynamic efficiency of regional markets in up, down, and overall market conditions.
and ESG markets in the Americas, Asia, and the Pacific, whereas the European market revealed an insignificant impact of VIX on efficiency. Furthermore, for all regional ESG markets, OVX reported a negative relationship in the upward trend and a direct association in the downward trend. However, Asian and Pacific markets demonstrated an inverse relationship for the overall market trend. GVZ has an indirect relationship with all ESG markets because increased uncertainty in GVZ causes inefficiency in the relevant ESG market and vice versa. EVZ manifested a significant negative relationship with ESG markets in downward and upward trends except for the American market. Finally, MOVE expressed a positive relationship in all trends for ESG markets in Europe, Asia, and the Pacific, thereby highlighting that the increase in the volatility of the treasury market increases the efficiency of respective ESG markets.

The following are the remaining sections of the paper: Section 2 explains the methodology, Section 3 provides the data and preliminary results, Section 4 presents the empirical results, and Section 5 concludes the study.

2. Methodology

2.1. Asymmetric multifractality detrended fluctuation analysis

This section presents the theoretical underpinnings and salient features of the A-MF-DFA. The EMH posits that asset prices in an efficient market follow a stochastic trend and random walk. However, at various instances, this postulation does not always hold true in the financial market. Further, the counter-evidence to EMH reinforces dependence in the long run, with price reversals and the presence of serial correlation in asset prices in financial markets (Poterba and Summers, 1988; Fama and French, 1988). Moreover, the notion of market efficiency is predicated on market equilibrium. During times of economic turmoil, such as the Global Financial Crisis (GFC) of 2007–2008 and the recent pandemic crisis, the existence of an equilibrium state is rare. Therefore, the fractal market hypothesis (FMH) of Mandelbrot and Taylor (1967) is used as a functional alternative to EMH.

According to FMH, investors’ reactions to information differ depending on their investment horizons, which can be short-, medium-, or long term (Weron and Weron, 2000; Onali and Goddard, 2009). Accordingly, investors with a long-term horizon are more concerned with fundamentals than with short-term fluctuations in financial markets or asset prices. Therefore, investors with heterogeneous horizons induce market stability (Kristoufek, 2013). By contrast, if a specific type of horizon dominates the market, trading in that horizon will not be associated with counteracts by reverse orders, thereby putting the market’s stability at risk and distorting the equilibrium.

In summary, the FMH hypothesis suggests two basic states in the equity markets. First, in a stable state, different investment horizons prevail in a fractal coexistence, and thus, demand and supply in the markets remain smooth. By contrast, during an unstable or crisis state, a specific horizon dominates, and therefore, investors’ demands and supply are not cleared, thereby causing market instability and inefficiency. Thus, asset prices frequently exhibit self-similarity or -affinity in the same market condition (normal or crisis periods). Furthermore, asset prices in normal times exhibit markedly different behavior than those in crisis. Previous research has identified two major sources of multifractality. First, consider the long-term temporal correlations between market fluctuations and then consider the return probability with a fat-tail distribution. Furthermore, because of the significant differences in the magnitude of fractality in bearish and bullish markets, multifractality can be asymmetric. Therefore, the existing literature has proposed various methods for analyzing multifractality.

The DFA, developed by Peng et al. (1994), identifies long-range correlations in non-stationary data. One of the most crucial characteristics of nonstationarity is the avoidance of superfluous long-range detection of dependence. Kantelhardt et al. (2006) then proposed the expanded multifractal DFA to measure the long-range correlations and multifractal characteristics of time series across multiple time scales. An asymmetric DFA (A-DFA) was developed by Alvarez-Remirez et al. (2009) to scale time series behavior by using upside and downside patterns. Recognizing asymmetries and nonlinearities in time series is critical for accurately reflecting efficiency. Therefore, we employ Cao et al.’s (2013) asymmetric MF-DFA (A-MF-DFA) approach. The method has several advantages over the symmetric MF-DFA method (Kantelhardt et al., 2006). The A-MF-DFA approach distinguishes between asymmetric upward and downward price movements assisting market participants in optimizing the fund allocation and accurately predicting future returns. Therefore, given that ESG equity markets react differently to good news and bad news, the A-MF-DFA is effective and flexible in capturing asymmetries in time series scaling behavior. Thus, the study is the first to investigate the multifractality in ESG regional stock markets during downward and upward trends. The concept is based on the empirical literature, which emphasizes the benefits of inspecting asymmetries in time-series scaling behavior, which influences portfolio allocation and risk management decisions (Lengin and Solnik, 2001; Ang and Chen, 2002; Bae et al., 2003). Furthermore, investor reactions and responses differ based on upward and downward trends in returns, thereby resulting in heterogeneous risk and price behavior between bearish and bullish market states, which serves as a catalyst for market inefficiency (Lee et al., 2018). Moreover, previous studies have widely used the A-MF-DFA approach to estimate market efficiency across developed and developing stock markets (e.g., Cajuereiro and Tabak, 2009).

