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Stock Market Behavior:
A Fractal Analysis of Saudi Stock Exchange

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ABSTRACT

The Saudi stock market is analyzed, using rescaled range analysis to estimate the fractal dimension of price returns and to test the Efficient Market Hypothesis. In order to determine the predictability of a time series, Hurst Exponent for each time series is measured and we find that Saudi market is not totally random during the time period under study. There exists long range dependence in Saudi stock market returns. For most instances, it is determined that the Saudi stock market returns comply with neither the weak form of the efficient market hypothesis nor the random walk assumption. Additionally, for completeness and as part of literature review we bring out Bachelier-Einstein's absolute Brownian dynamics, and Samuelson-Merton models of Martingale with geometric Brownian dynamic structure of equations.

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I. INTRODUCTION

This study attempts to investigate the efficiency of the Saudi stock market using fractal analysis. In this study, we estimate the fractal dimension of price returns and test the Efficient Market Hypothesis (EMH), employing rescaled range analysis in order to use fewer assumptions about the underlying system. This test is used instead of other tests of EMH, like the autocorrelation test, runs test, and simple volatility test, because it does not assume a normal distribution as well as allowing for different distributions such as fat tails, and power laws present in the time series, which may appear more pragmatic.

Applying standard asset pricing models is not appropriate due to the random walk assumption. This is evident because of the presence of stock market inefficiency and bias of security returns. The validity of the random walk assumption determines the accuracy of the asset pricing models. The Saudi stock market is typified by thinly traded stocks and high index weights for some companies. Of the few studies performed on stock market efficiency in Saudi Arabia, most are done to test the conventional weak-form of the EMH.

The paper is organized as follows: Section II presents review of related literature; Section III describes methodology and sources of data; Section IV provides results; and the final section gives conclusions of the study.

II. ANALYTICAL APPROACH AND HISTORICAL PERSPECTIVE

The French mathematician, Louis Bachelier (1900), first studied market efficiency in his “Theory of Speculation,” and his method was independently re-discovered by Albert Einstein five years later, and that made Paul Samuelson to call it Bachelier-Einstein approach to Brownian dynamics. Bachelier characterized stock market speculation as “fair game” (or Martingale property) of an unbiased random walk wherein no speculator could earn excess returns due to random price fluctuations. His study was popularized in late 1950 and was translated to English in 1964 by Paul Cootner. Cootner in his works (1960, 1960) amplified his take on the issue.

Let us sketch the Bachelier-Einstein derivation of the partial differential equation of probability diffusion of Fokker-Plank variety by going through partial difference equations. Considering n = log x, Bachelier‘s expression was as follows:

$$P_{n.t} = \frac{1}{2} P_{n+1,t-1} + \frac{1}{2} P_{n-1,t-1}$$

or

$$P_{n.t+\Delta t} = \frac{1}{2} P_{n+\Delta n,1,t} + \frac{1}{2} P_{n\Delta n,t}$$

$$\frac{\Delta t}{(\Delta n)^2} \frac{P_{n,t+\Delta t} - P_{n,t}}{\Delta t} = \frac{1}{2} \frac{P_{n,t+\Delta t}}{\Delta t} + \frac{1}{2} \frac{P_{n,-\Delta n,t} = P_{n,t}}{(\Delta n)^2}$$

If $\Delta t \to 0$, with $\frac{\Delta t}{(\Delta n)^2} \to 2c^2$, Paul Samuelson (1965a) gets the Fourier parabolic equation from the above as follows:

$$c^2 \frac{\partial P(n,t)}{\partial t} = \frac{\partial^2 P(n,t)}{\partial n^2}$$

Samuelson (1965a, 1965b, 1969 with Robert Merton) - in three successive papers - contributed further to the early ideas of market efficiency. Most importantly, he took the absolute Brownian motion that admits of negative price with high probabilities into geometric Brownian dynamics for meaningful economic model whereby Bachelier's structure:

$$P(X, x; T) \equiv P(X - x; T)$$

is changed into

$$P(X, x; T) \equiv P(\frac{X}{x}; T), x > 0$$
$$P(X, 0; T) \equiv 1$$

for all $X > 0$.

