Adaptive Market Hypothesis in ASEAN Exchanges: A Multi-Non-Linear Approach, Multifractal and Wavelet-Based Sample Entropy
สมมติฐานตลาดปรับตัวในตลาดหลักทรัพย์อาเซียน: วิธีการหลายมิติที่ไม่เป็นเชิงเส้น, มัลติแฟรคทัล และเอนโทรปีตัวอย่างที่ใช้เวฟเล็ต

Ramede Khunnawannaphong
ราเมศวร์ คุณวรรณพงษ์
Burapha Business School, Burapha University
คณะบริหารธุรกิจ มหาวิทยาลัยบูรพา
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Abstract

In this study, the adaptive market hypothesis (AMH) is tested in the context of six ASEAN exchanges by employing two nonlinear analytical methods: wavelet-based sample entropy (SampEn) and multifractal detrended fluctuation analysis (MF-DFA). Daily price indices (earliest availability–June 2025) are analyzed after STL preprocessing to focus on residual dynamics, obtained from the Bloomberg database, and employed. The results demonstrate that all markets exhibit distinct multifractal characteristics. Indonesia shows the highest maltifactual level (Δh=0.616); Vietnam displays the highest persistence (H(q=2)=0.629) but the lowest Δh (0.176); Singapore and the Philippines hover near random walk behavior. Rolling H and Δh highlight efficiency that changes with market states, aligning with AMH. The Hurst index and the entropy complexity values also change over time. These results are similar to those of other studies in the field (Niere, 2013; Yalamova, 2006; Phan & Pham, 2019). Practical implications: adopt adaptive allocation and risk controls tied to each market's efficiency cycle; confirm signals with rolling, multi scale backtests; and, from a policy angle, strengthen liquidity and transparency, especially around macro shocks.

Keywords: Adaptive market hypothesis; Efficient market hypothesis; Multifractal detrended fluctuation analysis; Wavelet-based sample entropy; ASEAN exchanges

บทคัดย่อ

ในการศึกษาครั้งนี้ ได้ทำการทดสอบสมมติฐานตลาดปรับตัว (AMH) ในบริบทของตลาดหลักทรัพย์อาเซียน 6 แห่ง โดยใช้วิธีการวิเคราะห์แบบไม่เป็นเชิงเส้น 2 วิธี ได้แก่ เอนโทรปีตัวอย่างโดยใช้เวฟเล็ต (SampEn) และการวิเคราะห์การผันผวนที่ขจัดแนวโน้มแบบหลายแฟร็กทัล (MF-DFA) ดัชนีราคาประจำวัน (ตั้งแต่เริ่มมีข้อมูลจนถึงเดือนมิถุนายน

2568) ถูกใช้ในการวิเคราะห์หลังจากการทำ STL เพื่อเน้นที่พลวัตของส่วนที่เหลือ โดยเก็บมาจากฐานข้อมูล Bloomberg ผลลัพธ์แสดงให้เห็นว่าตลาดทั้งหมดมีลักษณะมัลติแฟรกทัลที่แตกต่างกัน อินโดนีเซียแสดงระดับมัลติแฟกทอลที่สูงที่สุด (Δh=0.616); เวียดนามแสดงความคงทนสูงที่สุด (H(q=2)=0.629) แต่มี Δh ต่ำที่สุด (0.176); สิงคโปร์และฟิลิปปินส์มีพฤติกรรมใกล้เคียงกับการเดินแบบสุ่ม Rolling H และ Δh เน้นย้ำถึงประสิทธิภาพที่เปลี่ยนแปลงไปตามสภาวะตลาด ซึ่งสอดคล้องกับ AMH ค่าดัชนีเฮิร์สต์และค่าความซับซ้อนของเอนโทรปีก็มีการเปลี่ยนแปลงไปตามกาลเวลาเช่นกัน ผลลัพธ์เหล่านี้คล้ายคลึงกับผลลัพธ์จากการศึกษาอื่นๆ (Niere, 2013; Yalamova, 2006; Phan และ Pham, 2019) ผลกระทบในทางปฏิบัติ: ปรับรูปแบบการจัดสรรหลักทรัพย์และการควบคุมความเสี่ยงให้เชื่อมโยงกับการเปลี่ยนแปลงประสิทธิภาพของตลาด ยืนยันสัญญาณด้วยการทดสอบย้อนหลังแบบหลายระดับและต่อเนื่อง และในมุมมองเชิงนโยบาย เสริมสร้างสภาพคล่องและความโปร่งใส โดยเฉพาะอย่างยิ่งในช่วงที่เกิดการเปลี่ยนแปลงในระดับเศรษฐกิจมหภาค

คำสำคัญ: สมมติฐานตลาดหลักทรัพย์ที่ปรับตัวได้; สมมติฐานประสิทธิภาพตลาด; การวิเคราะห์การแปรผันแบบมัลติเฟรคทัลที่ถูกปรับแนวโน้ม; เอนโทรปีตัวอย่างที่ใช้เวฟเล็ต; ตลาดหลักทรัพย์อาเซียน

Introduction

According to the Efficient Market Hypothesis (EMH) stock prices should reflect all publicly available information and thus it should be impossible for investors to earn systematically above-normal returns without accepting higher risk (Fama, 1970). But this view is contradicted by many empirical studies. Phenomena such as the momentum, mean reversion, the January and day of the week effects and disruptive events such as the 1987 crash and dot-com bubble show obvious departures from EMH predictions (Ajadi, 2023; Carlson, 2007; Chen et al., 2018; Kasidi & Banafa, 2022; Kiymaz & Berument, 2003; Lekhal & El Oubani, 2020; Poterba & Summers, 1988; Wissawapaisal, 2023).