The A-MF-DFA approach is noted in several significant steps. Let us assume a time series \( \{x(t)\}, t = 1, 2, \ldots, N \) of length \( N \). The trajectory of original series \( x(t) \) is as follows:

\[
y(j) = \sum_{t=1}^{j} (x(t) - x, j = 1, 2, \ldots, N)
\]

where \( y(j) \) is the mean of \( x(t) \) and profile is obtained by subtracting each record of \( x(t) \) from its mean in the time series.

In the subsequent step, the series \( x(t) \) and its profile \( y(j) \) are segregated into nonoverlapping continuous segments of equal length \( n \), such as \( N = int(N/n) \), where function \( int(\cdot) \) is the integer part of \( N/n \). The segments are selected from 5 to \( N/4 \) based on the recommendation of Peng et al. (1994). Furthermore, because the length of series \( N \) is not a multiple of \( n \), the length of the final segment can be shorter than \( n \). To avoid losing a small part at the end of the profile, the segmentation procedure is performed in the opposite order. Thus, \( 2N/5 \) segments. \( S_j = \{y_{jk}, k = 1, \ldots, n\} \) shows the \( j \)th subseries of length \( n \), whereas \( Y_j = \{y_{jk}, k = 1, \ldots, n\} \) denotes the subseries for the \( j \)th time interval.

The coming step fits two linear models by ordinary least squares for each \( j \)th segment of the series \( Y_j \) and profile \( Y_j \) as follows:

\[
\hat{S}_{jk} = a_j' + b_j'k
\]

\[
\hat{Y}_{jk} = a_j' + b_j'k
\]

where \( S_{jk} \) and \( Y_{jk} \) are the respective fitted figures of \( S_j \) and \( Y_j \), \( a_j' \) are the intercepts and slopes, respectively. \( S_{jk} \) determines the positive or negative sign of the trend through its slope \( b_j' \), and \( Y_{jk} \) detects the \( Y_j \).

The variance or fluctuation parameter \( F_j(n) \) of each \( j \)th segment is obtained as follows:

\[
F_j(n) = \frac{1}{n} \sum_{k=1}^{n} (y_{jk} - \hat{y}_{jk})^2
\]

The subsequent step evaluates the asymmetric cross-correlation scaling features considering the two average fluctuation functions, where series \( x(t) \) is divided into positive and negative fragmented
The two directional average fluctuation functions of the qth order are as follows:

\[ F_q^+(n) = \left( \frac{1}{M} \sum_{j=1}^{2N_q} \frac{\text{sign}(b_j^+)}{2} [f(n)]^q \right)^{1/q} \]  

(5)

\[ F_q^-(n) = \left( \frac{1}{M} \sum_{j=1}^{2N_q} \frac{-\text{sign}(b_j^-)}{2} [f(n)]^q \right)^{1/q} \]  

(6)

Where \( F_q^+(n) \) and \( F_q^-(n) \) are respective upward and downward average fluctuation functions of q-order, whereas \( M^+ = \sum_{j=1}^{2N_q} \text{sign}(b_j^+) \) and \( M^- = \sum_{j=1}^{2N_q} \text{sign}(b_j^-) \) are the number of sub time series with positive and negative trends, respectively. We assume that \( b_j^+ \neq 0 \) for each \( j = 1, 2, \ldots, 2N_q \), then \( M^+ + M^- = 2N_q \). Concurrently, the average fluctuation function of symmetric q-order in the original MF-DFA of Kantelhardt et al. (2006) is described as follows:

\[ F_q(n) = \left( \frac{1}{3N} \sum_{j=1}^{2N_q} [f(n)]^q \right)^{1/q} \]  

(7)

The final step computes the generalized Hurst exponents for identifying asymmetries in time-series scaling behavior. For long-range correlations of a series, the power-law relationship states the following:

\[ n^{H_{(q)}} \sim F_q^+(n) \sim n^{H_{(q)}^+}; \quad F_q^-(n) \sim n^{H_{(q)}^-} \]  

(8)

Where \( n^{H_{(q)}} \), \( n^{H_{(q)}^+} \), and \( n^{H_{(q)}^-} \) are the overall, upward, and downward scaled exponents denoting generalized Hurst exponents, respectively. These exponents assess random walk or stationarity of the time series data during analysis.