Many scholars, e.g., Sprenkle (1961), Osborne (1959), Boness (Cootner, 1964), and so on, have magnified and made meaningful advances even before Samuelson's works in print. In his doctoral dissertation, Fama (1965) proposed the tenets of the EMH as well as the definition for efficient markets: "A market where there are large numbers of rational, profit-maximizers, actively competing, with each trying to predict future market values of individual securities, and where important current information is almost freely available to all participants. In an efficient market, competition among the many intelligent participants leads to a situation where, at any point in time, actual prices of individual securities already reflect the effects of information based both on events that have already occurred and on events which, as of now, the market expects to take place in the future. In other words, in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value."

A more restrictive random walk model requires independence involving higher conditional moments like the variance, skewness, and kurtosis of the probability distribution of price changes. Unlike the random walk model in which they are largely alike, the efficient market hypothesis requires only the independence of the conditional expectation of price changes from the available information.

Three forms of market efficiency were outlined by Roberts (1967). Weak form efficient markets cannot consistently earn excess returns using past prices and returns. Semi-strong efficient markets cannot consistently earn excess returns using public information. Finally, a market which is 'strongly efficient' cannot consistently earn excess returns using private information or, for that matter, any information.

The joint hypothesis problem (Fama, 1965) has shown that, barring a rejection of the model of market equilibrium, or the price setting mechanism in which it states that when a model yields a return significantly differ from the actual return, market efficiency could not be rejected. One could never confirm the existence of an imperfection in the model or conclude the market is inefficient. The model can only be changed through the addition of factors to account for the return, or alpha. The alpha is not a result of a flaw in the model or of market inefficiency.

A measure of the independence of changes in prices or returns, which is the conventional approach using only historical asset prices, is necessary in order to statistically test the efficient market hypothesis. Finding the presence of significant independence is evidence of weak sense market efficiency which is widely tested. Kendall (1953) examined 22 stock and commodity prices in the UK and found them to be efficient. Using daily price data from 1957 to 1962, Fama (1965) tested 30 Dow Jones Industrial Average stocks utilizing serial correlation and concluded that the Dow was efficient. Emerging markets also exhibited weak-form efficiency. In Singapore (Hong, 1978), Malaysia (Barnes, 1986), and Greece (Panas, 1990). Granger and Morgenstern (1963) used the spectral analysis technique to examine the New York Stock Exchange finding no significant serial correlation.

Although early empirical studies tended to favor the EMH, more current studies indicate a tendency for a lack of resilience of the EMH in stock returns, even in its weak-form. This may be an indication of some degree of asset price predictability. Lo and MacKinlay (1988) proposed using a variance ratio test which is based on comparing variance estimators derived from data sampled at different frequencies. Interestingly, when they used this test for weekly returns in the US stock market from 1962 to 1985, they strongly rejected the random walk hypothesis. When Poterba and Summers (1988) examined mean reversion in US stock prices using the variance ratio test on monthly data they found positive serial correlation in stock returns for periods of less than one year, and negative serial correlation in longer horizon returns. Fama and French (1988) found similar autocorrelation patterns.

In emerging markets Wong and Kwong (1984) used the runs test to examine the weak form efficiency in the Hong Kong stock market and concluded that it is inefficient. Urrutia (1995), argued for the rejection of the random walk hypothesis when using the variance ratio test to study market efficiency in four major Latin American stock markets (Argentina, Brazil, Chile, and Mexico).

Of the few studies involving Saudi Arabian stock market efficiency, most investigated the conventional weak-form of the EMH. Emerging markets are more likely to be inefficient due to their small size, thin trading, and lack of regulation. The empirical findings of Saudi and Kuwaiti stock market efficiency also indicate a tendency toward market inefficiency, although there are a few weak-form efficient markets. Gandhi et al. (1980), studied efficiency in the Kuwaiti Stock Exchange (KSE) for the period of 1975 to 1978. They tested KSE for market efficiency, using autocorrelation coefficients test, runs test, and simple volatility tests, and they found that stock prices are highly serially correlated and volatile, thus concluding that KSE is inefficient. Butler and Malaikah (1992) examined efficiency of Saudi and Kuwaiti stock markets from 1985 to 1989 on individual stock returns, using serial correlation and runs tests with similar results. These results indicated significant serial correlation in both markets, which can be considered clear evidence of market inefficiency. Other studies have also found market inefficiency in the stock markets of Saudi Arabia (Nourredine, 1998) and Kuwait (Al-Loughani, 1995). Moreover, a more recent research of Elango and Hussein (2008) has shown by virtue of runs test that the stock markets of Kuwait, Saudi Arabia, UAE, Oman, Qatar, and Bahrain (GCC Countries) the weak-form efficiency could be rejected for all GCC markets from 2001 to 2006.