Managerial Implications Behavioral finance also contradicts EMH in emphasizing that psychological biases including overconfidence and loss aversion lead to divergence of asset prices from their fundamentals (Kapoor & Prosad, 2017). These constraints of EMH have given rise to alternative paradigms, such as Lo's (2004) Adaptive Market Hypothesis (AMH) which integrates evolutionary theory with psychological and other behavioral constructs. AMH interprets markets as complex systems, in which efficiency is updated as a function of the behavior of participants, the opportunities that are identified, and the institutional structure.

Increasing empirical research favours AMH, especially in developing countries. For instance, Mostafa and Oubani's (2020) study has reported on time changing efficiency on the Morocca market, a study in Vietnam has also documented similar behavioral response (Tran & Pham 2019). With high volatility, low trading volume and a variety of regulatory and institutional environments the ASEAN region is an attractive stage for AMH study. Former research reveals that the ASEAN markets are characterized by non-random walk behavior, indicating adaptive rather than static behavior (Shaik & Maheswaran, 2016). Special factors such as concentrated ownership patterns, governance standard, and law enforcement also drive market behavior in a manner not explained by EMH (Chung & Ariff, 2015; Thampanya et al., 2020; The Stock Exchange of Thailand, 2023). The comparative AMH assessment specifically for

ASEAN considers alternating global-to-local spil lovers, commodity exposures, regulatory heterog eneity, and market structure differences across six markets. Taken together, these situational features and the accumulating evidence in favor of state dependent efficiency motivate the use of multifractal detrended fluctuation analysis (MF DFA) and wavelet based sample entropy (SampEn) to compare efficiency dynamics across the six ASEAN exchanges.

Objective

1. To examine the existence and strength of multifractality in the daily return series of six ASEAN exchanges using the MF-DFA.

2. To evaluate the informational efficiency and complexity of these markets over time using SampEn

3. To investigate the time-varying nature of market efficiency across different countries, reflecting the adaptive behavior of market participants as theorized by AMH.

Literature review

The proposal of AMH by Lo (2004) departs from the static philosophy that EMH comes under suggesting that market efficiency changes over time depending on the changing environment such as macroeconomics events, regulatory changes and investors' information and interest. AMH claims that investors are learning and adjusting, so that efficiency fluctuates through time.

Empirical evidence shows that predictability of stock returns varies over time, supporting AMH. For example, Kim et al. (2011) studied the autocorrelation of the Dow Jones Industrial Average have shown that the temporal autocorrelations of the stock market have different timescales, and they are enhanced during the financial crisis. Lim et al. (2008) and Ito and Sugiyama (2009) also described the similar phenomena in the Asian markets and U.S. market, respectively. Rolling-window and bootstrap methods (Lim et al. 2013) demonstrate that market efficiency changes through regimes, whereas Urquhart and McGroarty (2014) found the existence of calendar anomalies that come and go over time.

Ito et al. (2014, 2016) applied time-varying vector autoregressive (TV-VAR and TV-AR) models and proved that market efficiencies in the world and in the U.S. change over time, especially under crises. Noda (2016) also evidenced this in Japan, where stock indices exhibited varying degrees of efficiency. Using variance ratio tests and rolling windows, Khunnawannaphong (2022) also test the Thai market and endorse time-varying changes in volatility and efficiency.

Evidence has also been found of the weak-form EMH violation in the emerging Asian markets. Early work by Huang (1995), Kawakatsu & Morey (1999) and Worthington & Higgs (2004) did not support random walk. This was also confirmed by Hoque et al. (2007), Hamid et al. (2010), Mishra (2012), Nisar & Muhammed (2012), Paulo (2013), and Sodsai & Suksonghong (2018), employed a variance ratio as well as unit root tests.

Multifractal and entropy-based methods have been proven of value for the study of AMH among non-linear techniques. Yalamova (2006) proved that Asia-Pacific markets are multifractal, they possess long range dependence, fat tails and volatility cascades, during times of distress. Niere (2013) used MF-DFA to ASEAN stock markets and found significant multiscale nature and time-dependent Hurst exponents. The study found that Singapore exhibited the highest degree of efficiency and Vietnam the lowest.

In addition, entropy related measures quantify the uncertainty of the return series. Approximate Entropy (ApEn) was developed by Gulko (1999) and Pincus (1991) Measure regularity in non-stationary time series. More entropy means more randomness and less entropy means durability or pattern. Kristoufek & Vosvrda (2014) used ApEn to build a composite efficiency index for the market and showed that the developed ones were more efficient than the emerging.

ApEn has been modified to yield Sample Entropy (SampEn), which is also less sensitive to noise for shorter series. It eliminates bias from self-matching and converges faster, which is more suitable for financial time series. Patra & Hiremath (2022) confirmed the efficiency across various markets whereas Olbrys & Majewska (2022) observed that the SampEn values often diminish in financial crises, which implies that the predictability is increasing, and the inefficiency is temporary.