Parallel to the DFA approach, the scaling behavior of the fluctuation functions in Eq. (8) can be determined by plotting the log-log plots of \( F_q(n), F_q^+(n) \), and \( F_q^-(n) \) for n against each value of q.

The positive and negative values of generalized Hurst components reveal the type of correlation in the series. If the value of \( H(q) \) is constant for the complete series, it is then monofractal and has positive and negative values; the series has multifractal characteristics. The positive correlation persists if \( H(2) > 0.5 \). That is, a relatively small (large) increase in the series is followed by another small (large) increase. A greater \( H(2) \) reveals stronger persistence. For negative values, an anti-persistent term is used if the value of the correlation is \( H(2) < 0.5 \), that is, the consistent pattern of large (small) values is probably followed similarly following a random walk process. Furthermore, if \( H^+ > H^-(q) \), then a symmetric correlation exists. However, if \( H^+ \neq H^- \), an asymmetric correlation exists, thereby revealing both positive and negative patterns. For measuring the degree of asymmetry, is used in the following manner:

\[ \Delta H(q) = H^+(q) - H^-(q) \]  

(9)

For a constant q, the larger \( \Delta H(q) \) shows the stronger degree of correlation. If \( \Delta H(q) \) > 0, then the series show stronger correlations in an upward direction than its downward trend. Moreover, if \( \Delta H(q) \) < 0, then the series is more in a downward trend than its upward trend.

Finally, Wang et al. (2009) introduced market efficiency measure (MDM) to compute efficiency (inefficiency) of markets. For regional ESG markets, MDM is computed as follows:

\[ MDM = \frac{1}{2} \left( \frac{(H(4) - 0.5) + (H(-4) - 0.5)}{2} \right) \]  

(10)

Where \( H(-4) \) and \( H(4) \) denote the scale components of small and large fluctuations, respectively. A market performs efficiently if all fluctuations (including small and large) follow the random walk process, which implies that \( H(q) \) equals 0.5 for any q. Accordingly, the value of MDM closer to zero exhibits that a market is highly efficient, whereas larger MDM fluctuations represent inefficient markets.

2. Impact of global factors on time-varying efficiency

A thread of literature has examined the influence of global factors on stock returns in different stock markets worldwide (e.g., Aloui et al., 2015; Ji et al., 2018). However, limited attention is given to investigating global factors’ role in driving stock market efficiency. Further, to the best of our knowledge, no study has the role of global factors in driving efficiency in ESG markets. Therefore, in this study, we use multiple regressions to examine the impact of global factors on the dynamic efficiency of regional ESG markets via time-varying MDM components:

\[ MDM_t = \beta_0 + \beta_1 VIX_t + \beta_2 OVX_t + \beta_3 GVZ_t + \beta_4 EVZ_t + \beta_5 MOVE_t + \epsilon_t \]  

(11)

Where \( MDM_t \) is the time-varying dynamic component of efficiency (overall, upward, and downward) for ESG market t at time t, whereas \( \epsilon \) denotes error term. We used five global factors: VIX, which represents stock market volatility; OVX, GVZ, EVZ, and MOVE denote oil, gold, currency, and treasury market volatilities, respectively. The global factors are used to determine whether global factors influence the efficiency of regional ESG markets in overall, upward, and downward trends. A significant positive impact reveals a high uncertainty of a given global factor, inducing high efficiency in the corresponding ESG market and vice versa. By contrast, the overall, upward, and downward trends with positive (negative) values indicate that a specific global factor drives efficiency (inefficiency) in the relevant ESG market.

