DYNAMIC CHARACTERISTICS ANALYSIS OF MALAYSIAN CRUDE PALM OIL PRICE USING FRACTAL THEORY

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MASTER OF ECONOMICS

GRADUATE SCHOOL
CHIANG MAI UNIVERSITY
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A THESIS SUBMITTED TO CHIANG MAI UNIVERSITY IN PARTAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ECONOMICS

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THE REQUIREMENTS FOR THE DEGREE OF
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Molida Yi

หัวข้อวิทยานิพนธ์	การวิเคราะห์ลักษณะเฉพาะพลวัตของราคาน้ำมันปาล์มดิบของประเทศมาเลเซียด้วยทฤษฎีสาทิสรูป	
ผู้เขียน	นางสาวโมลิดายี	
ปริญญา	เศรษฐศาสตรมหาบัณฑิต	
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	รศ.ดร.กาญจนา โชคถาวร	อาจารย์ที่ปรึกษาร่วม

บทคัดย่อ

วิทยานิพนธ์นี้นำเสนอการวิเคราะห์ลักษณะเฉพาะพลวัตของราคาน้ำมันปาล์มดิบมาเลเซียด้วยการใช้การวิเคราะห์อาร์เอสเพื่อจะระบุเลขชี้กำลังเฮิร์สต์เลขชี้กำลังตามกฎเลขชี้กำลัง ค่าความจำ และประสิทธิภาพการตลาดราคาน้ำมันปาล์มดิบมาเลเซียที่ครอบคลุม379 เดือนตั้งแต่มกราคม 2526 ถึงกรกฎาคม 2557 ได้รับการคำนวณด้วยการวิเคราะห์อาร์เอส เพื่อให้ได้เลขชี้กำลังเฮิร์สต์ของราคาน้ำมันปาล์มดิบมาเลเซียผลของเลขชี้กำลังเฮิร์สต์มีค่าน้อยกว่า 0.5 กล่าวคือเท่ากับ 0.3647 ดังนั้น ราคาน้ำมันปาล์มดิบมาเลเซียมีลักษณะแอนไทเพอร์ซิสเท็นท์และมีสหสัมพันธ์เป็นลบจากช่วงเวลาในอดีต ปัจจุบันจนถึงอนาคต ยิ่งไปกว่านั้นเลขชี้กำลังตามกฎเลขชี้กำลัง มีค่า1.7294 ซึ่งบอกให้ทราบว่าราคาน้ำมันปาล์มดิบมาเลเซียเป็นกระบวนการแบบสัญญาณสีชมพู และความชันของราคามีลักษณะชี้ลงด้านล่าง นอกจากนั้น ราคาน้ำมันปาล์มดิบมาเลเซียมีค่าความจำเป็นในระยะยาวเพียง 9 เดือน เมื่อพิจารณาจากเลขชี้กำลังเฮิร์สต์แล้วราคาน้ำมันปาล์มดิบมาเลเซียเป็นไปตามสมมุติฐานตลาดสาทิสรูป ผลการวิจัยยังเป็นประโยชน์ต่อการทำนายราคาน้ำมันปาล์มดิบมาเลเซีย และสามารถใช้เป็นข้อแนะนำสำหรับการกำนโยบายแลการตัดสินใจการลงทุนของนักลงทุน

Thesis Title	Dynamic Characteristics Analysis of Malaysian Crude Palm Oil Price Using Fractal Theory
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ABSTRACT

This thesis aims at the dynamic characteristics analysis of Malaysian Crude Palm Oil (CPO) price using R/S analysis to identify the Hurst exponent correlation coefficient, power law exponent, memory term, and market efficiency. To get the generalized Hurst exponent of Malaysian CPO price in this study, the price of CPO that covers 379 months since January 1983 to July 2014 is calculated with Matlab by using R/S analysis. The result of the Hurst exponent shows that H value is less than 0.5 (H = 0.3647). It means that Malaysian crude palm oil price has anti-persistent characteristic with negative correlation from the past, present, to future period. Moreover, the power law exponent α is 1.7294, which tells that the CPO price is Pink noise process and the slope of the prices is downward. In addition, the Malaysian CPO price has long memory term only 9 months, which it is too small, so it has short-term memory more than long-term memory due to some external factors. With respect to the Hurst exponent, the Malaysian CPO price follows the Fractal Market Hypothesis (FMH).The results are also beneficial to Malaysian CPO price forecasting and can give some suggestions for policy-making and investors making-decision.

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CHAPTER 1

Introduction

1.1 The Rationale Background

Crude Palm Oil (CPO) is an edible vegetable that comes from the oil palm trees and it is extracted to produce palm oil, which now becomes a crucial industrial commodity and is used for variety of consumer goods from foods to medical using to biofuels. CPO is the most important products used widely in the world. In terms of consumption and production, it became a world's leading vegetable oil with 45.3 million tonnes produced worldwide in 2009 (Dallinger 2011).

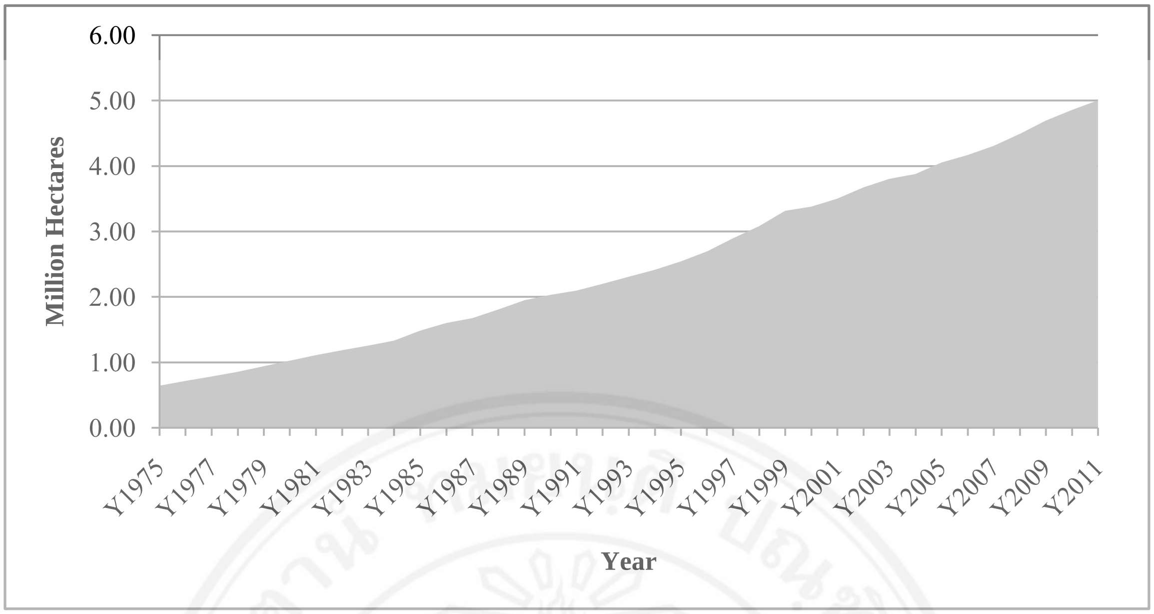
In the past, CPO was not popular commodity used by people in the world comparing to the soybean oil. For example, in 1961, CPO was produced only 1.5 million tonnes while soybean oil was produced 3 million tonnes. However, CPO production increased surprisingly surpassed soybean oil production for the first time in 2006 and it started to rise to 48.6 million tonnes comparing to 41.6 million tonnes of soybean oil (Greene 2013). Based on the R.E.A Holding Plc report, there were over 75 million tonnes of oil and fats exported worldwide during 2012-2013 while palm oil was the largest exports around 44 million tones (76% of total export).

From the global outlook, the oil palm industry can get the value between $40 billion to $50 billion and the global demand needs around 49.5 million tonnes. The production of CPO was increased over the global demand by reaching to 58 million tonnes in 2013 and it is expected to increase to 62.5 million tonnes by 2015 in order to fulfill the demand for food, chemical, and bio-diesel industries.

There are a lot of reasons why CPO is a popular product in the world, investors especially try to invest to grow it and spread the size of land for oil palm tree plantation. CPO plays a major role in the world market because it can produce highly efficient sources of vegetable oil rather than other vegetable oil. It can produce ten times as much vegetable as soybean. Therefore, palm oil products can be found more than 50% of all market products in most development market. Moreover, CPO is considered as the product that offers many benefits not only health but also wealth and development because it helps to reduce the poverty especially in the developing countries like Southeast Asia region. Greene (2013) studied the Palm Oil in Indonesia and Malaysia by focusing on a controversial industry and he found that palm oil provides many benefits to economy in both countries. The palm oil production contributes to the economic development of countries by providing the benefit for both producers in the local economies and consumers in global markets since it can help to improve the infrastructure, income and employment to the people, expansion of food and product supplies. Palm oil industry provides direct employment opportunities for millions of people. Furthermore, it also helps to develop the infrastructure in the rural and poor areas such as roads, schools, hospitals, telecommunications, and other projects. From this industry, it is estimated to provide benefit for around 6 million people, which it helps to secure the many people from the poverty (Geonadi 2008).

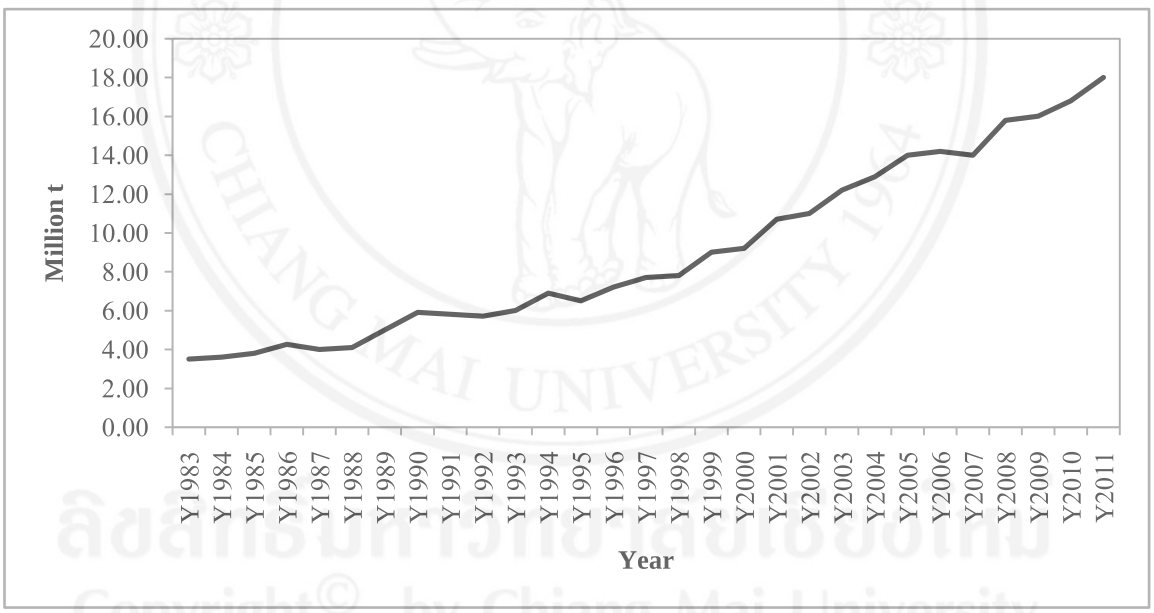
One of the biggest CPO producers in the world from the Southeast Asia region is Malaysia. Malaysia is the second CPO exporter and producer that have the biggest size of plantation land after neighboring Indonesia. Malaysia has exported CPO to more than 100 countries. According to Amin Idrees (2014) in MPOC report, Malaysia covers a market share of 39% of world palm oil production and 44% of world exporters. Malaysia plays an important role to fulfill the growing global need for oil and fats since it is one of the biggest producers and exporters of CPO. CPO is a major commodity crop in Malaysia and provides both country and people a lot of benefits. Malaysia had total planted area around 4.917 million hectares and exported CPO to the world 17.99 million tonnes.