Taking together, these entropy works support the primary argument of AMH that market efficiency is not binary but varies with market states, and they encourage the combined use of fractal and entropy diagnostics. However, two gaps remain: first, a regional comparative lens that treats the six ASEAN exchanges as an integrated yet diverse setting, and second, a methodolo gical integration that jointly applies MF DFA and wavelet based SampEn within a unified, multi horizon framework anchored by simulation based efficiency benchmarks. Accordingly, this study is one of the first comparative investigations to integrate MF DFA and SampEn for the ASEAN exchanges.

Methodology

This study uses MF-DFA to identify multifractality and nonlinear long-range relationships in each return series. MF-DFA is a well-established technique for revealing multifractal scaling in non-stationary financial time series (Kantelhardt et al., 2002; Laib et al., 2018; Milos et al., 2020). Firstly, to isolate the true stochastic variability in each market, return series were decomposed using STL decomposition using LOESS (Cleveland et al,1990).

$$r_t = T_i + S_i + R_i \quad (1)$$

Were r_t is log return of the series

MF-DFA is conducted on the residual series Ri to examine the multifractal structure of market fluctuations. The procedure comprises several computational steps.

Step 1 Profile Construction: Let Ri be a time series of the remainder component obtained from the STL decomposition of stock market returns and subtract its mean to form a "profile", Yj,:

$$Y_j = \sum_{i=1}^{j} (R_i - \bar{R}), i = 1, \ldots, N \quad (2)$$

Step 2 Segmentation: Divide the profile Yj into Ns = int(Ns), non-overlapping segments of length s, covering the entire series.

Step 3 Detrending: In each segment, fit a local trend and compute the detrended variance. The variance is calculated using the following formulas:

$$F^2(s, v) = \frac{1}{s} \sum_{j=1}^{s} \left\{ \begin{matrix} Y[(v-1)s + j] \\ - y_v(j) \end{matrix} \right\} \quad (3)$$

for each segment v, v = 1, …, Ns, and

$$F^2(s, v) = \frac{1}{s} \sum_{j=1}^{s} \left\{ \begin{matrix} Y[(v - N_s)s + j] \\ - y_v(j) \end{matrix} \right\} \quad (4)$$

for v = Ns+1, …, 2Ns, where yv(j) is the polynomial fit in segment v.

Step 4 Fluctuation Functions: To assess the fluctuation across all segments, the q-order fluctuation function is computed as:

$$F_q(s) = \left\{\frac{1}{2N_s}\sum_{v}^{2N_s}[F^2(s,v)]^{\frac{q}{2}}\right\}^{\frac{1}{q}} \; if \; q \neq 0 \quad (5)$$

and

$$F_q(s) = \left\{\frac{1}{4N_s}\sum_{v}^{2N_s} ln[F^2(s,v)]\right\} if \; q = 0 \quad (6)$$

The parameter q serves in identifying between segments exhibiting minor and significant fluctuations.

Step 5 Scaling Exponents: The scaling behavior of Fq(s) across different window sizes s reveals the generalized Hurst exponent hq, according to the power-law relation:

$$F_q(s) \propto s^{h_q} \quad (7)$$

For monofractal signals, hq remains constant across q, whereas a dependency of hq on q indicates multifractality, reflecting complex dynamics such as long memory and volatility clustering. To further characterize the multifractal nature, the singularity spectrum F(α) is obtained via the Legendre transform of the mass exponent function

$$\tau(q) = qh_q - 1 \quad (8)$$

$$\alpha = h_q + q\frac{\partial h_q}{\partial_q} - \tau(q) \quad (9)$$

$$f(\alpha) = q\alpha - \tau(q) \quad (10)$$

The width of the spectrum f(α) serves as a proxy for the degree of multifractality in the market; wider spectra suggest more heterogeneous scaling behavior and thus greater deviation from market efficiency.

To quantify the strength of multifractality, the range of the generalized Hurst exponents is calculated as

$$\Delta h = \max(h_q) - \min(h_q) \quad (11)$$

A larger value of Δh suggests a wider dispersion of scaling exponents, indicating stronger multifractal characteristics and a higher degree of market inefficiency.

To capture time-varying efficiency, the above MF-DFA procedure is implemented in a rolling-window framework. Specifically, a window size of 500 trading days with a step size of 20 days is employed to compute the time-varying Hurst exponent h2, as well as the dynamic range Δh. This dynamic version of MF-DFA enables the detection of changes in market efficiency over time, as expected under the AMH framework. Values of h2 close to 0.5 indicate a random walk and thus market efficiency, whereas significant deviations suggest persistent inefficiencies (Raza et al., 2024; Aloui et al., 2018).

Consistent with Kumar & Kamaiah's (2014) approach, this study measures market efficiency using a SampEn analysis. SampEn is a more recent advancement in time series analysis that enhances methods created by Grassberger and colleagues to determine the regularity or complexity of a time series. A notable improvement is SampEn's capacity to eliminate out self-matches; a lower SampEn value indicates higher self-similarity or predictability (Richman & Moorman, 2000).

To test market efficiency, they simulate an efficient market to act as their benchmark. An efficient market's prices are theorized to follow a geometric Brownian motion, meaning there's no predictable pattern in its price movements over time. Additionally, the returns in an efficient market should follow a normal distribution. So, to determine if a real market is efficient, they create a simulated series. This simulated data is independent and identically distributed (i.i.d.) and normally distributed, mirroring the mean and standard deviation of the actual dataset being analyzed.

Next, they apply the same two analytical steps to both the real and simulated data. A key part of this analysis involves wavelet decompo sition using an LA (least asymmetric) wavelet filter with a length of 8. Finally, they compare the entropy curves of both series at various scales. If the market is truly efficient, the entropy curve of the original data should align closely with that of the simulated, random walk series. For more details, see also Kumar & Kamaiah (2014).