3. Data and empirical findings

3.1. Data

The study uses data of MSCI Leader ESG indexes for four regional markets, namely, the Americas (including South and North regions), Europe, Asia, and the Pacific. The indexes assist market participants to comply with their investment decisions with ESG goals. These ESG indexes have grown rapidly in the last three decades and attained a notable position in global financial markets by offering unique investment strategies. The first index in our sample, i.e., the MSCI Latin ESG Leaders Index, is a weighted index of companies with high ESG performance in six emerging markets. The index includes countries from both the North and South American regions, including Brazil, Colombia, Argentina, Mexico, Chile, and Peru. Second, the MSCI Europe ESG Leaders Index includes large and mid-capitalized companies from fifteen developed markets in Europe demonstrating strong ESG performance. This index includes France, Germany, the United Kingdom, Italy, the Netherlands, Spain, Switzerland, Sweden, Norway, Portugal, Austria, Belgium, Denmark, Finland, and Ireland. Third, the MSCI AC Asia ESG Leaders Index is a weighted index of large and mid-capitalized companies from three developed Asian markets (Japan, Hong Kong, and Singapore) and nine emerging Asian markets (China, Indonesia, India, Malaysia, Pakistan, Philippines, South Korea, Thailand, and Taiwan). Finally, the MSCI Pacific ESG Leaders Index includes large and mid-capitalized companies from the Pacific region’s five developed markets: Australia, New Zealand, Hong Kong, Japan, and Singapore. All of the indices are denominated in USD. The indices are designed to help market participants looking for broad, diverse sustainability benchmarks.2

The daily data have been sourced from DataStream spanning January 2014 to March 2021. The sample period includes the
catastrophic events of COVID-19 pandemic when financial markets worldwide tumbled because of widespread panic, thereby resulting in substantial economic losses. For example, after the World Health Organization declared COVID-19 a global pandemic, equity funds worth US$7 trillion were wiped out of global stock markets. Therefore, in accordance with behavioral finance theory, which suggests that investment decisions in uncertain times are heavily influenced by investor sentiment, the study investigates asymmetric multifractality in ESG equity markets during the COVID-19 outbreak period. We calculate continuously compounded returns by converting the price series into log first differences as per the standard practice. According to the descriptive statistics in Table 1, the Americas yield the highest average returns, followed by Asia, the Pacific, and Europe. Moreover, the variability in the return series is reportedly higher in the American ESG market followed by Europe with Asia and Pacific ESG markets exhibiting similar variability in the return series. The slightly negative skewness values of four regional ESG markets indicate that they may have suffered losses during the study period. The Jarque–Bera test yields abnormal results for all regional ESG markets studied, thereby indicating that markets are not normally distributed. Furthermore, the Augmented Dicky–Fuller (ADF) test of stationarity yields high negative significant values, thereby confirming the data’s stationarity. Appendix A (Table A1) comprises detailed descriptive statistics for all global factors.

3.2. Asymmetric multifractality of regional markets

Given the prior studies on the efficiency of financial markets (Lee et al., 2017), we first measure the multifractality of the regional ESG markets by determining the asymmetric MF-DFA function $F_q(n)$ against time-scale $n$ in Fig. 1. Panel A–D corresponds to the four regional markets: the Americas, Europe, Asia, and the Pacific, respectively. The time-scale $n$ shows the values between 1 and 2.5 for the complete study period ranging from January 2014 to March 2021. The black dots represent the overall multifractality trend, which includes both upside and downside patterns for the underlying ESG markets, whereas the red circles and green triangles represent multifractality for upward and downward market trends, respectively.

Lee et al. (2017) advocate that the multifractality approach is particularly useful for estimating market efficiency when the underlying financial markets depict both downward and upward trends. Moreover, their findings support a higher degree of asymmetric multifractality in the United States stock market during economic downturn. Considering these findings, we can reasonably expect that market efficiency deteriorated in ESG regional stock markets during the recent COVID-19 outbreak. Fig. 1 depicts the level of multifractality for the study period for overall, upward, and downward market trends. As expected, the downward market trend is the dominant outbreak in all regional ESG markets (time scale 2.0 to 2.5). The findings validate the presence of asymmetric multifractality in ESG markets with multifractality in the underlying markets increasing with time scale. Further, the multifractality in a downward trend is greater than the multifractality in an upward trend for all regional ESG stock markets. In higher scales, the deviation from the symmetric behavior is more pronounced.

The findings imply that market participants generally focus more on long-term persistence, which increases asymmetric behavior when the time scale is higher. The findings imply that long-term investors should be cautious in their investment opportunities because upward and downward market trends have a significant impact on the efficiency of ESG markets. Furthermore, the findings show that of the four regional ESG markets, the ESG market in Europe has the lowest degree of asymmetric multifractality during downward trends. The findings support the higher market efficiency of developed stock markets during slowdowns. Furthermore, the findings show that the European ESG stock market performed exceptionally well during the recent pandemic crisis.