A few other studies, however, did indicate weak-form efficiency in some gulf stock markets. One such study was by Dahel and Labbas (1999), who examined the random behavior of stock markets of Saudi Arabia, Kuwait, Bahrain, and Oman. They were unable to reject the random walk hypothesis when they used unit root, autocorrelation, and variance ratio tests. That suggests that these markets were distinguished by weak-form efficiency. Abraham et al. (2002) used the runs test and variance ratio test to examine efficiency in the GCC stock markets of Saudi Arabia, Kuwait, and Bahrain. They found indications of weak-form market efficiency in Saudi Arabia and Bahrain, but not in Kuwait. Inconsistent outcomes have occurred in many cases of developed and emerging markets.

III. METHODOLOGY AND DATA

Since random walk (martingale) is not applicable in this case, we employ the Hurst Exponent (Hurst, 1951) to test the EMH because it affords a measure for both long-term memory and fractality of a time series, has fewer assumptions about the underlying system, and does not assume a normal distribution. Hurst's allowance of different distributions, fat tails, and power laws present in the time series is advantageous in that it more closely resembles reality and permits a measure of the long-memory in the time series. Hurst exponent (H) measures the impact of information on the series. A value of H = .50 implies a random walk, confirming the EMH, i.e., yesterday's events do not impact today's and today's events do not impact tomorrow's. This means the events are not correlated which indicates that old news has already been absorbed and discounted by the market. An H exceeding 0.50, however, suggests today's events do impact tomorrow's. Thus, information received today continues to be discounted by the market after it has been received. This is not a simple serial correlation, where the impact of information simply decays, but a longer memory function where information can impact the future for longer timespan. It is important to bear in mind, while utilizing this view of time-series analysis, that fractal distributions are additive; that is, increments of time have individual transactions embedded in them. Additional observations are not needed, but longer time series are.

A Fractal dimension is a number that quantifies how an object fills its space. In Euclidean geometry, objects are solid and have integer dimensions. Fractals are rough and discontinuous like coastlines and do not have an integer as a dimension. The Hurst is directly related to the fractal dimension of a time series, which is the measure of the roughness of the process. The fractal dimension is equal to D = 2 – H, where H represents the Hurst exponent. The Hurst is an estimate, not a definitive measure. We used a rescaled range (R/S) analysis in this study to estimate it. To determine if the value of the Hurst was robust, a Monte Carlo simulations of random numbers was done. Then the Hurst was computed for the random series. To further check robustness, the data series was tested using a scrambled Hurst. The time series was scrambled after which the Hurst was calculated. If there was an underlying structure in the data series it should have been destroyed with the scrambled Hurst and a value close to the Hurst of a random series should have emerged.

The values of the Hurst Exponent range between 0 and 1 and the values of the fractal dimension range from 1 to 2. A Fractal Dimension of 1.5, or a Hurst of 0.5

indicates a random walk, where there is no long memory process among the data. This type of series is hard to predict.

A Fractal Dimension of greater than 1.5, or a Hurst exponent between 0 and 0.5 indicates an anti-persistent behavior in which an increasing trend will be followed by a decreasing one, which is referred to as mean reverting. A Fractal dimension of less than 1.5 or a Hurst exponent between 0.5 and 1 indicates persistent and trending behavior. The Hurst is different from volatility, in which a stock can have a relatively low volatility while having an H close to 0.5. Matured markets usually have a Fractal Dimension closer to 1.5 and a Hurst closer to 0.5 than emerging markets.

Thiele (2007) tested China's stock market prior to and subsequent to reforms applying fractal dimension. The rescaled (R/S) analysis showed that the markets had a biased random walk reporting a fractal dimension of less than 1.5. This will be one of our base methodologies to test efficiency.

Qian and Rasheed (2004) used the Hurst exponent to establish the predictability of the time-series as well as to estimate the embedding dimension and separation. These are concepts from chaos theory which use auto mutual information and false nearest neighbor methods. They then utilized neural networks to predict the returns on the Dow-Jones index in which they found periods with large Hurst exponents could be predicted more accurately than those with values close to a random series. The results indicated that stock markets can have periods of strong trend structure and others that are random. The periods of strong trend structure can be learned by the neural network. The authors found more accurate results from the use of the Hurst exponent before trying to build a model, and that it saved effort and time. This model will be utilized in this study.