Population and Sample

The population for this study consists of the daily closing prices of the stock indices from six ASEAN countries: Thailand (SET), Indonesia (JCI), Malaysia (FBMKLCI), the Philippines (PCOMP), Singapore (STI), and Vietnam (VNINDEX). The population assumption takes these daily observations as the proxy for weak-form efficiency assessment in ASEAN, recognizing that efficiency may vary between markets and regimes, as AMH states. The sample is composed of daily closing price data from the earliest date in each market up to June 12, 2025.

Research Tools

This paper uses two main set of statistical methods for analyzing the complex and non -stationary nature of financial markets through MF-DFA and SampEn. The MF-DFA algorithm introduced by Kantelhardt et al. (2002) enables the analyst to identify persistent market return inefficiency. Cumulative SampEn (SampEn analysis described in Kumar and Kamaiah (2014)) employs wavelet decomposition, using LA(8) filter, and an entropy method to measure randomness and structual complexity of financial time series at multiple scales. Supporting tools are STL decomposition (referring to Cleveland et al., 1990). All tools are programmed in R and Python, providing accuracy in statistical estimation, and reproducibility in analysis. Detail parameters setting reported in the result section.

Data Collection

All the data in this study was sourced from the Bloomberg database, where wildly use in financial studies.

Statistical Analysis

All return series were put through standard, diagnostic testing before the main empirical procedures. Stationarity was tested by the Augmented Dickey-Fuller (ADF), normality by the Jarque–Bera and Shapiro–Wilk tests. This study employed ARCH-LM test to detect the presence of volatility clustering in all series. In addition, autocorrelation functions (ACF) were calculated for lags 1–40 to look at the temporal dependence structure. Once residuals from STL decomposition were verified to be stationary and with non-Gaussian behavior, two primary analytical protocols were performed. In the first stage, we use MF-DFA to calculate the generalized Hurst exponent $h(q)$, multifractal spectrum $f(\alpha)$ and the extend of multifractality Δh, and next use the window rolling method to get these quantities over time. Second, the Wavelet-Based SampEn analysis was performed in the actual and artificial returns series to check the efficacy of information on several time scales. The comparison between the entropy of empirical markets with that of synthetic efficient markets offers a complementary element of predictability and structure of information.

Result

In table1. provide the summary statistics of daily log returns across six ASEAN stock markets have demonstrated significant departure from normality, especially for Indonesia and Malaysia by exhibiting high kurtosis and fat tails embodying higher frequency of extreme observations. This is all consistent with the kinds of things you expect to see in emerging markets. These deviations are corroborated by normality tests that are carried out on the residuals, and by ARCH tests that show the presence of significant volatility clustering in all markets. Stationarity of returns series is also supported by ADF test results. These results indicate that the EMH cannot be used to interpret the patterns of data that have been observed, and we are justified to applying the AMH model as a more suitable method of analysis (Ammermann, 2016; Jansen, 2020)

Table 1

The fundamental statistics of daily Log return series

Country	Malaysia	Vietnam	Indonesia	Philippine	Singapore	Thailand
Mean	0.0002	0.0004	0.0004	0.0003	0.0001	0.0001
Std_Dev	0.0125	0.0145	0.0145	0.0152	0.0108	0.0150
Skewness	-0.3641	-0.4115	2.4632	-0.0948	-0.3570	-0.3370
Kurtosis	41.8114	3.5183	83.6313	11.4088	6.7078	10.0549
Jarque-Bera p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Shapiro-Wilk p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ADF p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ARCH p	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Observations	11,908	6,018	10,261	9,472	6,478	9,279

To examine the data structure and prepare the data for multifractal and wavelet analysis under the AMH framework, this research employed STL decomposition to separate the components of log return into trend, seasonality, and residual. The STL technique is highly flexible in capturing nonlinear structures and is widely accepted in time series research (Cleveland et al., 1990; Hyndman and Athanasopoulos, 2018).

In this study, the following parameters were used: period is 252 to reflect the number of trading days in a year, which is suitable for daily stock markets (Tsay, 2010); the seasonal window is 17 to capture short-term structures, noting that emerging markets often do not exhibit clear seasonality and the trend window was set as an odd number at 1.3 times the period to ensure trend smoothing accommodates medium-term changes without being too fine to lose actual volatility, following the recommended practices in STL implementation (Cleveland et al., 1990).

After processing, the residuals of each country passed the ADF test with a p-value less than 0.01 in all cases, indicating that the residuals are stationary and suitable for the next step in the AMH assumption analysis. The Jarque–Bera test results in a p-value close to 0 in all countries, confirming that the residuals do not conform to a normal distribution. Furthermore, the autocorrelation function tested at a lag of 0 to 40 showed values approaching 0 rapidly in all datasets, as shown in Table 2, Figure 1, and Figure 2

Table 2

STL Residual Diagnostics

Country	ADF p-value	Skewness	Kurtosis	Jarque-Bera p	Stationary
Malaysia	0.0000	-0.3641	41.8114	0.0000	Yes
Vietnam	0.0000	-0.4115	3.5183	0.0000	Yes
Indonesia	0.0000	2.4632	83.6313	0.0000	Yes
Philippine	0.0000	-0.0948	11.4088	0.0000	Yes
Singapore	0.0000	-0.3570	6.7078	0.0000	Yes
Thailand	0.0000	-0.3370	10.0549	0.0000	Yes

MF-DFA results

The MF-DFA analysis uses standard parameters from literature (Kantelhardt et al., 2002; Laib et al., 2018; Milos et al., 2020). Additionally, the q-parameter is set from-10 to +10 to create the general Hurst exponent function H(q), which is used to calculate the mass exponent τ(q), singularity spectrum f(α), and the spectrum width (Δh=max(H(q))−min(H(q))), which are used to interpret the degree of multifractality reflecting the complexity of market changes.