Figure 1.1 shows the increase of palm oil plantation area in Malaysia from 1975 to 2011. This area increases to 0.6 million hectares in 1975 and to 5.0 million hectares in 2011. It is expected to increase in the next following year.



Source: Malaysian Palm Oil Board (MPOB)

Figure 1.1: The oil palm plantation area in Malaysia: 1975-2011

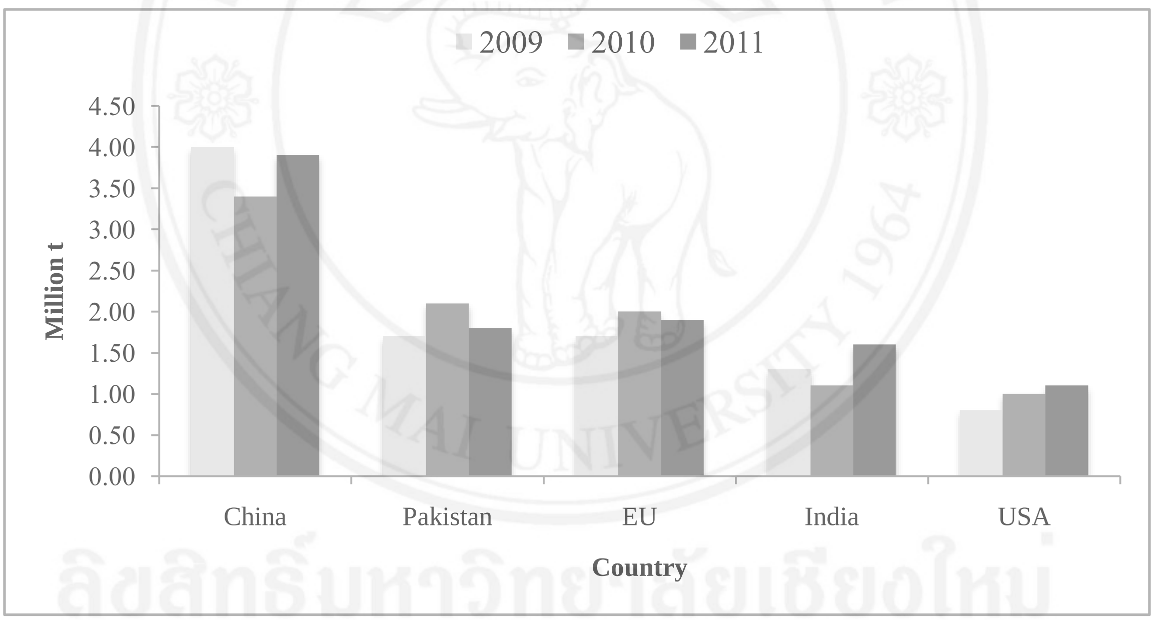


Source: Malaysian Palm Oil Board (MPOB)

Figure 1.2: Annual export of palm oil products: 1983-2011

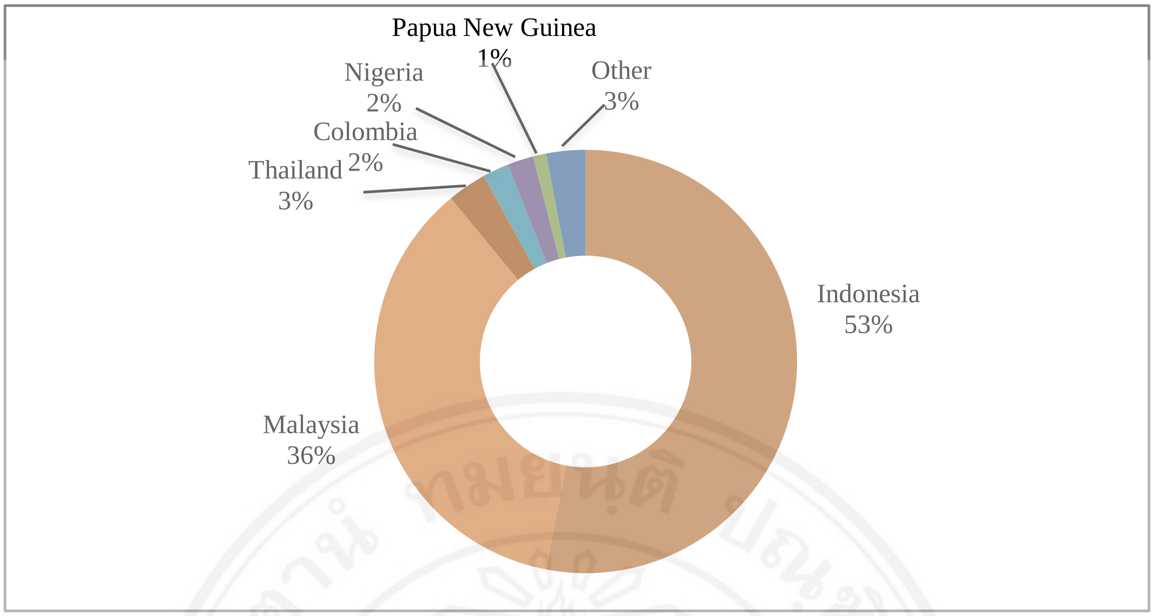
Figure 1.2 shows the annual export report of palm oil in Malaysia from year 1983 to 2011. Comparing to other commodity products, palm oil has been increasing every year and has an increasing growth rate. The annual export of the palm oil increases steadily from 2.7 million metric tonnes (MMT) in 1983 to 18 MMT in 2011.

The monthly report of Economic Review on 21 June 2013 mentioned that agriculture sector distributed 11.9% to the total GDP of Malaysia while CPO contributed 9% among all agriculture products. May (2012) study the economic transformation advance oil palm industry in Malaysia. The oil palm was a value agricultural crop as Malaysia could earn around $27 billion from annual export in 2011. The highest export earning was from the increasing of CPO price in the world market ($1,056 per metric tonnes, 19.2%). Malaysia exported 24.27 MMT of CPO in 2011. The main customers are China, the European Union, Pakistan, India, and the United States (Malaysia Palm Oil Board). Figure 1.3 shows the major CPO importers of Malaysia in three years. China is the outstanding customer of Malaysia, which imports around 3.5 million tonnes in average. While Pakistan and EU imports almost the same amount around 2 million tonnes, India and USA imports only about 1 million tonnes in average.



Source: Malaysia Palm Oil Board (MPOB)

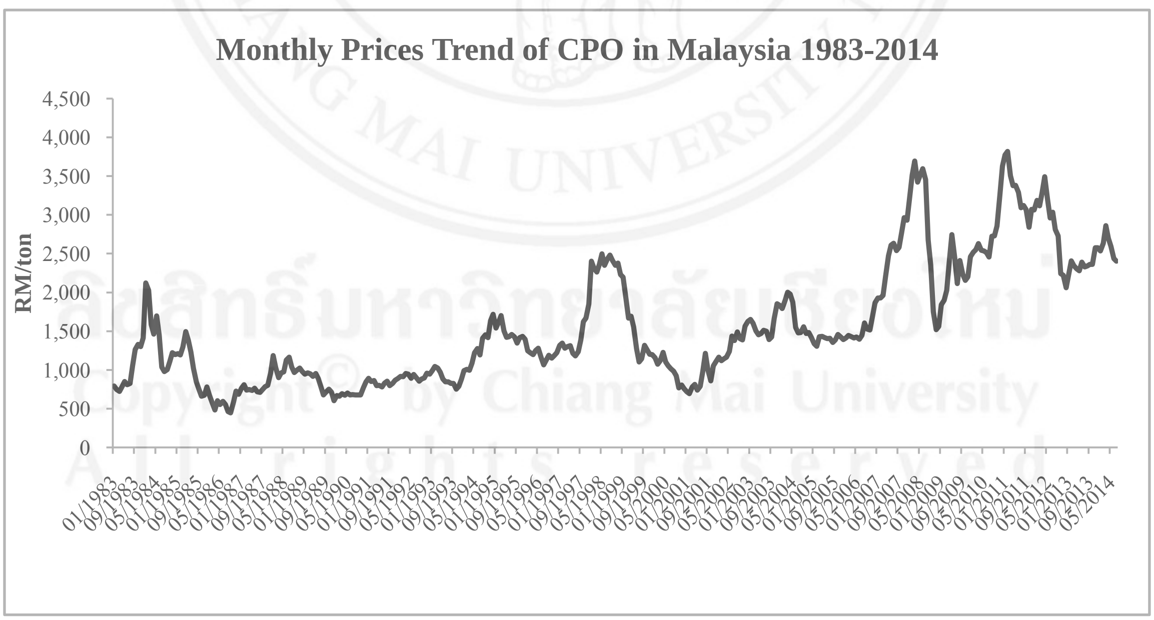
Figure 1.3: Major importers of Malaysian CPO: 2009-2011



Souce: IndexMundi, 2012

Figure 1.4: Main exporters of palm oil in 2012

Figure 1.4 shows the main exporter of palm oil in the global market in 2012. Indonesia is the biggest leading exporter and it is also a main competitor of Malaysia as it covers 53% of the world export.



Source: CEIC Database

Figure 1.5: Monthly prices movement of CPO 1983 to 2014

The prices of CPO in Malaysia fluctuate during 2010-2014. Ofon and Lee (2012) did the observation and estimation of CPO. The CPO price arrived at MYR 3,450/t for 2012, MYR 3,620/t for 2013. However, it started to fall down to MYR 3,228/t for 2014 but they estimate it will grow to MYR 3,456/t for 2015. Figure 1.5 shows the movement of the Malaysian CPO price by month in 1983 to 2014. In the last three years, CPO price had a big drop between October and December of 2012.

There are a lot of research studies, which publish on applications of Econophysics analysis focused on the dynamic characteristics of financial instruments, e.g. stock prices and returns, and exchange rates. The dynamic characteristics of commodities receive less interest. Any scholar has not yet studied the particular, the CPO price for its price dynamic characteristics even though it is one of the most crucial products in the world market. A critical question arises regarding modeling and analysis of CPO price movement. It is necessary to know whether the CPO price dynamics exhibits randomness in its evolution of trends or it shows a behavior with long memory. To correctly answer the question, the fractal theory is employed for the dynamic characteristics analysis of the CPO price movement.

Fractal theory was used and introduced in 1960 by Benoit Mandelbrot. The theory is introduced under a branch of nonlinear science to analyze irregular or non-smooth phenomena in nonlinear system. However, the first concept of fractal is designed to use in fields of sciences and technology and there are a lot of researches that used fractal theory to apply in these fields such as physics and chemistry, geography, finance, agriculture, biology, medicine, sociology and economics (Klonowsk 2000). Even though fractal theory is popular among all other fields both sciences and technology, it seems not well-known in economics until Mandelbrot used it for the first time to investigate the price changes in an open market of cotton price during 1963. From that time, he developed the fractal geometry and discussed on the characteristics of fractal in financial time series during 1970 and 1980. The special characteristics of fractal in economics are better to explain the behavior of complex system and the financial market such as self-similarity and long-term memory. The explanation of the market is based on the science and it is observed that the variance of prices is expected to have a big change. Based on Mandelbrot's foundation of fractal theory and fractal geometry, two main sentences are raised to show what the characteristics of fractal theory and how fractal theory are important in economics field for researchers for its application to the financial market, commodity price, and price production forecasting. Two key sentences are—“Clouds are not spheres, mountains are not cones, coastlines are not circles and bark is not smooth, nor does lighting travel in straight lines.” (Mandelbrot 2004) and “The very heart of financial is a fractal.” (Mandelbrot, 2004). After the introduction of the fractal theory, there have been many research activities that used this theory as the hot spot in those research fields. It especially has become one of the hottest topics in the economics field since many researchers have studied of fractals and have employed its theory in their research studies. Other researchers have later on developed Mandelbrot’s fractal theory by adding more functions to apply in economics. A new fractal market hypothesis was also proposed from the viewpoint of the fractal theory to analyze the operation mechanism of the market products and has then become a new direction for the financial research (Peters 1994). It was pointed out that the fractal theory is an effective tool for the classification of dynamic characteristics of time series (Cromwell et al. 2000).