In another investigation, Qian and Rasheed (2007), used multiple classifiers including artificial neural networks, k-nearest neighbor and the decision tree method to predict stock market prices. Utilizing an ensemble approach to improve prediction performance, they grouped the different forecasting methods in various ways to produce a 60% accurate prediction rate. The researchers expected ensembles of multiple classifiers to become popular in the field of financial prediction in the near future.

Studies of GCC stock markets are scarce. One barrier is the fact that these markets are populated by thinly traded stocks and high index weights for some companies. To deal with this issue, data for ordinary shares in the Saudi Stock Exchange will be examined during a period of five years for the largest three constituents of MSCI (Morgan Stanley Capital International) Domestic index. The index is adjusted for free float as well as for minimum float, liquidity and size guidelines. Free float adjusted means the government holds shares which are not traded and are accounted for in the index by taking them out of the weight. We will use the largest weighted three stocks in the index since they will represent the majority of the index.

Reuter's historical database was utilized as the source of data because it was the first company in the region to be supplied with historical financial information. To lessen the likelihood of data-snooping bias, data were adapted for dividends and splits. We used the raw data of financial time series of the Close and limited the examination period to five years, the accepted interval of the three stocks for comparison. The frequency of the data was set to daily data.

Saudi Arabia is the biggest economy in the region with a stock market capitalization of over half a trillion dollars. Tadawul is the only stock exchange in the country and it lists 167 publicly traded companies. The Tadawul All Share Index consists of all the listed companies in Saudi Arabia.

The MSCI indices are the benchmark of established investors in the region because they use them to measure their tracking error and deem them an ideal substitution for the Saudi Arabian market. To attend to the issue of survivorship bias (the propensity for failed companies to be omitted from performance studies) the three most highly weighted companies rather than the index were chosen.

The MSCI Saudi Arabia Domestic Index was created in 2006 and it measures the performance of the large and mid-cap stocks of the Saudi Arabia market. This index covers approximately 85% of the free float-adjusted market capitalization in Saudi Arabia. The three constituents of the MSCI Saudi Arabia Domestic Index are Saudi Basic Industries Corp. (2010.SA), AlRajhi Bank (2230.SA), and Etihad Etisalat Co. (7020.SA). These companies account for 21.87%, 15.96%, and 6.17% of the weighting of the MSCI Saudi Arabian Domestic Index at the time of the research (Sept 2010). All the stocks are of high liquidity in their markets in which they were traded on more than 90% of the trading days in the market. Below is a brief overview of these three companies.

IV. RESULTS

A. Saudi Basic Industries Corp. (2010.SA)

Saudi Arabian Basic Industries Corporation (SABIC) is one of the world's leading petrochemical companies. It is the largest public company in the region. The Saudi Government owns 70% of its shares. SABIC is the third largest polyethylene manufacturer, the fourth largest polyolefins manufacturer and the fourth largest polypropylene manufacturer. SABIC is also the world's largest producer of mono-ethylene glycol, MTBE, granular urea, polyphenylene, and polyether imide.

SABIC operates in five business sectors; Basic Chemicals (ethylene, methanol, propylene, styrene, etc.), Intermediates (industrial gases, ethylene glycol, ethylene dichloride, caustic soda, etc.), Polymers (polypropylene, polyvinyl chloride, polyesters, polystyrene, etc.), Fertilizers (ammonia, urea, phosphates, sulfuric acid), and Metals (long and flat steel products). Jubail Industrial City is where most of the operations are located. Not to mention its overseas operations in which it has 16 affiliated companies which started as joint ventures with Dow Chemical, Exxon, Mitsubishi, and other major companies worldwide. SABIC is one of the lowest-cost producers, with the help of subsidized petroleum from Saudi Arabia. The company has grown into diversified international operations with more than 9 billion in revenues. SABIC today is the largest listed company in the Middle East.