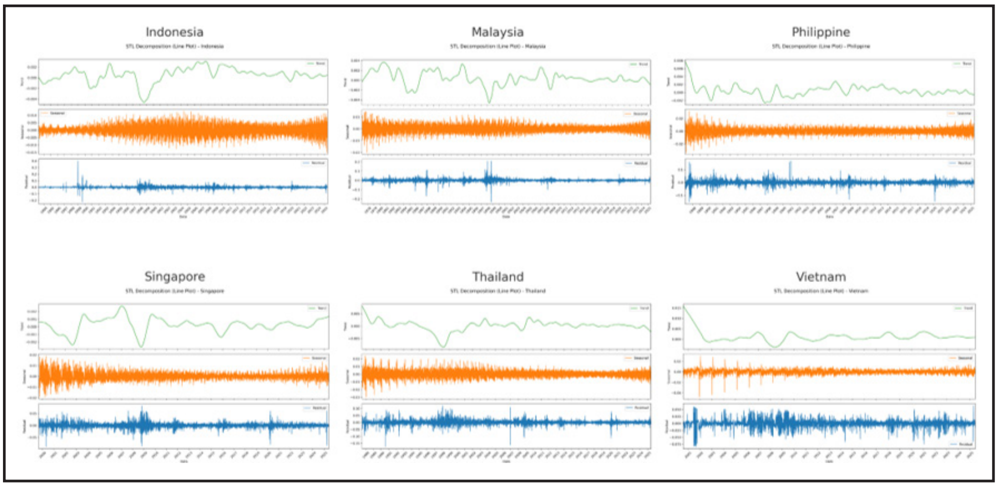

Figure 1 *STL decomposition of Log return*

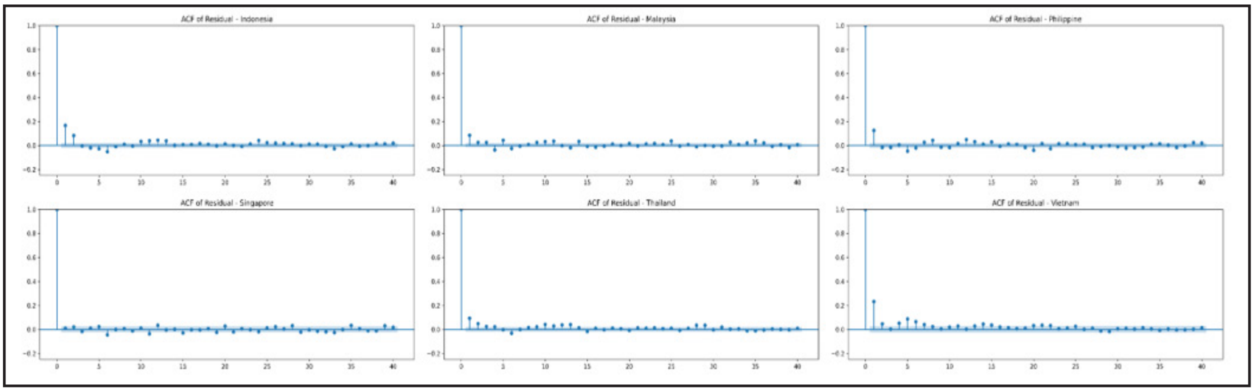

Figure 2 *Autocorrelation function*

MF-DFA, as shown in Figure 3, indicates pervasive multifractality across all markets, with marked cross-sectional differences. Indonesia exhibits the widest spectrum (largest Δh), signaling the strongest multifractality. Vietnam records the highest H(q=2), evidencing strong persistence, but simultaneously shows the narrowest spectrum (lowest Δh), implying comparatively lower multifractal complexity. This pattern, high persistence paired with low Δh, suggests that Vietnam's return dynamics are persistent yet less heterogeneous across fluctuation orders, which differs from markets such as Indonesia where both persistence and complexity co-intensify. These interpretations align with Table 3, where Indonesia records the largest Δh and Vietnam the smallest Δh alongside the highest H(q=2).