1.2 Objective of the Study

1) To analyze the dynamic characteristics of the Malaysian CPO price via the Hurst exponent.

2) To identify the dynamic characteristics of the Malaysian CPO price.

3) To analyze the market efficiency of the CPO price via the fractal theory.

1.3 Advantage of the Study

1) The Hurst exponent of the Malaysian CPO price is known.

2) The dynamic characteristics of the Malaysian CPO price are identified whether the price is purely random or long-memory with persistence or anti-persistence characteristics. An appropriate mathematical model can then be selected depending or the Hurst exponent magnitude, e.g. Brownian or fractal Brownian motion. Based on further parametric study of the selected mathematical model, the price movement can be known and the results are useful to Malaysian CPO price forecast in the global market and CPO strategy planning for Malaysian government.

1.4 Organization of the Study

The thesis contains five chapters. The first chapter will provide the general introduction. The related theories and literature reviews are conducted in chapter 2. Chapter 3 introduces the methodology of analysis. The data and empirical results of the thesis will explain in chapter 4. Last but not least, conclusion will present in chapter 5.

CHAPTER 2

Theory and Literature Review

2.1 Theory

The term fractal is originated from the Latin word "fractus" meaning irregular/broken or fractured. Fractal is a relationship of similarity between the parts and the whole, which it has the same scale in every shape. It has self-similar characteristics when the fractal scale move up or down at the same amount (Mandelbrot 1997).

The original of fractal is from mathematic and then science employs it in the study and research paper, so mathematics and science have close relationship with each other. Fractal geometry studies both non-living and living systems in the coalescence of spontaneous self-similar fluctuations over many orders of time and how the complex system works over multiple levels of space (Klonowsk 2000). Klonowsk (2000) presents more that fractal dimension plays a role as a quantifier of complexity since it is used to measure the rate of additional of structural detail with increasing magnification, scale or resolution. A small dimension is not a good measure in both natural and engineering systems. Hausdorff (1918) introduces a concept to analyze the irregular sets, which it was called Hausdorff dimension that can also be called a successor in fractal dimension. Furthermore, it is generally that a small group of fractals have certain of its own dimension, which is scale invariant. These fractals are known as a self-similar or mono-fractal based on the "Hausdorff" dimension. The differences of fractal dimension depend on the scale. Many fractals have different fractal dimension called "multifractals" which is noted by the infinite spectrum of generalized dimension (Zmeskal et al. 2001).

In fractal analysis, fractal dimensions play a main role to study as a dependent variable in the context of many independent variables (Klonowsk 2000). The main aim of measuring fractal dimensions is to reach deeper insight into the development of complex systems and the processes of contribution to system forming. Moreover, other aim of measuring fractal dimension is also to add a new structural parameter to the existing one, and describing a new and special structural characteristic. Besides these aim, So et al. (1999) adds that fractal dimension can be used to estimate the minimum number of freedom degree that it isused to describe dynamical behavior of a system.

Hurst (1951) the first researcher who applied the method of rescaled range analysis (R/S analysis) by using the single fractal feature as the first test based on fractal theory. The R/S analysis yields the so-called Hurst exponent *H*. To study more detail and deeper of fractal, Mandelbrot introduced another fractal theory called the multi-fractal method in order to present the microscopic local fractal features. Multi-fractal is the combination of many fractals with different fractal dimensions (Zmeskal et al. 2001).

Hurst exponent is used to predict the financial time series that capital markets theory also applies in order to expect the value of the security price. Basically, the security prices will be happened as the random walk and its returns are not predictable. Therefore, this theory is used to represent one of the variants of the broader Efficient Market Hypothesis (EMH), which is called Random Walk Hypothesis (RWH). The existence of long-range dependence implies the fact of inefficiency. In other words, the Hurst exponent can be used as an indicator of market efficiency.

The noise process is divided into different colors based on its each power law exponent α . The color of noise divides into four colors such as white, pink, brown, and black. Schroeder (1991) classifies the color of noise like in Table 2.1 below.

Table 2.1: Classification of noises by power law exponent

Noise Classification	Power Law $f^{-\alpha}$
White	0
Pink	1
Brown	2
Black	$\|\alpha\| > 2$

Source: Schroeder, M. R. (1991), *Fractal, Chaos, Power Law*. New York: W.H. Freeman

A noise process uses statistical approaches to analyze the dynamic behavior whether it is random or what. However, it is never fully random even it is in the short run. Noise processes with different colors result in different behaviors. The white noise is not predictable, the brown noise is unpredictability in increments, while the black noise shows the long run term persistence and memory and some form of predictability. The white noise is associated with $\alpha = 0$ which means that all the value of the process is completely independent since the past. Schroeder (1991) finds the pink noise and he defines that pink noise can happen when the process falls down somewhere between white noise and brown noise with $\alpha = 1$. He adds that the process must be found in nonlinear models of chaotic behavior since it is associated with hyperbolic behavior. The pink noise is a result from hyperbolic power laws and normally it happens in physical phenomena as well as in music composition. Another noise, the brown noise is a noise that also known as a Brownian motion when $\alpha = 2$ and it has the independent of past history of increments Δ (Mandelbrot and Van Ness, 1968). The last noise, the black noise is found with catastrophes including droughts, hurricanes and it happens when $\alpha > 2$. In case of the black noise, it has the explosive behavior, which is regulated because the separation of a series with independent increments becomes dependent upon the square root of time. These processes can represent a high level of persistence. Normally, black noise processes occur in a strong economic growth or decline.

The Hurst exponent can also be expressed as a function of α as below:

$$H(\alpha) = (\alpha - 1)/2 \tag{1}$$

Since the Hurst exponent H is related to the power law exponent α, the dynamic characteristics of time series can be known when the fractal dimensions H is determined. Knowing the dynamics characteristics of time series, suitable mathematical models can be rationally selected.

2.2 Literature Review

Morales et al. (2009) studies about the fractal behavior of complex systems and they find out that the complexity is a major property of the system among the most important properties of systems. They mention that normally the scholars can define the complexity of a system by observing how many numbers of elements that the complexity of a system contains like the nature and number of interrelations and the number of levels of embeddedness. Complex system happens when the complexity reaches to a high level in a system. The complex system is divided into two types—hard systems and soft systems. Basically, elements of hard systems show interrelated in a non-linear way. However, it will be complex systems when it has a big number of elements interacting in non-linear way. To understand more about the type of this system, it has developed from year to year in the diverse mathematical tools and later the development of this system is called fractal analysis, which is a well-known theory that many researches imply it in many fields of study from physics to economics.

Related to the color noise theory based on power law, Morales et al. (2009) also raises that ordinary power-law scaling is occurred in many physical systems when these systems distribute the property of scale invariance. However, since environment noise has an ability to destroy system symmetry, the notion of symmetry and invariance is just non-generic. In contrast, some systems do not follow the power law scaling but the scaling function is not independent, so it depends on ratios of the parameters logarithm (Sittler and Hinrichsen 2001).

Kantelhardt et al. (2002) propose a method by using Multi-Fractal Detrended Fluctuation Analysis (MF-DFA) to analyze the multi-fractal characterization of non-stationary time series. The authors do the comparison between the function-based of multi-fractal formalism and the MF-DFA method. It proves that both of the methods can show the stationary signals equally. However, the result is changed after they analyze by using several examples to prove more and it shows that the MF-DFA can be more reliable than the original multi-fractal to determine the multi-fractal scaling exponent H of time series with compact support. Moreover, there are two types of multifractality in time series that can be distinguished of scaling exponent for both small and large fluctuations in time series in their observation—multifractality of a time series based on a broad probability density function for the values and multifractality based on different long-range correlations for small and large fluctuations. They also compare the results between MF-DFA with the Wavelet Transform Modulus maxima (WTMM) method, which has a complicated procedure. However, the result shows that the MF-DFA is better than WTMM to analyze the scaling exponent of time series. Therefore, the MF-DFA is a method to analyze multi-fractal in order to study further of local fractal features.

Price of commodity has been a major subject of economic and statistical analysis that many researchers want to study and observe its behavior in the global market. There are some scholars study the commodity price and find out that the short term price fluctuation have reflected to the activity on future markets, disequilibrium adjustments on spot markets, risk taking among industrial purchasers and agricultural processors, and export revenue instability of commodity especially exported developing countries—Maizels (1992), Newberry and Stiglitz (1981), and Privolos and Duncan (1991). Those scholars analyze the fluctuations of commodity price to measure to know whether it occurs randomly, regularly,or it is at somewhere between suggestion nonlinear and fractal patterns.

Cromwell, labys, and Kouassi (2000) studies on how the behavior of commodity prices effects to the market and the changeable of demand and supply of those commodities based on its price. They employ fractal approaches to test how the apparent random movements associated in short term happen while the long run behavior also exams at the same time. In their study, they select 15 basic commodity prices that people use every day for their daily life such as bananas, beef, cocoa, coffee, copper, lead, rice, rubber, soybeans, sugar, tea, tin, wheat, wool, and zinc from January 1960 to June 1994. To get the result to know the color noise of each commodity price, the authors test both fractal and statistics including Hurst exponent and fractal dimension test. The result is not surprised as Hurst exponent explains that most of selected commodities move closer to black noise rather than to white, pink, or brown noise ($\alpha > 2$) except bananas moved closer to pink noise which it means that most commodities have correlation between the price in past to the price in future.

Alvarez Ramirez et al. (2002) apply Econophysics methods to understand the change of crude oil petroleum daily price. In this research, multi-fractal analysis method is a main objective to analyze the daily price of crude oil from 1981 to 2002 by selecting from different type of oil mixtures including Brent, WTI (West Texas Intermediate), and Dubai from Bloomberg L.P. databases. Rescaled rang Hurst analysis explains the result of these crude oil markets that it is consistent with the random-walk assumption only at time scale of the order of days to weeks.

Jin and Frechette (2002) do a research on agricultural cash price dynamics in USA by applying Mandelbrot’s fractal geometry with time series to investigate whether agricultural prices are self-similar at different time scales and non-periodic cyclical patterns. The time series data uses the daily agricultural commodity cash prices from three main sources such as the Chicago Board of Trade (CBOT), Kansas City (KC), and New York Board of Trade (NYBOT) from August 28, 1992 to March 8, 2000. The R/S analysis is employed to test the Hurst exponent and most of agricultural commodity prices show the positive results since its Hurst exponent $H > 0.5$. It is also interpreted that it has persistent long-term memory even though some cannot distinguish from 0.5. Therefore, the empirical results indicate that the long-term memory, fractional dimension, and self-similarity from the analysis can provide strong evidence to the price series have fractal structure.

K. E. Lee and J. W. Lee (2005) apply the multi-fractal to test the Korean stock market by using data recorded every minute from Korean Composite Stock Price Index (KOSPI) from March 30, 1992 to November 30, 1999. In this paper, R/S analysis is used to observe what kind of persistent behavior of KOSPI. There are three kinds of behavior that are explained by result of Hurst exponent: persistent $\mathrm{H} > 0.5$, random walking $\mathrm{H} = 0.5$, and anti-persistent $\mathrm{H} < 0.5$. The result from their study of KOSPI informs that it has persistent behavior. The authors clarify this result that it happens due to the behavior of traders, so when the price of stock goes down, the traders will follow the trend and cause the stock price falls down too. In conclusion, they assume that the Korean stock market is unstable if compare to well-developed market like the US market.