1. Hurst Exponent

The first calculation performed was the Hurst Exponent for the Saudi Basic Industries return from 09/21/2005 to 09/21/2010. The Hurst Exponent for SABIC was determined for five years[1]. For the regression we utilized $t=2^2, 2^5, \ldots, 2^{10}$. Figure1 illustrates the

R/S Analysis for the SABIC daily returns from 09/21/2005 to 09/21/2010. As shown in Table 1, the fractal dimension for SABIC was 1.41693, and the average Hurst was 0.58307. These results suggest "persistent behavior", or that the time series is trending. Typically, the larger the H value is, the stronger the trend. Which signifies that today's events are impacting tomorrow's. Thus, we have a lengthier memory function in which information can affect the future for very long periods of time.

Figure 1
R/S analysis for SABIC daily return from 09/21/2005 to 09/21/2010

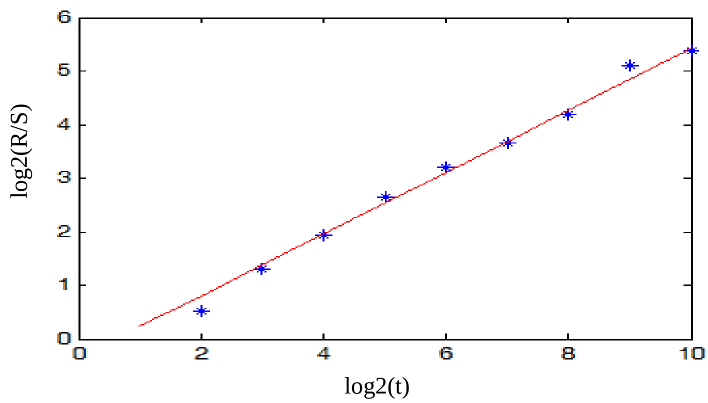


Table 1
Fractal dimension for SABIC

Fractal Dimension	1.41693
Average Hurst	0.58307

2. Monte Carlo Simulation

Using the Monte Carlo Simulation to test the Hurst exponent of a random series to which it could be compared, we then produced 10,000 Gaussian random series, each with a period of 1246 values, the equivalent of five years of trading. The Hurst Exponent was computed for each series, averaged, and repeated ten times. The mean Hurst was 0.5474 (expected Hurst exponent is close to 0.5) which indicates both a random series and unpredictability in that time series. This implied that the SABIC time series was not random.

3. Scrambled Hurst Test

In order to determine if the SABIC time series had a definite structure for that period, we recalculated the Hurst Exponent after scrambling the series. This scrambled series, a random sequence, would maintain the distribution as the original series. The scrambling served to terminate any underlying structure in the data series.

Table 2
Scrambled Hurst for SABIC

Scrambled Hurst	0.56290
Standard Deviation	0.040807

Table 2 shows that the Hurst Exponent, after the scrambling, is similar to the generated random series, or 0.5474. We deduced there must be an underlying structure in the SABIC stock market data for that particular period.

B. Al Rajhi Bank (1120.SA)

Al Rajhi Bank is the world's largest Islamic Bank and was founded in 1957. This bank is one of the largest banking corporations in Saudi Arabia with total assets of SR 172 ($45,867) billions. It has international presence in countries such as Kuwait, Malaysia, and Jordan. This bank focuses on Sharia compliant banking and money products as did Kuwait Finance House.

1. Hurst Exponent

The summary data for the Hurst Exponent for the Al Rajhi return from 09/21/2005 to 09/21/2010 are enumerated in Table 3.

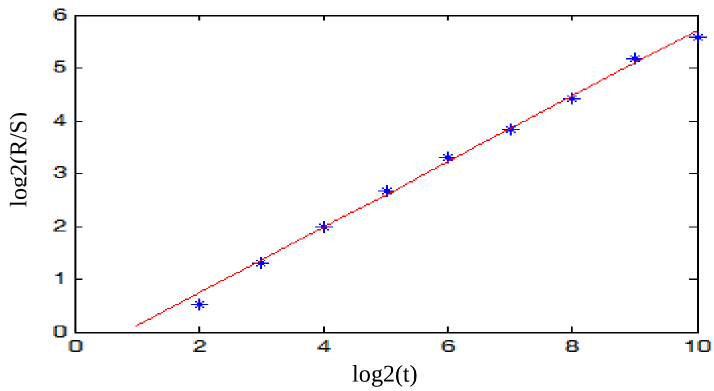
Table 3
Fractal dimension for Al Rajhi Bank

Fractal Dimension	1.38596
Average Hurst	0.61404

To calculate the Hurst Exponent for Al Rajhi for five years we calculated the regression using $t=2^2, 2^5, \ldots, 2^{10}$. Figure 2 presents the R/S Analysis for Al Rajhi daily returns from 09/21/2005 to 09/21/2010. Since the fractal dimension was 1.38596, and the average Hurst was 0.61404, persistent behavior is exhibited. In other words, information received today continues to be discounted by the market after it has been obtained.