Fig. 2 displays the excess asymmetry in multifractality for the regional ESG stock markets, where $\Delta H(q) = H^+(q) - H^-(q)$ of Eq. (9) quantifies the excess asymmetry of the regional ESG markets. The higher value of $\Delta H(q)$ reveals the higher asymmetric behavior of the ESG market. Further, if $\Delta H(q)$ is equal or close to zero, multifractality is considered symmetric for both upward and downward trends. Furthermore, a positive value $\Delta H(q)$ indicates that underlying ESG markets generated more cross-correlations during upward (positive) trends than during downward (negative) trends and vice versa. Fig. 2 depicts the excess asymmetry in multifractality in four regional ESG stock markets, validating the use of the asymmetric MF-DFA method to examine market efficiency in ESG regional stock markets. In Fig. 2, a closer look at the regional ESG markets reveals that the Americas, Asia, and the Pacific exhibit a similar pattern of excess asymmetry in the multifractality. We note that excess asymmetry in multifractality has more negative values for most time scales, thereby clearly highlighting higher inefficiency in the regional ESG markets during crisis periods, such as the recent pandemic. The findings indicate that high contagion causes high market inefficiency in the regional ESG stock markets during turbulent times. Similarly, Umar et al. (2020) and Iqbal et al. (2021) found ESG/sustainable investments are prone to exorbitant risk considering the turbulent market conditions. Further, we notice that with the exception of the European ESG market, the positive trend dominates at lower time scales and gradually shifts to the negative at higher time scales. The findings highlight the superior efficiency of the European ESG market over other sample markets once again. Moreover, in general, the findings illustrate the higher market efficiency of developed markets compared to emerging stock markets. The findings further show that the European ESG market can be considered a refuge during the crisis periods. Moreover, portfolio managers and investors can use this opportunity to hedge their risks of other regional ESG markets.

Fig. 3 depicts the generalized Hurst exponents $H(q)$, $H^+(q)$, and $H^-(q)$ values for $q$ fluctuating between $-4$ and $4$ for examining the multifractality of regional ESG indexes. The values of Hurst components for overall (black dots), upward (red circles), and downward (green triangles) vary substantially across different time scales and market trends, thereby confirming the multifractality of the regional ESG indexes irrespective of the market circumstances. Notably, the value of $H(q)$, $H^+(q)$, and $H^-(q)$ declines with the increase in the value of $q$ for all regional ESG indexes. The findings point to a higher persistence of small $q$ and weak correlations between overall, downward, and upward trends. Furthermore, in the case of three regional ESG markets, namely, the Americas, Asia, and the Pacific, the gap between Hurst components for downward and upward trends is smaller when fluctuations are small and increases when fluctuations are large. Furthermore, the large gap in

| Markets       | Mean  | Std. Dev. | Skewness | Kurtosis | JB     | ADF     |
|---------------|-------|-----------|----------|----------|--------|---------|
| THE AMERICAS  | 0.037 | 1.091     | -1.115   | 27.271   | 46805.820*** | -13.357*** |
| EUROPE        | 0.008 | 1.065     | -1.544   | 23.681   | 34449.610*** | -42.377*** |
| ASIA          | 0.028 | 0.891     | -0.355   | 6.814    | 1185.641*** | -28.994*** |
| THE PACIFIC   | 0.023 | 0.891     | -0.413   | 7.414    | 1588.954*** | -28.192*** |

Note: Std. Dev., JB, and ADF indicate standard deviation, Jarque–Bera test of normality, and Augmented Dicky–Fuller test of stationarity. *** indicates significance at 1%.
this scenario emphasizes pronounced asymmetry. The correlation asymmetry is thus more pronounced for larger gaps than for smaller gaps. Surprisingly, the gap remains more pronounced in the European ESG market. The findings show that the underlying ESG market has a high degree of asymmetry and multifractality. The findings show that despite its larger size and relatively stable nature, the European ESG market is still vulnerable to significant market inefficiencies.