Liu and Hu (2007)do the research of the fractal properties of China's capital market by studying on Shanghai market's stock price. From the R/S analysis, the Shanghai stock price index has positive image as its Hurst exponent *H* is greater than 0.5. So it concludes that the changing of China stock price follow the Brownian motion. Furthermore, this stock market is persistent behavior, so the China stock market faces high risks since it can continuous increase or decrease. Hence, it effects to investors and they can benefit or lose based on their understandings about the properties of the stock market.

He and Zheng (2008)observe the international crude oil price market. They choose the crude oil price from Brent and WTI as a daily spot from May 20, 1987 to November 21, 2006 to study in their paper. Based on the scaling/multi-scaling analysis, the result finds that scales oil price shows Brownian noise in the short term. However, it also shows long-term memory as the non-periodic cycles exist with different lengths. Moreover, Gerogiorgis (2009) also employs time series analysis to investigate and exam the presence of fractal scaling of two different crude oil types based on daily price—Brent and WTI of the period 1986-2008. He investigates whether the crude oil price is a fundamentally non-Gaussian stochastic process and how it relates to fractal scaling law (power law). The result shows that both crude oil types have positive price changes than negative one. Both also have short and long term effects before and after 2008.

Fengge and Jing (2010) use the empirical study on fractal characteristics of real estate market in China with R/S analysis from August 23, 2001 to May 11, 2010. The result shows that the China real estate market has fractal characteristic and follows a fractal Brownian motion. It means that the real estate in China market was fluctuating so it is quite risky for investors to do investment on real estate in China market. The authors recommend to the investors to study the financial problems and other external effectiveness.

Mitra (2012) employs the Hurst exponent value to test the financial time series. In his study, he tests the Hurst exponent of twelve stock index series from across the globe using daily values of for past ten years from April 30, 2010. The result shows that the Hurst exponent *H* of the index series is closed to 0.5. However, the Hurst exponent *H* changes to the high value when it is estimated the smaller series. It explains that the twelve stock index series has long-term memory and the trade of stock prices has better profit.

Yin et al., (2013) study the fluctuation of the gold market in China by using R/S analysis and fractal dimension analysis according to fractal theory conducted by Mandelbrot in 1967. This paper uses the data from the AU99.99 closing price data of the Shanghai gold exchange in daily between October 30, 2002 and November 30, 2012. R/S analysis find out that the Hurst exponent *H* of the daily yield of gold in China market is greater than 0.5 and it indicates that the daily yield series has a long-term memory and a fractal structure during 112 days but it returns to random walk after that period. In conclusion, the researchers stress that the gold market is so complicated to estimate as it contains randomness and uncertainty due to multi-fractal structure. Therefore, the price can change and be fluctuating all the time beyond the expectation. The investors need to pay more attention on the external sector that can effect to the gold price.

Table 2.2: Summary of literature

Authors	Topic	Data	Method(s) of Analysis	Results
Cromwell, Labys, and Kouassi (2000)	What color are commodity prices? A fractal analysis. January 1960-June 1994.	Fifteen international commodity spot prices in monthly: bananas, beef, cocoa, coffee, copper, lead, rice, rubber, soybeans, sugar, tea, tin, wheat, wool, and zinc.	R/S analysis	Most of commodities are black noises, except bananas is pink noise.
Alvarez Ramirez et al., (2002)	Multi-fractal Hurst analysis of crude oil prices. 1981-2002.	Daily crude oil price from Brent, WTI, Dubai.	R/S analysis	The price exhibits a random walk behavior.
Jin and Frechette (2002)	Fractal geometry in agricultural cash price dynamics in USA. August 28, 1992-March 8, 2000.	Daily commodity cash price from CBOT, KC, NYBOT.	R/S analysis	Most of commodities have persistent long-term memory.
K. E. Lee and J. W. Lee (2005)	Multifractality of the KOSPI in Korean stock market. March 30, 1992 – Nov 30, 1999.	Every minute of Korean Composite Stock Price Index (KOSPI).	R/S analysis	KOSPI shows a persistent behavior.

Table 2.2: Summary of literature (continued)

Authors	Topic	Data	Method(s) of Analysis	Results
Liu and Hu (2007)	Research on the fractal properties of China's capital market.	The closing price of the Shanghai Composite Index (HSEC).	R/S analysis	Have persistent behavior and follow by Brownian motion.
He and Zheng (2008)	Empirical evidence of some stylized facts in international crude oil markets. May 20, 1987 - November 21, 2006.	Daily price of crude oil from Brent & WTI.	Scaling/multi-scaling R/S	The price follows Brownian noise in short term and has long-term memory.
Gerogiorgis (2009)	Chemical product and processmodeling .1986-2008.	Daily price of crude oil from Brent and WTI.	Fractal scaling law (power law)	1. The price has positive price change. 2. The price has short and long term effect before and after year 2008.

Table 2.2: Summary of literature (continued)

Authors	Topic	Data	Method(s) of Analysis	Results
Fegge and Jing (2010)	The empirical study of fractal characteristics of real estate market of China. Aug 23, 2001-May11, 2010.	The closing price of the stock market real estate index.	R/S analysis	The market has fractal characteristics and follows a fractal Brownian motion.
Mitra (2012)	Is Hurst exponent value useful in forecasting financial time series? April 30, 2010-date of study.	Twelve stock index prices: AORD, BSE30, CAC40, DAX, DJI, FTSE, HIS, KSE, N225, NDX, SP500, STI.	R/S analysis	The twelve stock index series has long-term memory.
Yin et al., (2013)	Fractal analysis of the gold market in China Oct 30, 2002 - Nov 30, 2012.	The AU99.99 closing price data of the Shanghai gold.	R/S analysis	The market has long-term memory characteristic with duration of 112 days.

CHAPTER 3

Methodology

3.1 Method of Analysis

3.1.1 R/S Analysis

Mandelbrot introduced fractal theory for the first time in 1967. He explains that fractal theory studies the relationship of similarity between the whole and the parts that has the self-similar characteristics with the stable and locally random. Its special characteristic is the traditional Euclidean geometry cannot describe it. The fractal test needs to employ the R/S analysis and fractal dimension analysis to analyze empirically the fractal characteristics of time series from the different angles. Moreover, the R/S analysis is also used to test the Hurst exponent and non-periodic in order to verify the term memory of the time series.

The R/S analysis is the most used non-parametric statistical method in fractal analysis and it is also a popular method among several methods that can be used to exam the fractal structure of economics and financial time series. Hurst who is a hydrologist develops the R/S analysis to study on his project—Nile River Dam Project during 1907. The main idea of R/S analysis is to know the scaling behavior. The procedure of R/S analysis is as follow.

According to H.E. Hurst (1951), the time series $\{P_t\}$ (i=1,2,3,…N+1), and $\{R_t\}$ is the timer series of length N, which is divided into A (integer) groups of continuous subseries, is computed $\{R_t\} = \{\Delta P_i = P_{i+1} - P_i\}$(i=1,2,3,..N). The subseries of length n are given as $I_a(a = 1,2,3,..., A)$ and the data of subseries are $R_{k,a}(k = 1,2,3,..., n)$. Let$(e_a)$ be the mean of the subseries, which it is computed as:

$$e_a = (1/n)\sum_{k=1}^{n} R_{k,a} \qquad (2)$$

Then, the mean e_a is used to calculate the cumulative deviation of interval elements, i.e.

$$X_{k,a} = \sum_{i=1}^{k} (R_{i,a} - e_a), k = 1,2,3,\ldots,n \tag{3}$$

The range (R_a) is calculated as follow equation:

$$R_a = \max(X_{k,a}) - \min(X_{k,a}), k = 1,2,3,\ldots,n \tag{4}$$

The standard deviation of each subseries is:

$$S_a = \sqrt{(1/n)\sum_{k=1}^{n} (R_{k,a} - e_a)^2} \tag{5}$$

The mean value of the rescaled range for all the subseries is then obtained as:

$$(R/S)_n = (1/A)\sum_{a=1}^{A} (R_a / S_a) \tag{6}$$

3.1.2 The Hurst Exponent

Hurst exponent (*H*) was given this name after the English hydrologist H.E. Hurst who introduced it in 1951. The Hurst exponent is a parameter that normally appears in time series and explains the relationship of past, present, and future. The Hurst exponent value is in the range between 0 and 1. The Hurst exponent is defined by:

$$(R/S)_n = C * n^H \tag{7}$$

Where *R/S* is the rescaled range, *n* is the length of the time intervals, *C* is a constant, and *H* is the Hurst exponent.

To get the Hurst exponent *H,* the logarithm is taken for both sides of (7), i.e.

$$\log(R/S)_n = \log C + H \log n \tag{8}$$

The slope of linear regression between $\log(R/S)_n$ and $\log n$ then yields the Hurst exponent *H*. *C* is model factor and *n* is the length.

The Hurst exponent is divided into three categories as follow:

1) If *H* = 0.5, then there is no relationship between past, present, and future in whole time series and it is a random and uncorrelated one.

2) If $0.5 < H \leq 1$, the time series have a continuity characteristic. Moreover, the time series have a persistent process with long-term memory, which prove that the fluctuation of analyzed time series in every period of past, present, and future has a positive correlation with each other. In the other explanations, if the time series move up or down in the past, it must cause the movement of present and continue to future to move to the same direction. The trend of the movement will be stronger and stronger when *H* keeps moving closer to 1 or the continuity of time series is stronger too.

3) If $0 < H \leq 0.5$, the time series have an anti-continuity characteristic or anti-persistent memory with negative correlations. In contrast from *H* within [0.5,1], when the present trend of time series moves up or down, it will move to the opposite direction in the future. The closer *H* is to 0, the stronger the anti-continuity is at the same time.

The correlation function of the impact of the present on the future price in the time series can be expressed as the equation below:

$$CR = 2^{2H-1} - 1 \tag{9}$$

The explanation of the result of equation (9) is based on the value of *H* and *CR*. When *H* = 0.5, it means that *CR* = 0, so it shows the time series are uncorrelated with each other between present and future. However, if *H* = 1, then *CR* = 1, and it can explain that the time series have a perfect positive correlation from present to future price. In contrast, if $H \in [0,0.5]$, it means that *CR*< 0; therefore, it concludes the time series have anti-persistent with negative correlations. It means that if the price of future will reverse from the present price. For example, the present price increases, so the future price will go down.

3.1.3 V-Statistic

The length of aperiodic circulation or memory term is the process of the time series, which means that every memory in nature is not permanent due to the affection of external factors and it will disappear completely. The memory term is usually a mean for the whole time series. The R/S regression analysis is a way to study in order to find the memory term of the time series. To calculate the memory term, the V-statistic can be defined as follow equation.

$$V_n = \frac{(R/S)_n}{\sqrt{n}} = \frac{Cn^H}{\sqrt{n}} = Cn^{H-0.5} \tag{10}$$

The result of memory term of the time series is explained based on the Hurst exponent *H*. If H = 0.5, the process of time series is random and independent while the diagram between $\log V_n$ and $\log n$ is a level line. If 0.5<H<1, the R/S moves faster that the square root of time and the diagram between $\log V_n$ and $\log n$ is upwardly inclined. If 0<H<0.5, the movement of R/S is slower than the square root of time and the diagram of $\log V_n$ and $\log n$ is downwardly inclined.

3.2 Research Procedure

The fractal theory studies the irregularity and similarity of geometrical objects, which in this context are the time series of the Malaysian CPO price. Hurst exponent, which is the result from the fractal analysis, is a crucial index for characterizing the dynamic behavior of the time series. Correspondingly, it is vital to determine the Hurst exponent of the Malaysian CPO price time series in order to analyze and identify their dynamic characteristics. Accordingly, the research starts from collecting the monthly Malaysia CPO price.

The method of fractal analysis, which employs the R/S analysis, uses to determine the Hurst exponent. The dynamic characteristics of the Malaysian CPO price are then summarized. The research procedure is shown in Figure 3.1.