The Monte Carlo Simulation used before was for comparison purposes, to scrutinize the Hurst exponent of a random series. Again, we generated 10,000 Gaussian random series, each with a period of 1246 values, the equivalent of five years of trading. The Hurst Exponent for each series was determined and averaged then repeated 10 times. The mean Hurst was 0.5474. This indicates the series is random thus implies unpredictability in that time series. This led us to the conclusion that the Al Rajhi time series was not random.

Figure 2
R/S analysis for Al Rajhi daily return from 09/21/2005 to 09/21/2010



2. Scrambled Hurst Test

To continue our investigation of whether the Al Rajhi time series has a genuine structure in that period, we scrambled the series, and then recalculated the Hurst Exponent. Although the scrambled series preserved the distribution as the original series, the sequence was still random. Any original structure in the data series would have been destroyed through scrambling.

Table 4
Scrambled Hurst for Al Rajhi

Scrambled Hurst	0.56354
Standard Deviation	0.0414

Table 4 above shows the Hurst Exponent, after the scrambling, closely resembled the generated random series, which was 0.56354. Thus it can be concluded that there necessarily exists an underlying structure in the Al Rajhi stock market data for the specific period studied.

C. Etihad Etisalat (7020.SA)

Etihad Etisalat or Mobily (Brand name) is the second Telecommunications company in Saudi Arabia. The company broke the nation's monopoly in telecommunications. It was established in 2004 by a consortium led by Etisalat, the UAE based telecom conglomerate. Mobily was the first Saudi Company to offer 3G services in the Kingdom. In December 2004, Mobily was listed in the Tadawul Stock Exchange. Today Mobily has more than 40% of the market share in Saudi Arabia.

1. Hurst Exponent

The summary statistics for the Hurst Exponent of the Etihad Etislat return from 09/21/2005 until 09/21/2010 are listed in Table 5.

Table 5
Fractal dimension for Etihad Etisalat

Fractal Dimension	1.45411
Average Hurst	0.54589

Figure 3 shows the R/S analysis for the Etihad Etislat daily returns from 09/21/2005 to 09/21/2010, a five-year period. The fact that the fractal dimension was 1.45411, and the average Hurst was 0.54589 imply a random walk time series. A random walk is characterized by a lack of correlation between the present returns and the future returns thus making time series of this type difficult to predict. The mean Monte Carlo Simulation Hurst was 0.5474 indicating the time series is random and unpredictable. Thus, the Etihad Etislat time series was indeed random.

Figure 3
R/S analysis for Etihad Etisalat daily return from 09/21/2005 to 09/21/2010

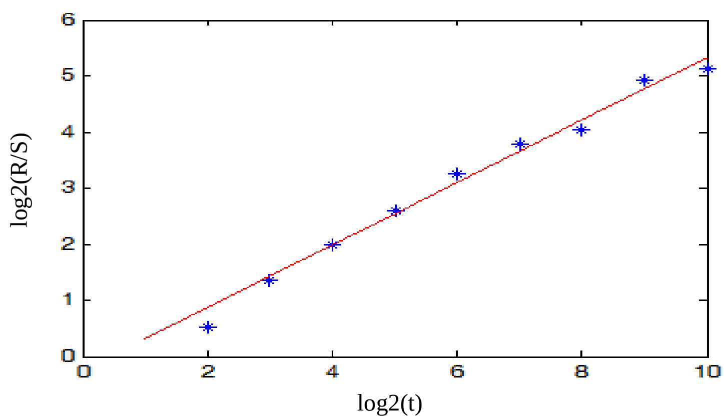


Table 6
Summary of all stocks

Stock	Average Hurst	Fractal Dimension
SABIC	0.58307	1.41693
ALRAGHI	0.61404	1.38596
ETIHAD	0.54589	1.45411