Fig. 4 illustrates the multifractal spectrum for $f(\alpha)$ against singularity strength, $\alpha$, which exhibits overall, upward, and downward market trends in the regional ESG markets. This spectrum highlights the significance of multifractality in a time-series analysis. In particular, the width of the spectrum determines the level of multifractality, wherein a wider spectrum exhibits higher multifractality. Furthermore, a monofractal time series shows converged points, where $\alpha = H$ and $f(\alpha) = 1$. Here, $H$ represents the classical Hurst exponent. The process follows the multiplicative cascade model with generalized Hurst components by using the formula $H(q) = \frac{1}{q} \log \frac{c q + d q}{\log 2}$. With this process, an infinite number of exponents, $H(q)$, is explained only by two independent parameters, namely, $c$ and $d$. Thus, $\Delta \alpha$ determining the multifractality strength is obtained by subtracting the maximum and minimum values of $\alpha$ and is not limited by the $q$ range. The multifractality strength using the multiplicative cascade model is stated as follows: $\Delta \alpha = \log \frac{c}{d} + \log 2$. The inverse parabolic multifractal spectrum for all ESG indexes that substantiates the multifractality in the ESG markets is presented in Fig. 4. The common hump shape represents multifractality signals. The width of the multifractal spectrum of the downward pattern is more pronounced than the width of the multifractal spectrum of the upward and overall market trends. Furthermore, the results show that the European and American ESG markets have the widest multifractal spectrum, thereby implying that the underlying ESG markets are more multifractal and complex. In contrast to the other two markets, the multifractal spectrums of regional ESG markets in Asia and the Pacific are narrower.

In general, two primary sources are used to assess multifractality in time series: 1) long-range correlations for small and large fluctuations and 2) fat-tailed probability distributions (Naeem et al., 2021). To measure these two sources, we used the methodology proposed by Cao et al. (2013) for each ESG market. Long-range correlations are first captured using the “shuffling” process, wherein the order of the original time series is shuffled to compare the multifractality of the original and shuffled series. In particular, if multifractality disappears from the series
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after the shuffling process, the key source of multifractality is temporal correlations. The second method is phase randomization, which is used to determine the contribution of the fat-tailed distribution. For this method, surrogate series is obtained from the Fourier phase randomization method, and multifractality of original and surrogate series is then compared. The phase randomization method distributes the fat-tails into surrogate time series, and if the surrogate curve of $H(q)$ is closer to the original time-series curve, then fat-tails are not the primary cause of multifractality. Moreover, the measure $\Delta H^+(q) = |H^+(q) - H^-(q)|$ quantifies the asymmetric multifractality, where $H^+(q)$ Hurst exponents for upward and downward trends exist. Furthermore, the greater value of $\Delta H^+(q)$ reveals stronger asymmetric multifractality. For a better description of results, the original, shuffled, and surrogate series are denoted as $\Delta H_{\text{orig}}$, $\Delta H_{\text{shuf}}$, and $\Delta H_{\text{surr}}$, respectively.

Fig. 5 illustrates the original, shuffled, and surrogate time series of ESG indexes for four regional markets. In the case of American and European ESG stock markets, the values of $\Delta H_{\text{shuf}}$ and $\Delta H_{\text{surr}}$ are smaller than $\Delta H_{\text{orig}}$, thereby indicating that both temporal correlations and fat-tail distributions cause the asymmetric multifractality in the underlying ESG markets. By contrast, the results for the other two ESG markets suggest that for some time scales, the value of $\Delta H_{\text{shuf}}$ is greater than $\Delta H_{\text{orig}}$, thereby implying fat-tail distributions are primarily responsible for asymmetric multifractality. In general, for the ESG indexes, the values of $\Delta H_{\text{shuf}}$ are smaller than in the lower time scales, thereby indicating that asymmetric multifractality during small fluctuations can be attributed to long-range correlations. Furthermore, fat-tail distributions cause asymmetric multifractality during large fluctuations.

To further examine the sources of multifractality, Table 2 presents the $\Delta H$ of original, shuffled, and surrogate series by using the A-MF-DFA model, where in most cases of the overall series, $\Delta H_{\text{orig}}$ is greater than both $\Delta H_{\text{shuf}}$ and $\Delta H_{\text{surr}}$, thereby implying that both temporal correlations and fat-tailed distribution influence the multifractality in the series. The upward series shows higher values of shuffled series for the Americas, Asia, and the Pacific, whereas a lower value of $\Delta H_{\text{shuf}}$ for Europe implies that multifractality is contributed by fat-tailed distribution in the former and temporal correlations in the latter. By contrast, the downward trend exhibits higher values than both $\Delta H_{\text{shuf}}$ and $\Delta H_{\text{surr}}$, thereby reiterating that multifractality is caused by both fat-tailed distributions and long-range correlations in the downward market trend.
3.3. Dynamic market efficiency of ESG indexes

To examine the efficiency of the regional ESG markets, we must measure the dynamics over time through the MDM efficiency approach proposed by Wang et al. (2009).