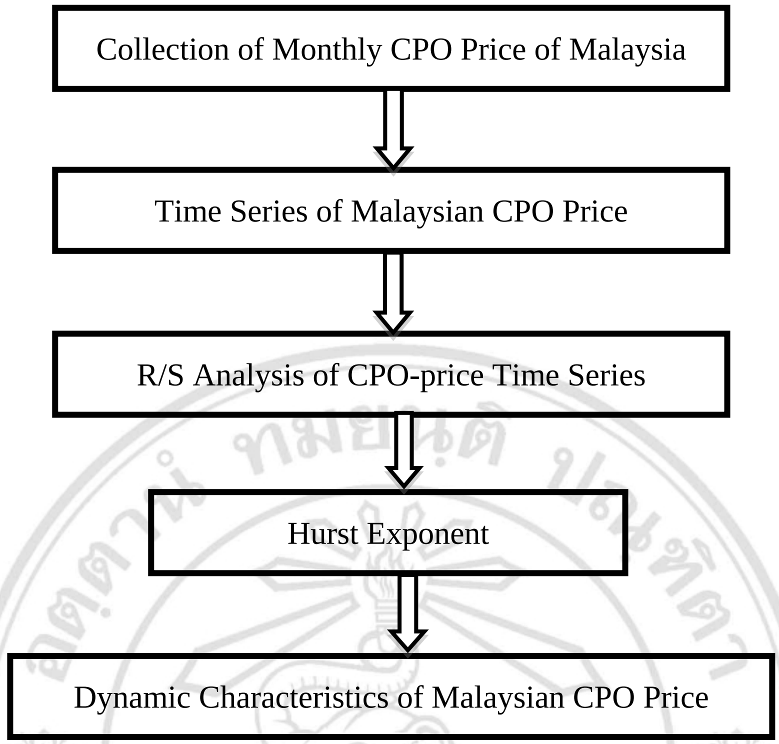


Figure 3.1: Research procedure

3.3 Data Collection

The CPO prices of Malaysia employs the secondary data, which is taken from CEIC database at Faculty of Economics, Chiang Mai University. The CPO prices are monthly based and measured in Ringgit Malaysia per ton. The prices cover the period between January 1983 and July 2014 (379 months in total).

CHAPTER 4

Empirical Results and Discussions

4.1 Analysis Results

In this study, the CPO price of Malaysia employs the secondary data, which is taken from CEIC database and covered 379 months between January 1983 and July 2014 (Figure 4.1).

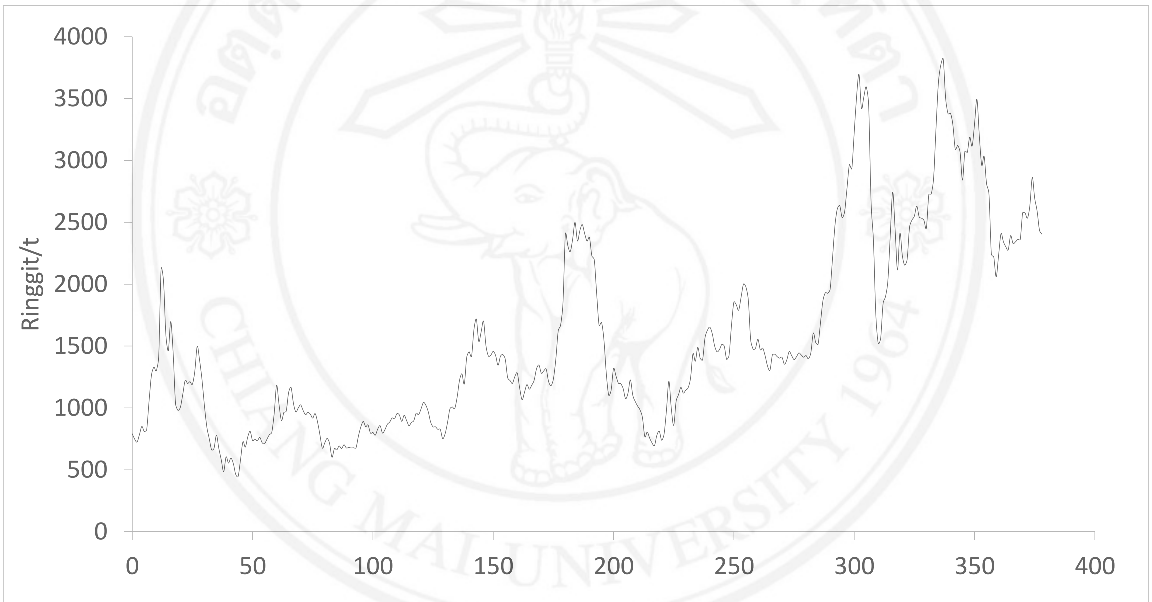


Figure 4.1: Crude palm oil price

From the price of CPO of Malaysian, the fluctuation of the return price are defined and got the result as the following Figure 4.2 after it is plotted in Matlab. According to this calculation, the linear regression with least-square method is taken and the result shows that $\log(R/S)_n = 4.1248 + 0.3647 \log n$ which it tells the Hurst exponent of CPO price is less than 0.5. The Figure 4.3 shows the log-log plot and linear regression of Malaysian CPO price.

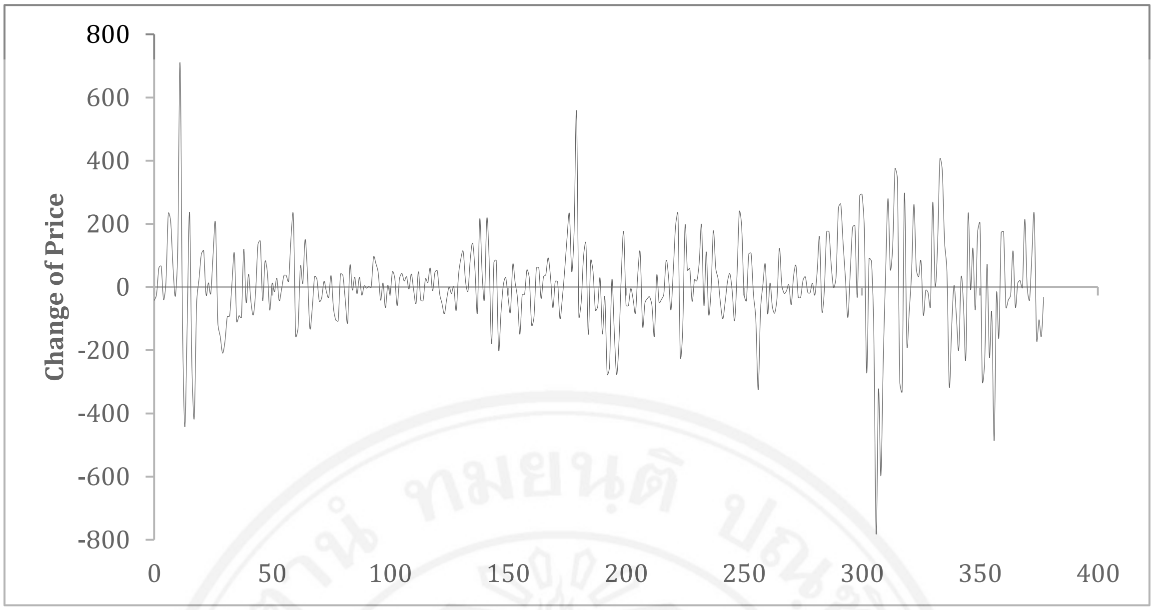


Figure 4.2: Malaysian CPO price fluctuation return

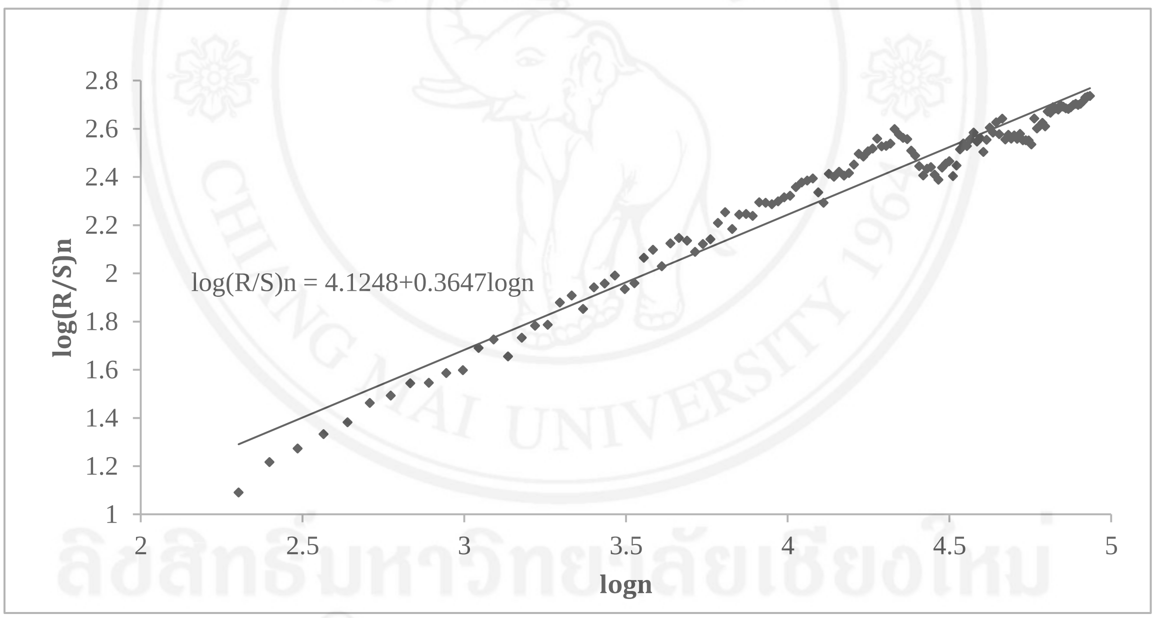


Figure 4.3: Log-log plot and linear regression for CPO price

The memory term of the time series is marked from the first turning point on the plot between V-statistic and $\log n$ (Eq. 10), so the memory term shows *N* = 9 months for CPO price. Moreover, *V*-statistic is downward sloping based on the Hurst exponent value (*H*=0.3647) and the *R/S* is scaling at a slower rate than the square root of time. Figure 4.4 points the spot of the first turning point on the graph.

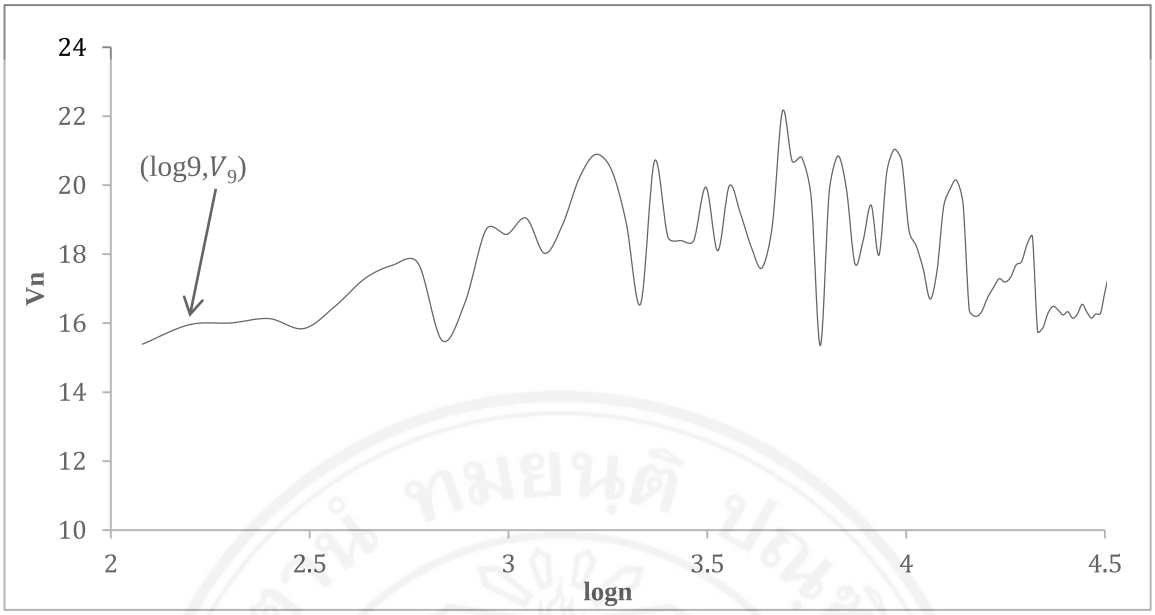


Figure 4.4: Malaysian CPO price memory term

The result of memory term proves that the Malaysian CPO price has the memory effect of 9 months. The limited memory term can be attributed to some external factors such as political action, economic crisis, policy-reform, currency exchange, competitors, weather, etc. (Dong 2009).With respect to the Hurst exponent result, the Malaysian CPO price follows the Fractal Market Hypothesis (FMH). All the above-described results are summarized in Table 4.1 below.