For SABIC and Al Rajhi stocks, the Hurst exponent results do not support the EMH, while those of the Etihad Etislat stock do. Table 6 above shows Etihad Etislat with the lowest Hurst exponent of 0.5458 which implies non-predictability for that specific five-year time series. On the other hand, SABIC and Al Rajhi had higher Hurst values: 0. 0.58307 and 0.61404 respectively, demonstrating persistent behavior. After testing the reliability of the Hurst utilizing the Monte Carlo simulation and the scrambled Hurst test, it was found the two stocks had a fractal nature. This finding was counter to the EMH and the Capital Asset Pricing Model (CAPM), the Arbitrage Pricing Theory (APT), and the Black-Scholes option pricing model, which are quantitative models derived from the EMH. In the literature review it was shown that tests on market efficiency in the Saudi Arabian market were inefficient. Only one stock in this study was found to be efficient in that five-year frame of the time series.

V. CONCLUSION

Our data indicates that there are two Saudi stocks with large Hurst exponents and one with a low Hurst value among the three major stocks investigated. These results indicate the markets were not totally random during the time studied. Clearly, the results do not support the Efficient Market Hypothesis for the two stocks with high Hurst values. These stocks were Hurst processes, or biased random walks. Thus, it can be concluded that some stocks in the market are in fact efficient while others are not. This is counter to prior studies which indicated that the entire Saudi Arabian Stock Market was inefficient.

Although the Hurst independent random processes of the Monte Carlo simulation were about .55, the Hurst exponents of the data sets fell between 0.54 and 0.61. Al Rajhi, for example, had a Hurst of near 0.61, which makes it clear that if prices were higher during that time, there would be about a 61% probability that the stock would rise during the subsequent period. This is counter to the weak-form efficient market hypothesis (EMH) assumptions.

This study seeks to remedy the lack of quantitative evidence about the inefficiency and long-memory bias of Saudi Arabian equity returns. Preceding analyses found asset pricing theories which postulate that stock markets are efficient and that stock prices follow a random walk. It followed, then, that investment models, like modern portfolio theory or CAPM, assumed asset returns were normally distributed and that the distribution shape was symmetric. The absence of a normal distribution or ordinary Brownian motion in the Saudi Arabian stock market may lead to incorrect asset pricing assumptions and indicate the limitation of modern asset pricing theories in Saudi Arabia.

This investigation attempted to measure the long-range memory of the largest MSCI Index stocks in Saudi Arabia. The presence of long-memory is directly related to the fractal dimension of a time series. An independent and random process has a fractal dimension of 1.5 and a Hurst exponent of $H = 0.5$ (Peitgen et al., 1992). Based on the findings of this study, the following conclusions were drawn.

The Saudi Arabian stock market returns did not comply with the assumption and properties of a normal distribution in most cases, yet in a few cases they exhibited characteristics of a normal distribution. Nor did they conform the weak form of the efficient market hypothesis and the random walk assumption in most cases. In the absence of a normal distribution and the random walk assumption, asset-pricing models may not adequately capture the investment risk and probabilities of equity returns; one should test the individual stock to determine if it qualifies as a normal distribution. This is the first time the Saudi Arabian market has been analyzed for efficiency using the methodology we incorporated. Traditional tests had assumed a normal distribution but this was not the case for many financial time series. Our methodology allowed for power laws, fat tails, and many other forms of distribution.

Finding evidence in this study of long-memory in stock returns could help investors understand the limitations of traditional asset pricing models in the region. In this way, investors are in a better situated to assess the actual investment risk and returns in the Saudi Arabian stock market.

Despite stock market reforms initiated in 2001, the Saudi Arabian market is still inefficient and there are many cases of speculative trading. Regulators should implement major reforms in the regulatory and transparency aspects of the markets including privatization of the government ownership in corporations.

Based on these findings, investors should apply asset pricing models with caution in the markets studied. When there is evidence of long-memory, the random walk assumption of modern asset price theories is violated and this additional risk should be figured into investors' strategies. It is also recommended that investors, financial practitioners and academicians apply the rescaled range analysis, and soft computing to financial time series. This study also shows the greater role of nonlinear asset pricing models in these markets.

Investors should make themselves and their clients aware of the distinctive investment risk in the region. The existence of long-memory in Saudi Arabian equity returns may lead to less than expected performance of some investment strategies because of inaccurate risk management.

ENDNOTE

1. Hurst measure has been extensively employed by Mandelbrot (1967, 1968, and 1969).

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