Using the MDM dynamic approach, we present the comparative efficiency of four regional ESG indexes for the complete sample period, including the recent COVID-19 outbreak period in Fig. 6. We use the three-year rolling window method. The overall, upward, and downward market trend is represented by the colors black, red, and green. We observe highly volatility values of MDM across the sample period, thereby indicating that the efficiency of regional ESG markets varies over time. In this case, the results validate the time-varying nature of market efficiency across all regional ESG indexes. In general, all underlying markets exhibit a higher degree of market efficiency in upward trends than in downward trends. Moreover, during downward movements, all ESG indexes exhibit a higher level of market inefficiency. The findings emphasize the importance of risk management and portfolio decisions. More importantly, during the COVID-19 pandemic, market inefficiencies skyrocketed. Following the argument of Naeem et al. (2021b, 2021c), we can expect higher market inefficiency in ESG stock markets during the outbreak period because behaviorally driven responses by market participants caused international stock markets to become highly volatile, which leads to severe economic losses. The American regional market has the highest level of market inefficiency of any ESG market. Overall, the findings support the theory that uncertain financial conditions promote a higher degree of multifractality (Lee et al., 2017). Further, with the restoration of economic activity, the efficiency in regional ESG stock markets has rapidly improved.

3.4. Global factors and efficiency

In this section, we investigate the impact of global factors on the efficiency of the regional ESG stock markets. To do so, we estimate the influence of global factors on the MDM efficiency component for given regional ESG markets. As previously stated, we use implied volatility (fear) indices of five financial markets as global factors and then examine their impact on the market efficiency of four regional ESG stock markets. Tables 3-6 show the effect of global factors on the dynamic efficiency of regional ESG markets. First, various global factors have a significant impact on the efficiency of the regional American ESG market. Indeed, we observe that global factors are better predictors of
underlying market efficiency during downward trends than during upward trends. The findings show a positive relationship among market efficiency, stock volatility, and treasury volatility. According to the findings, an increase in the volatility of stocks and treasury instruments leads to an increase in market inefficiencies in the underlying ESG index. By contrast, we observe a negative relationship between the American ESG index and gold market volatility. Furthermore, the implied volatility of the oil market has a significant impact on the efficiency of the aforementioned ESG market.

Second, the findings show that gold and currency implied volatility have a positive influence on the efficiency of the European ESG index. By contrast, we find a negative relationship between treasury implied volatility and the underlying ESG market, thereby implying that high uncertainty in the treasury market influences the efficiency of European ESG stock markets. Interestingly, the results show a functional role for global factors in determining the efficiency of the European ESG index during times of economic downturn.

Finally, the findings show that all global factors have a significant impact on the market efficiency of Asian and Pacific ESG stock markets. The results imply that the content in global factors can be effectively used to predict market efficiency of Asian and Pacific regional stock markets. In case of the Asian ESG index, stock, oil, and treasury markets are positively associated with MDM, whereas two global factors, such as gold and currency market, are negatively associated. Similarly, we see an inverse relationship between the Pacific ESG index and global factors, namely, oil, gold, and currency. Furthermore, the results show that the global factor predicts market efficiency better in downward trends than in upward trends.

Overall, the investigation of the relationship between the global factors and market efficiency of the regional ESG markets unveils that the efficiency dynamics of the underlying ESG markets depends on implied volatilities of stock, oil, gold, currency, and treasury markets. Thus, the findings conform to previous evidence that global factors influence the efficiency of financial markets. The results have crucial implications for risk management and asset allocation. The findings suggest that portfolio managers and investors in ESG markets should closely monitor the movements of implied volatility indices before making ESG market investments. Further, the information content of fear indices can be used to forecast market inefficiencies in regional ESG indexes, particularly during economic and financial meltdown. Furthermore, considering the negative correlation between a few global factors and the ESG indexes, the market participants can take offsetting

Fig. 4. Multifractal spectrum $f(\alpha)$ versus $\alpha$ for regional ESG markets. Note: This figure depicts the values of the multifractal spectrum $f(\alpha)$ versus the singularity strength $\alpha$ for overall, upward and downward patterns in the regional ESG markets. The multifractal spectrum provides relevant information about the relative importance of multifractality properties of the time series under study. The black curve represents the multifractal spectrum under the overall market trend, whereas the red and green curves refer to the upward and downward market trend, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
positions across these markets to hedge portfolio risks.