Table 4.1: Summary of numerical results and characteristics

Commodity	*H*	*CR*	*N*
Crude Palm Oil	0.3647	-0.1710	9 months

4.2 Discussion of Results

Using the R/S analysis the Hurst exponent of the time series of the Malaysian CPO price is obtained as 0.3647. This means that the Malaysian CPO price is an anti-persistent characteristic with negative correlation. Moreover, this result tells the fluctuation of analyzed time series of the CPO price in every period in the past, present, and future has negative correlation with each other and this fluctuation will keep going up or down in the next period with reversion characteristics if the price is increased or decreased in the previous time. Peters (1994) proves that anti-persistent behavior is very important in the market against the quote of Mandelbrot (1982) since it can help the investors or traders to understand the market much clearer, when they know the relationship between volatility and turbulent flow. Importantly, the relationship between physical systems and markets can be explained deeply. From the result of H in this study, the Hurst exponent H moves closer to 0.5, so it means that Malaysian CPO price has non-linear fluctuation and is very unstable with facing a lot of risk and it is difficult to estimate for the future price (Xu and Lu 1999).

It should be noted that the Malaysian CPO price movement has the contrast characteristics from the previous studies, which are mentioned in the literature review. Most of the results of the previous researches find that the Hurst exponent H is greater than 0.5. It means that it has the persistent process with the long-term memory and has the positive correlation. Compare to other commodity ones in (Cromwell et all. 2000), most of 15 commodity price movements have positive correlation and their power law exponents are greater than 2. The Malaysian CPO price has the high fluctuation between month and month; therefore, the result of return price seems too small. This fluctuation has the significant impact on the CPO market in global. Malaysian government declares to keep forest around 58% in the country, so the plantation areas cannot spread more by 2020 for palm oil trees. The estimation of palm oil plantation areas is only 750, 000 hectares left (USDA 2011). Palm oil production is decreased due to bad weather including drought and heavy rains. Another issue is Ringgit weakened in the world market comparing with US dollar that this causes the CPO price falls down (Oriental Pacific Futures 2014). A big problem is the strongest competitor—Indonesia. Malaysia and Indonesia are the biggest CPO exporters in the world, so they always compete with each other by reducing the CPO price in the market. Malaysian Palm Oil council (MPOC) decides to cut export taxes of CPO to 4.5% in order to increase the CPO price. Indonesian government, however, also declares that they cut CPO export taxes to zero to pull up their supply. Credit Suisse Group shows that the reason of Malaysian CPO price declines because of weaker commodity prices in the globe market (Asia Briefing 2014).

To describe the correlation between the price of Malaysian CPO in the present and future, the correlation coefficient according to Eq.(9) is determined. Based on H = 0.3647, CR is equal to -0.1710. The correlation coefficient implies that the present price of Malaysian CPO has negative effects on the future price fluctuation, which means future price will be inverse direction from the present price.

Apart from the Hurst exponent and the correlation coefficient, the corresponding power law exponent is also estimated using Eq. (1). The result from the computation yields $\alpha = 1.7294$, which implies that the behavior of the Malaysian CPO price movement is Pink noise process. The Pink noise process is from the anti-persistent behavior of Hurst exponent $(H < 0.5, 1 \geq \alpha > 2)$, so the power exponent and the Hurst exponent have a relationship with each other (Mandelbrot and Van 1968). According to Peters (1994), Pink noise is very useful in modeling turbulence when α is in a gap between 1 and 2 because Pink noise is quite close to 1/f noise, which is called the relaxation processes. Thus, the result of power law exponent in this study is positive sign to understand the structure of anti-persistence and volatility in the CPO market in globe market.

To investigate the long memory and do the forecasting in financial market or stock market, there are many models that are employed by different authors. Lux and Kaizoji (2007) exam the Japanese stock market to know the long memory time series to improve the forecasts by deriving from the short-memory models with different kind of models such as ARFIMA, FIGARCH, and multifactal model. Among the three models, FIGARCH and ARFIMA are the failure models to observe the forecasts in order to improve the short-memory models. However, authors mention that FIGARCH and ARFIMA models provide much better results of estimation rather than individually estimated models. Multifractal, on the other hand, is a new model, which it is just introduced to analyze the long memory time series models shows strong positive results since its performance can be more reliable to forecast based on historical volatility than ARFIMA and FIGARCH.

Peters (1994) explains very detail between Efficient Market Hypothesis (EMH) and Fractal Market Hypothesis (FMH). EMH always shows that market has an equilibrium point. The market structure of EMH is known as the random walk with short-term memory and the investors decide to trade based on the different period of the information. FMH, in contrast, can provide the best answer to response to the questions why self-similar statistical structures exist and what risks investors face because the fractal market analysis is got from the economic and mathematical structure provided by FMH. When the market is stable, it can say the market has liquidity. Physically, FMH studies the behavior of the investors in the financial market due to liquidity and investment horizons. Peters (1994) categorizes the FMH processes into five to observe the investor behavior and market price movements. First, the market is stable while the investors are the owner of a big number of investment horizons. Second, investment horizon is impacted by information of market or technical factors in short-term rather than the long-term; however, information does not reflect too much except investment horizon. Third, if there is an event happens in the market, the fundamental information impacts on the long-term investors to stop trading and change their investment to the short-term one because of the information. This makes the market is unstable. Fourth, normally, prices in market are compiled between short-term technical trading and long-term fundamental valuation, but the short-term price are easier to change with a very fast trend than long-term trades, which it is difficult control. Thus, it cannot assume that the short-term trends and the long-term economic trend are related to each other. Fifth, the author summarizes that long-term trend cannot happen in an unsafe economic market because it is controlled by trading, liquidity, and short-term information. Therefore, Peters (1994) quotes that "the longer the investment horizon, the smoother the time series" to prove the know FMH in the financial market.

CHAPTER 5

Conclusions and Future Work

5.1 Conclusions

The Malaysian CPO price movement is investigated through the fractal theory. The method of R/S analysis is applied to determine the Hurst exponent correlation coefficient, and power law exponent. These parameters are in turn employed to analyze and identify the dynamics characteristics of the Malaysian CPO price. The data of 379 observations of Malaysian CPO price from January 1983 to July 2014 are considered in the analysis. Based on the R/S analysis, the following conclusions are drawn.

1. The Hurst exponent is equal to 0.3647. Accordingly, the correlation coefficient and power law exponent is -0.1710 and 1.7294, respectively. This means that the Malaysian CPO price is an anti-persistent characteristic with negative correlation. The Malaysian CPO price has pink noise process with downward slope of power exponent.
2. The correlation coefficient indicates that the present price of Malaysian CPO has negative effects on the future price fluctuation, which means future price will be inverse direction from the present price.
3. The memory term of the Malaysian CPO price has only 9 months; therefore, it has the short-term memory more than long-term memory due to some external factors.
4. Based on the Hurst exponent, the Malaysian CPO price follows the Fractal Market Hypothesis (FMH) rather than the Efficient Market Hypothesis (EMH).

5.2 Research Implication

The results are also beneficial to Malaysian CPO price forecast and can give some suggestion for policy-making and investors making-decision. Related to the limited memory term of Malaysian CPO price, we do suggestion to the Malaysian government or related ministries to find out solutions that the price is affected by some external factors such as new policy reform on tariff and export tax, money exchange, export growth as well as production growth. Furthermore, to know the characteristics of Malaysian CPO price via Hurst exponent, it is very useful for the investors on stock market on CPO price, especially, Malaysian CPO price in the world stock markets. This study can provide a clear estimation of the relationship between present prices to future prices. Basically, the result is an anti-persistent memory with the negative correlation, so it has the inverted way with the past. The answer, here, is so straightforward to contribute the positive looking in the CPO stock market for the investors and traders to predict and do forecast in order to gain profit due to investment.

5.3 Future Work

Based on the Hurst exponent of the Malaysian CPO price movement, the mathematical modeling for the purpose of capturing the dynamic characteristics of the price movement needs to take into account the fractal behavior. It is, therefore, recommended that the modeling based on fractional calculus should be considered.

Some researches tried to apply the fractional Brownian motion, which was introduced by Mandelbrot and Van in 1968 in order to know whether it is possible to apply in the financial modeling or it cannot. However, they did not succeed with this new test as they found out that there were many problems that fractional Brownian motion are not suitable to use in financial models. Later, Rostek and Schobel (2013) is a new study which want to find the remedy and clarify when and why fractional Brownian motion can be use in economic modeling by taking the work of Sethi and Lehoczky (1981) to be a sample to test in their new research paper. They found that fractional Brownian motion could be used in only the dynamic market incompleteness. To take the opportunity for the next study, we also want to test fractional Brownian motion in the Malaysian CPO price whether it does work and what the results would be shown.

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APPENDIX

Command in Matlab

Malaysian CPO price (Ringgit/ton)

N	Original Price	Return Price
1	791.5	
2	749	-42.5
3	724.5	-24.5
4	784.5	60
5	850	65.5
6	809.5	-40.5
7	824	14.5
8	1056	232
9	1265	209
10	1329	64
11	1300	-29
12	1412	112
13	2121.5	709.5
14	2028.5	-03
15	1586	-442.5
16	1461.5	-124.5
17	1697.5	236
18	1449.5	-248
19	1034.5	-415
20	980.5	-54
21	1004	23.5
22	1108	104
23	1222	114
24	1198	-24
25	1211.5	13.5
26	1191.5	-20
27	1295.5	104
28	1496.5	201
29	1384.5	-112
30	1229	-155
31	1020	-209
32	846.5	-173.5
33	752.5	-94
34	661.5	-91
35	674	12.5
36	780.5	106.5
37	671.5	-109
38	581.5	-90
39	485	-96.5
40	604	119
41	554.5	-49.5
42	595	40.5
43	551.5	-43.5
44	463	-88.5
45	446	-17
46	580.5	134.5

N	Original Price	Return Price
47	725.5	145
48	683.5	-42
49	765	81.5
50	810.5	45.5
51	737.5	-73
52	749	11.5
53	734	-15
54	762	28
55	719	-43
56	711	-7.5
57	747.5	36
58	784	36.5
59	802	18.5
60	956.5	154
61	1183.5	227
62	1028.5	-155
63	898.5	-130
64	963	64.5
65	975	12
66	1125.5	150.5
67	1166	40.5
68	1036	-130
69	967	-68.5
70	1000	32.5
71	1024.5	24.5
72	980	-44.5
73	945.5	-34.5
74	963.5	18
75	949.5	-14