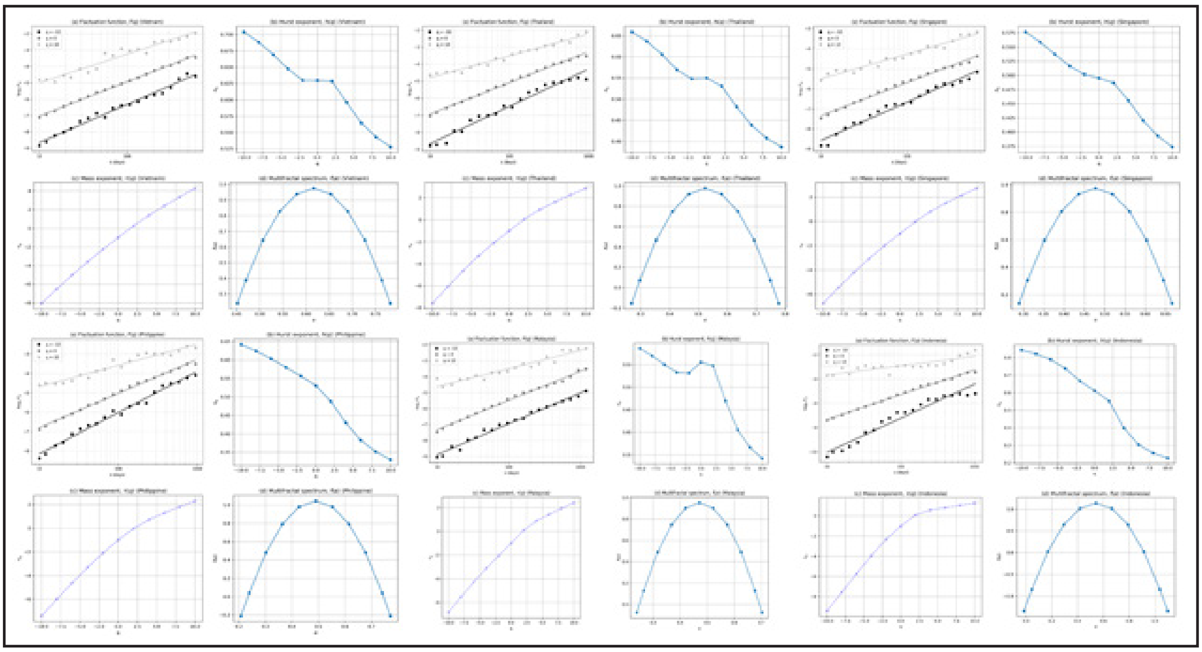

Figure 3 *MF-DFA analysis*

In contrast, the Singapore market exhibits characteristics that align most closely with the Efficient Market Hypothesis (EMH). The Hurst index value in the q=0 range is close to 0.5, indicating random walk behavior, and the narrowest f(α) value among all countries, reflecting a more stable and less predictable price structure. The Thai and Philippine markets are at a medium level, exhibiting quite clear multifractal behavior. Particularly in Thailand, there is a notable change in the value of h(q) between q<0 and q>0, indicating asymmetry in the distribution of volatility and possibly correlating with different speculative forces between bull and bear market conditions. Meanwhile, the Philippines shows increasingly pronounced anti-persistent characteristics when q>0 indicates a rebound effect in price behavior. The Malaysian market exhibits a mixed behavior, with the Hurst index ranging from approximately 0.5 to 0.6. The curvature of the τ(q) and f(α) functions indicates a moderate level of multifractality, which may reflect a combination of partially efficient market forces alongside crowd behavior at certain times.

Furthermore, Table 3 presents the key information from the MF-DFA analysis concisely and comprehensively, showing the Hurst exponent at q=2 (H(q=2)), the level of multifractal diversity

(Δh), and the range of the singularity spectrum (α min,α max) for each country in the ASEAN stock market group. This comparative display helps to clearly illustrate the overall dynamics and complexities of each market among all the markets. Vietnam shows values H(q=2) at its highest is 0.629, reflecting long-range dependence behavior, which may be due to structural factors or trend-following investment behavior. Meanwhile, Singapore and the Philippines show the lowest H(q=2) values at approximately 0.487–0.488, indicating more random price behavior. Additionally, Indonesia exhibits the highest level of multifractal diversity (Δh=0.616) along with the widest α-spectrum (α min=−0.016,αmax=1.100), reflecting a market structure with high irregularity, diverse behavioral scales, and a tendency to respond to external shocks or economic uncertainties. In contrast, Vietnam has a Δh=0.176 and the narrowest α-spectrum, indicating more consistent behavior and a more stable data structure.

Table 3

Summary of MFDFA results

Country	Hq2	Δh degree	alpha_min	alpha_max
Malaysia	0.54694	0.24345	0.23970	0.70278
Vietnam	0.62856	0.17605	0.45150	0.78193
Indonesia	0.55266	0.61594	-0.01615	1.10017
Philippine	0.48822	0.31212	0.20775	0.77170
Singapore	0.48677	0.20286	0.28864	0.66570
Thailand	0.53141	0.27251	0.26913	0.77752

The comparison of results in each country indicates that the markets in the ASEAN region exhibit diverse dynamics and do not conform to all traditional efficient market hypotheses. Particularly in developing markets such as Indonesia and Vietnam, there are signs of high multifractality, while Singapore's market is the closest to being random. These differences can be explained through the AMH, which suggests that market efficiency may vary according to context, economic conditions, and investor behavior.