4. Discussion and conclusion

Over the last three decades, ethical investments have piqued the interest of investors, policymakers, and academics worldwide. In contrast to conventional investments, ethically responsible investments necessitate a set of screening criteria that includes stocks based on integrity, trust, and societal and social values (Jawadi et al., 2018). In this context, ESG investments are becoming increasingly popular among investors because they allow them to align ethical concerns with financial returns. According to Global Sustainable Investment Alliance
data, ESG investments have increased by 34% from 2016. Indeed, the phenomenal growth of ESG funds in developed markets (e.g., Europe and the Americas) demonstrates that Socially Responsible Investing has become an integral part of fund management. Furthermore, the price movements of ESG stocks, including those of conventional equities, vary with economic conditions, particularly during periods of slowdown. During the recent COVID-19 pandemic, financial markets worldwide crashed in a way not seen in decades. In financial markets, behaviorally...
driven trading strategies transformed the pandemic into a Black Swan event for investors. Clearly, the terrifying and unprecedented risk during COVID-19 significantly influenced the price dynamics in financial markets. Similarly, ESG stocks were vulnerable to pandemic factors, thereby resulting in the improved efficiency and performance of ESG investments. This approach may be exploited patterns. The findings further show that multifractality in regional ESG markets is sensitive to time scales, trends, and major exogenous events, thereby demonstrating the importance of investor sentiment in driving efficiency dynamics. Multifractality, for example, increases with time scale, thereby indicating high market inefficiency at higher scales. Moreover, the evidence finds that multifractality in the regional ESG markets varies for upward and downward trends, wherein the multifractal properties are pronounced during downward market trends. Overall, we find that the European ESG market is more efficient than the other regions when compared with other ESG markets. One possible explanation for this finding is the underlying ESG market’s large market capitalization and level of maturity. Moreover, the efficiency can be attributed to its long-standing commitment to ESG investments and its consistent growth in ESG mutual funds from 2016 (Omar et al., 2020). The greater efficiency in the European ESG market suggests that European ESG investments have a greater potential to act as a potential diversifier, hedge, and safe-haven against risks in other regional ESG markets. Furthermore, the evidence reveals a significant impact of the COVID-19 pandemic on the efficiency dynamics of regional ESG indexes. The findings clearly show that multifractality in regional ESG markets increased significantly during the COVID-19 outbreak, thereby resulting in a decline in market efficiency. The findings imply that ESG investments are vulnerable to investor sentiment, particularly during times of crisis. Finally, our findings show a significant relationship between global factors and efficiency dynamics in the ESG sector. The findings suggest that market participants should take implied volatility index movements into account when forecasting market efficiency and related arbitrage opportunities in regional ESG markets.

The study’s evidence has several implications for policymakers, investors, and portfolio managers. Based on our findings, investors should recognize predictable patterns in the ESG markets, particularly during crisis periods, to identify arbitrage opportunities. Further, because regional ESG market efficiency is sensitive to market conditions, investors should carefully monitor switching behavior when trading in the underlying markets. Furthermore, investors should be aware of the limitations of conventional pricing methods, which assume that underlying asset prices follow geometric Brownian motion. Additionally, the relatively better performance of a few ESG indexes during the outbreak period suggests that investors can use such investments to diversify risks in traditional assets during extreme negative events. Policymakers should encourage and facilitate the development of ESG markets in this context because they provide avenues for ethically responsible investment and risk management. Furthermore, from regulators’ perspective, inefficiency in ESG markets implies that exploitable patterns persist, which intensify during extreme periods, such as COVID-19 pandemic. Therefore, policies that promote transparency and stability can be crucial to increasing market efficiency in ESG stock markets. Such policies will boost the confidence of individual and institutional investors, thereby resulting in the improved efficiency and performance of ESG stock markets. Because the study only used a few regional ESG indices for analyses, future research should look into more ESG markets to assess the efficiency dynamics of the ESG market. This approach may reveal further insights into the topic.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

The authors do not have permission to share data.
Appendix A

Table A1

|        | Mean   | Std. Dev. | Skewness | Kurtosis | JB     |
|--------|--------|-----------|----------|----------|--------|
| VIX    | 57.565 | 5.698     | 0.870    | 2.960    | 140.680*** |
| OVX    | 18.373 | 9.391     | 2.522    | 12.613   | 5440.818*** |
| GUV    | 39.252 | 26.536    | 4.671    | 31.078   | 40425.190*** |
| EVZ    | 14.793 | 5.318     | 2.005    | 8.610    | 2195.634*** |
| MOVE   | 7.393  | 1.677     | 1.726    | 10.450   | 3112.479*** |

Note: *** indicates 1% level of significance.

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