N	Original Price	Return Price
76	918	-31.5
77	954	36
78	887.5	-66.5
79	783	-104.5
80	676	-107
81	717	41
82	753.5	36.5
83	714	-39.5
84	601.5	-112.5
85	670.5	69
86	661	-9.5
87	692.5	31.5
88	671.5	-21
89	702	30.5
90	676.5	-25.5
91	680	3.5
92	676.5	-3.5
93	678	1.5
94	678	0
95	772.5	94.5
96	846.5	74
97	890.5	44
98	849	-41.5
99	862	13
100	797	-65
101	801.5	4.5
102	780	-21.5
103	828.5	48
104	856	27.5

N	Original Price	Return Price
105	797	-59
106	824	27
107	867	43
108	886	19
109	918.5	32.5
110	912	-6.5
111	953.5	41.5
112	943.5	-1
113	891.5	-52
114	940	48.5
115	899	-41
116	856.5	-42
117	882.5	26
118	896.5	14
119	957	60.5
120	945	-11.5
121	991	46
122	1043	51.5
123	1022.5	-20.5
124	970.5	-52
125	885.5	-85
126	847.5	-38
127	847.5	0
128	827	-20.5
129	827	0
130	752.5	-74.5
131	789.5	37
132	879.5	90
133	991.5	112

N	Original Price	Return Price
134	1008	16.5
135	995	-13
136	1084.5	89.5
137	1223	138.5
138	1275.5	52.5
139	1194.5	-81
140	1409.5	215
141	1453.5	44
142	1416.5	-37
143	1633.5	217
144	1717.5	84
145	1538	-179.5
146	1616	78
147	1700	84
148	1502	-198
149	1419.5	-82.5
150	1426.5	7
151	1456.5	30
152	1424.5	-31
153	1345.5	-79
154	1417	71.5
155	1431	14
156	1394.5	-36.5
157	1245	-149.5
158	1221	-24
159	1198.5	-22.5
160	1253	54.5
161	1281	28
162	1160	-121

N	Original Price	Return Price
163	1066.5	-93.5
164	1126	59.5
165	1188	62
166	1152	-36
167	1183.5	31.5
168	1223	39.5
169	1315.5	92.5
170	1346.5	31
171	1281	-65.5
172	1299	18
173	1314.5	15.5
174	1214.5	-100
175	1179.5	-35
176	1232.5	53
177	1388.5	156
178	1620.5	232
179	1668.5	48
180	1848.5	180
181	2404	555.5
182	2311.5	-92.5
183	2263.5	-48
184	2361.5	98
185	2499	137.5
186	2349.5	-149.5
187	2432	82
188	2481.5	49.5
189	2409	-72.5
190	2348	-61
191	2376.5	28.5

N	Original Price	Return Price
192	2228	-148.5
193	2197	-31
194	1921	-276
195	1668	-253
196	1692	24
197	1553	-139
198	1276.5	-276.5
199	1103	-173.5
200	1142.5	39.5
201	1317.5	175
202	1259.5	-58
203	1200.5	-59
204	1195.5	-5
205	1156.5	-39
206	1075	-81.5
207	1118.5	43.5
208	1226.5	108
209	1103.5	-123.5
210	1052.5	-50.5
211	1015.5	-37
212	984	-31.5
213	924	-60
214	768	-156
215	805.5	37.5
216	756.5	-49
217	717.5	-39
218	695	-22.5
219	779	84
220	812	33

N	Original Price	Return Price
221	739	-73
222	788.5	49.5
223	983	194.5
224	1215	232
225	998	-217
226	859.5	-138.5
227	1053	193.5
228	1106.5	53.5
229	1165.5	59
230	1120.5	-45
231	1143.5	23
232	1163	19.5
233	1240	77
234	1436.5	196.5
235	1377.5	-59
236	1489	111.5
237	1402.5	-86.5
238	1388.5	-14
239	1566	177.5
240	1626.5	60.5
241	1652.5	26
242	1602	-50.5
243	1501.5	-100.5
244	1454	-47.5
245	1471	17
246	1513	42
247	1499.5	-13.5
248	1392.5	-107
249	1425	32.5
250	1663	238
251	1855	192
252	1833.5	-21.5
253	1790	-43.5
254	1894	104
255	2000.5	106.5
256	1977.5	-23
257	1874	-103.5
258	1548.5	-325.5
259	1476	-72.5
260	1483	7
261	1555	72
262	1470	-85
263	1480	13
264	1420.5	-62.5
265	1338	-82.5
266	1305	-33
267	1427.5	122.5
268	1434	6.5
269	1414.5	-19.5
270	1402.5	-12
271	1409	6.5
272	1353.5	-55.5
273	1387.5	34
274	1455.5	68
275	1423	-32.5
276	1391	-32
277	1412.4	21.5
278	1444.5	32

N	Original Price	Return Price
279	1428	-16.5
280	1410	-18
281	1422.5	12.5
282	1397	-25.5
283	1446.5	49.5
284	1604.5	158
285	1529	-75.5
286	1515	-14
287	1689.5	174.5
288	1865	175.5
289	1929.5	64.5
290	1927	-2.5
291	1959	32
292	2209	250
293	2472	263
294	2609	137
295	2634	25
296	2537.5	-96.5
297	2582	44.5
298	2771	189
299	2956	194
300	2933	-32
301	3221	288
302	3515	294
303	3695	180
304	3423	-272
305	3512.5	89.5
306	3594	82
307	3454	-140
308	2673.5	-781
309	2349.5	-324
310	1752	-597.5
311	1520.5	-231.5
312	1562	41.5
313	1842	280
314	1898	56
315	2026.5	128.5
316	2402	375.5
317	2743.5	341.5
318	2444.5	-299
319	2114.5	-330
320	2411.5	297
321	2231.5	-180
322	2153.5	-78
323	2199	45.5
324	2460.5	261.5
325	2517.5	57
326	2549.5	32
327	2631.5	82
328	2543.5	-88
329	2533	-10.5
330	2515.5	-17.5
331	2454.5	-61
332	2723.5	269
333	2728.5	5
334	2855.5	127
335	3259	403.5
336	3629.5	270.5

N	Original Price	Return Price
337	3772	142.5
338	3818.5	46.5
339	3503.5	-315
340	3377.5	-126
341	3382	4.5
342	3289.5	-92.5
343	3091	-198.5
344	3121	30
345	3066.5	-54.5
346	2841	-225.5
347	3070	232
348	3065	-8
349	3188.5	123.5
350	3116	-72.5
351	3291	175
352	4393	202
353	3197	-296
354	2961.5	-235.5
355	3033	71.5
356	2811	-222
357	2729	-82
358	2243	-486
359	2220	-23
360	2060	-160
361	2232	172
362	2407	175
363	2343	-64
364	2302.5	-40.5
365	2277.5	-25

N	Original Price	Return Price
366	2392	114
367	2329.5	-62.5
368	2341.5	12
369	2362	20.5
370	2361	-1
371	2575.5	214.5
372	2575.5	0
373	2534	-41.5
374	2634.5	100
375	2862	227
376	2695.5	-166.5
377	2592	-103.5
378	2436	-156
379	2404	-32

Appendix 1: The Hurst Exponent Computation

```
X=cumsum(Price_return-mean(Price_return));
X=transpose(X);
Scale=[8,16,32,64,128,256];
F = zeros(1,length(scale));
m=1;
For ns=1:length(scale)
Segments(ns)=floor(length(X)/scale(ns));
   For v=1:segments(ns),
Idx_start=((v-1)*scale(ns))+1;
Idx_stop=v*scale(ns);
Index{v,ns}=Idx_start:Idx_stop;
X_Idx=X(Index{v,ns});
      C=polyfit(Index{v,ns},X(Index{v,ns}),m);
fit{v,ns}=polyval(C,Index{v,ns});
RMS{ns}(v)=sqrt(mean((X_Idx-fit{v,ns}).^2));
F(ns)=sqrt(mean(RMS{ns}.^2));
rs_plot_data = [log(scale)' log(F)'];
xlswrite('rs_plot.xlsx',rs_plot_data)
% Obtain Hurst Exponent H
const=polyfit(log(scale),log(F),1);
H=const(1)
log_C=const(2)
```

H	$\log C$	CR	α
0.3647	4.1248	-0.1710	1.7294

Appendix 2: Log-log plot and linear regression for Malaysian CPO price

```
s=length(CPO_price);
n=floor((s-100)/2);
For k=10:n
z=floor(s/k);
i=k*z;
x= CPO_price (s-i+1:s);
length(x);
b=reshape(x,k,z);
rescale=0;
   For p=1:z
c=b(:,p)
d=mean(c);
deviation=c-d;
deviationsum=cumsum(deviation);
range=max(deviationsum)-min(deviationsum);
stdddev=std(c);
rescale=rescale+range/stdddev;
   End;
rescaledmean=rescale/z;
regressstandby(k)=rescaledmean;
h(k)=regressstandby(k)/sqrt(k);
End;
y=log(regressstandby(10:n))
```

y					
Columns 1 through 6					
1.0909	1.2166	1.2732	1.3327	1.3822	1.4623
Columns 7 through 12					
1.4929	1.5441	1.5458	1.5864	1.5987	1.6909
Columns 13 through 18					
1.7260	1.6555	1.7332	1.7826	1.7868	1.8787
Columns 19 through 24					
1.9079	1.8526	1.9422	1.9578	1.9911	1.9345
Columns 25 through 30					
1.9594	2.0650	2.0980	2.0299	2.1245	2.1472
Columns 31 through 36					
2.1357	2.0895	2.1220	2.1414	2.2094	2.2537
Columns 37 through 42					
2.1844	2.2440	2.2466	2.2388	2.2951	2.2933
Columns 43 through 48					
2.2872	2.2989	2.3158	2.3224	2.3582	2.3774
Columns 49 through 54					
2.3849	2.3939	2.3362	2.2932	2.4130	2.4014
Columns 55 through 60					
2.4216	2.4055	2.4161	2.4517	2.4958	2.4847
Columns 61 through 66					
2.5066	2.5180	2.5591	2.5271	2.5219	2.5385
Columns 67 through 72					
2.5987	2.5761	2.5623	2.5568	2.5090	2.4888
Columns 73 through 78					
2.4449	2.4065	2.4343	2.4409	2.4100	2.3888
Columns 79 through 84					
2.4389	2.4554	2.4657	2.4036	2.4476	2.5145
Columns 85 through 90					
2.5389	2.5288	2.5565	2.5841	2.5469	2.5618

Columns 91 through 96					
2.5038	2.5543	2.6046	2.5844	2.6264	2.5773
Columns 97 through 102					
2.6420	2.5558	2.5752	2.5592	2.5724	2.5585
Columns 103 through 108					
2.5792	2.5521	2.5524	2.5517	2.5353	2.6428
Columns 109 through 114					
2.6018	2.6124	2.6250	2.6099	2.6719	2.6666
Columns 115 through 120					
2.6896	2.6846	2.6795	2.6978	2.6920	2.6851
Columns 121 through 126					
2.6825	2.6890	2.6992	2.7034	2.6990	2.7037
Columns 127 through 130					
2.7139	2.7296	2.7332	2.7363		

x					
Columns 1 through 6					
2.3026	2.3979	2.4849	2.5649	2.6391	2.7081
Columns 7 through 12					
2.7726	2.8332	2.8904	2.9444	2.9957	3.0445
Columns 13 through 18					
3.0910	3.1355	3.1781	3.2189	3.2581	3.2958
Columns 19 through 24					
3.3322	3.3673	3.4012	3.4340	3.4657	3.4965
Columns 25 through 30					
3.5264	3.5553	3.5835	3.6109	3.6376	3.6636
Columns 31 through 36					
3.6889	3.7136	3.7377	3.7612	3.7842	3.8067
Columns 37 through 42					
3.8286	3.8501	3.8712	3.8918	3.9120	3.9318
Columns 43 through 48					
3.9512	3.9703	3.9890	4.0073	4.0254	4.0431
Columns 49 through 54					
4.0604	4.0775	4.0943	4.1109	4.1271	4.1431
Columns 55 through 60					
4.1589	4.1744	4.1897	4.2047	4.2195	4.2341
Columns 61 through 66					
4.2485	4.2627	4.2767	4.2905	4.3041	4.3175
Columns 67 through 72					
4.3307	4.3438	4.3567	4.3694	4.3820	4.3944
Columns 73 through 78					
4.4067	4.4188	4.4308	4.4427	4.4543	4.4659
Columns 79 through 84					
4.4773	4.4886	4.4998	4.5109	4.5218	4.5326
Columns 85 through 90					
4.5433	4.5539	4.5643	4.5747	4.5850	4.5951