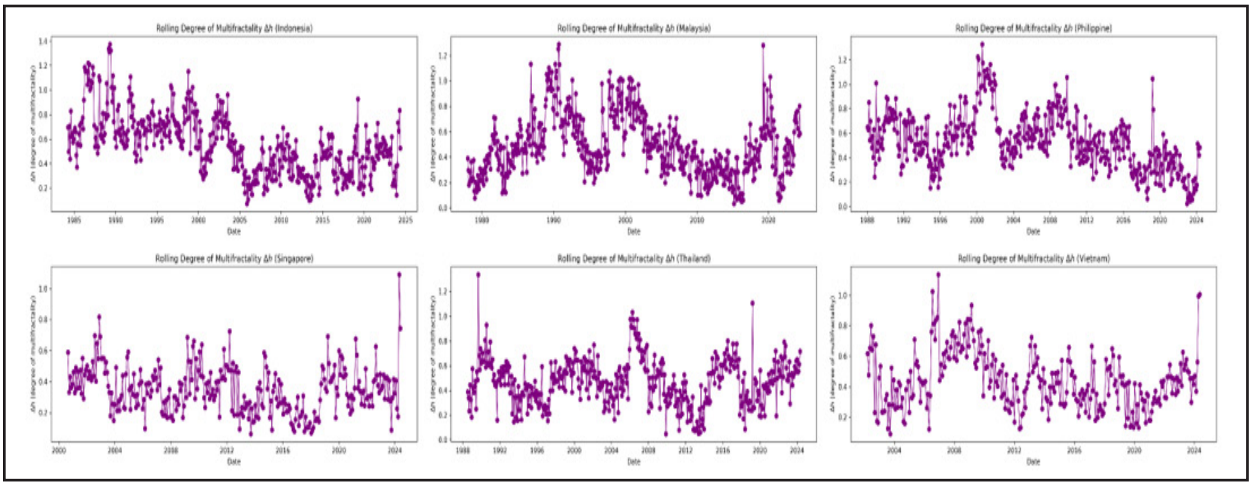

Figure 4 *Rolling Degree of Multifractality Δh*

Fig. 4 shows the rolling multifractality level (Δh) for the six ASEAN exchanges, which demonstrate the dynamic and time-varying multifractality properties. Indonesia and Malaysia have the highest Δh and are the most variable, sometimes above 1.2, indicating complex return patterns, potentially influenced by uncertainty or structural break. On the other hand, the Philippines and Thailand have a moderate level of multifractality, with Δh values usually within the range 0.2-1.0 and reaching for short periods the values >1, reflecting transient increases of market complexity. Singapore and Vietnam have the most stationary behavior, both exhibiting low and relatively narrow Δh values, which would mirror previous statistical evidence of highly unsaturated multifractal spectra for both markets.

Fig. 5 Rolling Hurst exponent (h2), which supports the hypothesis of time-varying market efficiency. The red dot-dashed line corresponds to the memoryless case related to the efficient market (h = 0.5). Indonesia, Malaysia and Thailand showed persistent behaviors, with the h2 typically larger than 0.5, which implies the memory effects and possible short-range predictability. The Philippines and Vietnam meanwhile display a fluctuating behavior, with h2 oscillating around 0.5 at different times. Singapore continues to be the least persistent, with h2 uniformly neighboring 0.5, corresponding just to near random and quasi-efficient behavior.

In all, the results from Figures 4 and 5 together indicate that the ASEAN markets do not adhere to the static assumptions of the EMH. Instead, their efficiency level appears to be evolving, as is in accordance with the AMH. Rolling-window MF-DFA is found to be efficient at capturing these dynamics, which indicates that market efficiency in ASEAN is dynamic and is not constant but adjusts in relation to changing economic situations, investor sentiment and learning

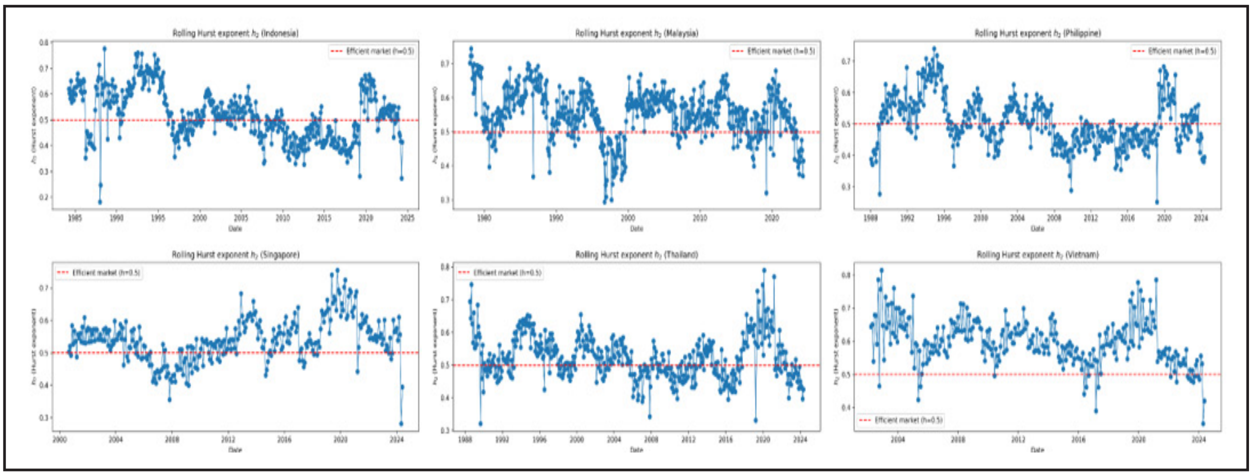

Figure 5 *Rolling Hurst*

Wavelet based sample entropy analysis

The wavelet based SampEn analysis (see Figure 6) offers new perspectives on the structural and complex traits of financial markets at different time scales. Real ASEAN market data always exhibit lower entropy values than the simulated efficient market for all scales (j 1 to 3), i.e., they possess more predictability and internal structure. This phenomenon is especially pronounced in Indonesia, Malaysia, and Thailand, whereas Singapore and the Philippines look more reminiscent of the efficiency frontier as the scale becomes larger (j >5). These findings imply that ASEAN exchanges are not always fully randomly efficient and are consistent with the AMH of the state of efficiency.