Columns 91 through 96

4.6052 4.6151 4.6250 4.6347 4.6444 4.6540

Columns 97 through 102

4.6634 4.6728 4.6821 4.6913 4.7005 4.7095

Columns 103 through 108

4.7185 4.7274 4.7362 4.7449 4.7536 4.7622

Columns 109 through 114

4.7707 4.7791 4.7875 4.7958 4.8040 4.8122

Columns 115 through 120

4.8203 4.8283 4.8363 4.8442 4.8520 4.8598

Columns 121 through 126

4.8675 4.8752 4.8828 4.8903 4.8978 4.9053

Columns 127 through 130

4.9127 4.9200 4.9273 4.9345

Appendix 3: Calculation of memory term for Malaysian CPO price

```
X=cumsum(CPO_price-mean(CPO_price));
X=transpose(X);
%scale=[8,16,32,64,128,256,512,1024];
scale= 8:256
F = zeros(1,length(scale));
m=1;
For ns=1:length(scale)
segments(ns)=floor(length(X)/scale(ns));
   For v=1:segments(ns),
Idx_start=((v-1)*scale(ns))+1;
Idx_stop=v*scale(ns);
Index{v,ns}=Idx_start:Idx_stop;
X_Idx=X(Index{v,ns});
      C=polyfit(Index{v,ns},X(Index{v,ns}),m);
fit{v,ns}=polyval(C,Index{v,ns});
RMS{ns}(v)=sqrt(mean((X_Idx-fit{v,ns}).^2));
   End
F(ns)=sqrt(mean(RMS{ns}.^2));
End
vn = F./sqrt(scale)
vn_plot_data = [scale' vn']
L=log(scale)
```

V_n					
Columns 1 through 6					
37.7498	39.0660	39.6316	39.6933	39.1037	40.4028
Columns 7 through 12					
42.3498	43.4341	43.9130	38.0814	40.6140	46.8509
Columns 13 through 18					
46.5281	46.6330	44.3507	46.6049	50.5629	51.1649
Columns 19 through 24					
51.0200	46.3454	41.3026	50.6894	46.2197	45.3574
Columns 25 through 30					
46.3732	49.5747	44.3183	50.5278	48.1079	44.9289
Columns 31 through 36					
45.0463	47.7748	55.2127	51.1538	50.9384	50.0974
Columns 37 through 42					
38.7336	49.5036	51.5922	48.6573	45.9325	47.1233
Columns 43 through 48					
49.2358	45.0484	50.4615	51.5291	50.6678	48.8209
Columns 49 through 54					
47.0925	44.7819	42.5524	44.0232	48.0965	49.3906
Columns 55 through 60					
49.3153	47.6556	43.3160	42.2120	42.5548	42.9746
Columns 61 through 66					
43.7325	43.7148	43.4659	43.1325	44.0282	44.2658
Columns 67 through 72					
44.7558	45.3376	42.3950	42.6815	43.8312	43.5961
Columns 73 through 78					
43.3268	42.9446	42.4107	41.9260	42.2275	42.1609
Columns 79 through 84					
41.6095	41.1504	40.6474	40.6702	42.2085	42.5969
Columns 85 through 90					
42.2605	41.1157	39.2159	29.8524	28.2738	27.5906

Columns 91 through 96

28.1022 29.3759 31.0720 33.5465 35.0444 35.4404

Columns 97 through 102

36.4794 36.8607 37.1223 37.5811 37.9132 38.0620

Columns 103 through 108

38.1240 38.0175 38.3893 38.6512 38.4060 38.0843

Columns 109 through 114

37.7294 37.3673 37.0369 37.1578 37.8589 38.1856

Columns 115 through 120

38.4699 38.6485 38.5158 38.3202 38.3343 31.5030

Columns 121 through 126

31.3538 30.9356 30.5360 30.1830 29.9007 29.6282

Columns 127 through 132

29.3379 29.1022 28.9528 28.8320 28.6564 28.6067

Columns 133 through 138

28.5727 28.5102 28.5764 28.6767 28.8202 28.9920

Columns 139 through 144

29.5619 30.3387 30.8663 31.7442 32.8096 34.6518

Columns 145 through 150

35.8732 36.9616 36.8478 36.7623 36.6372 36.4231

Columns 151 through 156

36.3195 36.1198 35.9154 35.6940 35.5121 35.3593

Columns 85 through 90

42.2605 41.1157 39.2159 29.8524 28.2738 27.5906

Columns 91 through 96

28.1022 29.3759 31.0720 33.5465 35.0444 35.4404

Columns 97 through 102

36.4794 36.8607 37.1223 37.5811 37.9132 38.0620

Columns 103 through 108

38.1240 38.0175 38.3893 38.6512 38.4060 38.0843

Columns 109 through 114

37.7294 37.3673 37.0369 37.1578 37.8589 38.1856

Columns 115 through 120

38.4699 38.6485 38.5158 38.3202 38.3343 31.5030

Columns 121 through 126

31.3538 30.9356 30.5360 30.1830 29.9007 29.6282

Columns 127 through 132

29.3379 29.1022 28.9528 28.8320 28.6564 28.6067

Columns 133 through 138

28.5727 28.5102 28.5764 28.6767 28.8202 28.9920

Columns 139 through 144

29.5619 30.3387 30.8663 31.7442 32.8096 34.6518

Columns 145 through 150

35.8732 36.9616 36.8478 36.7623 36.6372 36.4231

Columns 151 through 156

36.3195 36.1198 35.9154 35.6940 35.5121 35.3593

Columns 157 through 162

35.1833 34.9900 34.8646 34.9245 35.5358 35.9920

Columns 163 through 168

36.0913 36.0324 35.9016 35.7253 35.5877 35.4646

Columns 169 through 174

35.3845 35.1660 34.9434 34.9049 34.8781 34.7131

Columns 175 through 180

34.5877 34.4077 34.2050 33.9632 33.6637 33.2950

Columns 181 through 186

32.9523 32.7093 27.8936 28.0164 28.1009 28.0313

Columns 187 through 192

27.8955 27.7634 27.6218 27.5160 27.4677 27.4027

Columns 193 through 198

27.2880 27.1874 27.1035 27.0211 26.9508 26.9092

Columns 199 through 204

26.8497 26.7571 26.7020 26.6644 26.6395 26.6253

Columns 205 through 210

26.6349 26.7218 26.7796 26.8574 26.9495 27.0460

Columns 211 through 216

27.0886	27.1095	27.1608	27.1821	27.1246	27.0153

Columns 217 through 222

26.9528	26.9358	26.8563	26.7652	26.6642	26.5713

Columns 223 through 228

26.4748	26.3759	26.2684	26.1571	26.0453	25.9386

Columns 229 through 234

25.8288	25.7198	25.6225	25.5336	25.4487	25.3559

Columns 235 through 240

25.2538	25.1503	25.0482	24.9486	24.8490	24.7488

Columns 241 through 246

24.6491	24.5671	24.5243	24.4739	24.4120	24.3737

Columns 247 through 249

24.3646	24.3445	24.2938

$\log n$					
Columns 1 through 6					
2.0794	2.1972	2.3026	2.3979	2.4849	2.5649
Columns 7 through 12					
2.6391	2.7081	2.7726	2.8332	2.8904	2.9444
Columns 13 through 18					
2.9957	3.0445	3.0910	3.1355	3.1781	3.2189
Columns 19 through 24					
3.2581	3.2958	3.3322	3.3673	3.4012	3.4340
Columns 25 through 30					
3.4657	3.4965	3.5264	3.5553	3.5835	3.6109
Columns 31 through 36					
3.6376	3.6636	3.6889	3.7136	3.7377	3.7612
Columns 37 through 42					
3.7842	3.8067	3.8286	3.8501	3.8712	3.8918
Columns 43 through 48					
3.9120	3.9318	3.9512	3.9703	3.9890	4.0073
Columns 49 through 54					
4.0254	4.0431	4.0604	4.0775	4.0943	4.1109
Columns 55 through 60					
4.1271	4.1431	4.1589	4.1744	4.1897	4.2047
Columns 61 through 66					
4.2195	4.2341	4.2485	4.2627	4.2767	4.2905
Columns 67 through 72					
4.3041	4.3175	4.3307	4.3438	4.3567	4.3694
Columns 73 through 78					
4.3820	4.3944	4.4067	4.4188	4.4308	4.4427
Columns 79 through 84					
4.4543	4.4659	4.4773	4.4886	4.4998	4.5109
Columns 85 through 90					
4.5218	4.5326	4.5433	4.5539	4.5643	4.5747

Columns 91 through 96					
4.5850	4.5951	4.6052	4.6151	4.6250	4.6347
Columns 97 through 102					
4.6444	4.6540	4.6634	4.6728	4.6821	4.6913
Columns 103 through 108					
4.7005	4.7095	4.7185	4.7274	4.7362	4.7449
Columns 109 through 114					
4.7536	4.7622	4.7707	4.7791	4.7875	4.7958
Columns 115 through 120					
4.8040	4.8122	4.8203	4.8283	4.8363	4.8442
Columns 121 through 126					
4.8520	4.8598	4.8675	4.8752	4.8828	4.8903
Columns 127 through 132					
4.8978	4.9053	28.9528	4.9200	4.9273	4.9345
Columns 133 through 138					
4.9416	4.9488	4.9558	4.9628	4.9698	4.9767
Columns 139 through 144					
4.9836	4.9904	4.9972	5.0039	5.0106	5.0173
Columns 145 through 150					
5.0239	5.0304	5.0370	5.0434	5.0499	5.0562
Columns 151 through 156					
5.0626	5.0689	5.0752	5.0814	5.0876	5.0938
Columns 157 through 162					
5.0999	5.1059	5.1120	5.1180	5.1240	5.1299
Columns 163 through 168					
5.1358	5.1417	5.1475	5.1533	5.1591	5.1648
Columns 169 through 174					
5.1705	5.1761	5.1818	5.1874	5.1930	5.1985
Columns 175 through 180					
5.2040	5.2095	5.2149	5.2204	5.2257	5.2311
Columns 181 through 186					
5.2364	5.2417	5.2470	5.2523	5.2575	5.2627

Columns 187 through 192

5.2679	5.2730	5.2781	5.2832	5.2883	5.2933

Columns 193 through 198

5.2983	5.3033	5.3083	5.3132	5.3181	5.3230

Columns 199 through 204

5.3279	5.3327	5.3375	5.3423	5.3471	5.3519

Columns 205 through 210

5.3566	5.3613	5.3660	5.3706	5.3753	5.3799

Columns 211 through 216

5.3845	5.3891	5.3936	5.3982	5.4027	5.4072

Columns 217 through 222

5.4116	5.4161	5.4205	5.4250	5.4293	5.4337

Columns 223 through 228

5.4381	26.3759	5.4467	5.4510	5.4553	5.4596

Columns 229 through 234

5.4638	5.4681	5.4723	5.4765	5.4806	5.4848

Columns 235 through 240

5.4889	5.4931	5.4972	5.5013	5.5053	5.5094

Columns 241 through 246

5.5134	5.5175	5.5215	5.5255	5.5294	5.5334

Columns 247 through 249

5.5373	5.5413	5.5452

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