When compared to the results obtained through MF-DFA technique, both methods show time dependent inefficiencies and adaptive nature of investors. This robustness of SampEn considering the complexity at different time scales pairs with that of MF-DFA in reinforcing the empirical findings on AMH in ASEAN.

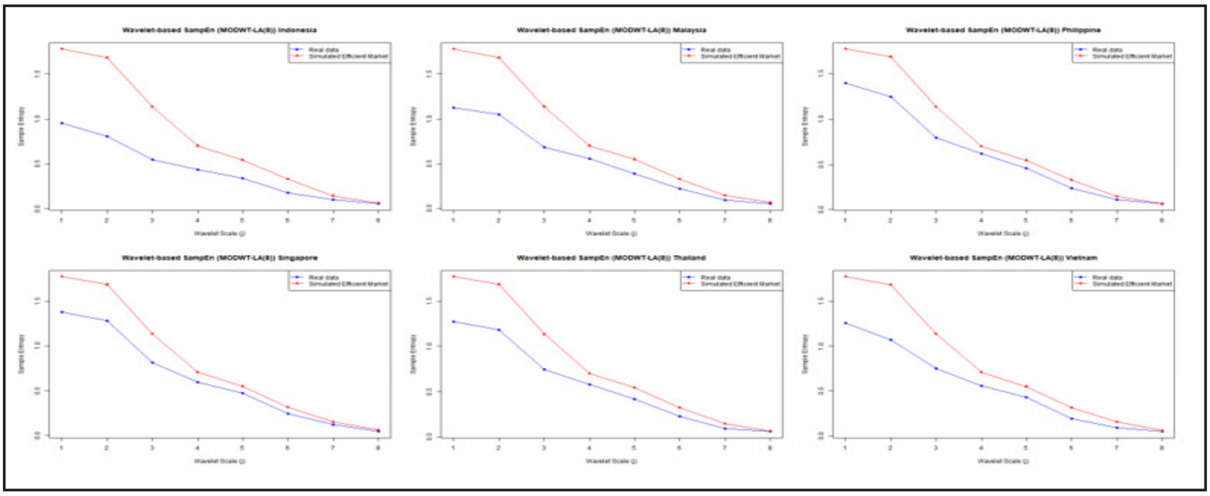

Figure 6 *Wavelet-based sample entropy*

Discussions

The evidence indicates pervasive multifractality with clear cross-sectional heterogeneity across the six ASEAN exchanges. In line with Table 3, Indonesia exhibits the widest multifractal spectrum (largest Δh), whereas Singapore shows a comparatively narrow spectrum and H(q=2) near 0.5, consistent with near -efficient dynamics. Vietnam stands out for the highest H(q=2) (strong persistence) combined with the lowest Δh (narrowest spectrum), implying persistence without high multifractal complexity relative to peers. These interpretations explicitly align with Table 3 and the rolling plots.

Temporal variation in H(q=2), Δh, and entropy measures clusters around well-known macro-financial episodes, including the 2008 global financial crisis, the 2013 taper tantrum, the 2015 RMB devaluation spillover, the 2020 COVID-19 shock, and the 2022–2023 global tightening cycle. During stress windows, H(q=2) tends to drift above 0.5 while Δh widens, indicating transient predictability and richer scale-dependent structure; normalization phases are associated with a reversion of H(q=2) toward 0.5 and a narrowing of Δh. This state- and horizon-dependent behavior is consistent with the AMH view of evolving market efficiency.

Vietnam, high persistence (H(q=2)) coupled with the lowest Δh, supports a characterization of persistent dynamics with comparatively low multifractal complexity, rather than the earlier description implying simultaneous strength in both dimensions. Comparative summary report in Table 4.

Table 4

Cross-country comparative summary of efficiency and complexity metrics

Exchange	Persistence H(q=2)	Multifractality **Δ**h
Indonesia (JCI)	Elevated	Highest (widest spectrum)
Malaysia (FBMKLCI)	Elevated	Moderate–High
Philippines (PCOMP)	Near 0.5	Comparatively narrow
Singapore (STI)	Near 0.5	Narrow
Thailand (SET)	Elevated	Moderate
Vietnam (VNINDEX)	Highest	Lowest (narrowest spectrum)

Recommendation

According to adaptive behavior, policy and practice should adapt rather than remain fixed. Policymakers can deploy an early-warning dashboard that tracks, for each exchange, rolling H(q=2), Δh, and the short-horizon SampEn gap to an efficient benchmark. A simple, actionable rule is flag Red when H(q=2)>0.55, Δh sits in the top quartile, and the SampEn gap ≤−1 standard deviation; in Red, supervisors intensify disclosure reviews and surveillance and ask market makers to raise displayed depth; in Green, settings revert. Exchanges can make incentives entropy sensitive by temporarily increasing market-making rebates when Δh widens and tightens volatility controls during red periods. Asset managers can gate short-horizon models to red regimes (negative SampEn gap with elevated Δh) and otherwise favor parsimonious, low-turnover allocations in near-efficient states (H≈0.5, narrow Δh). Future research should identify mechanisms linking efficiency states to microstructure, test cross-asset spillovers, examine sector/size segments, and compare entropy families. Limitations include sensitivity to preprocessing parameter choices, daily-frequency constraints that miss intraday drivers, and reliance on benchmark simulations that approximate rather than replicate conditional heteroskedasticity.

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