

## An Investigation of Structural Breaks on Spot and Futures Crude Palm Oil Returns

<sup>1</sup>Rozaimah Zainudin and <sup>2</sup>Roselee Shah Shaharudin

<sup>1</sup>Lecturer, Faculty of Business and Accountancy, University of Malaya,  
50603 Kuala Lumpur, Malaysia.

<sup>2</sup>Head of Research Department, 3 Persiaran Bukit Kiara, Bukit Kiara, 50490 Kuala Lumpur, Malaysia.

**Abstract:** The implications of omitting structural break in volatility clustering modelling process are largely discussed in various developed macroeconomic and finance variables. The empirical evidence highlights the importance of this structural break in modelling process that gives a more accurate volatility persistency estimation result. The main purpose of the paper is (i) to identify the existence of structural breaks in crude palm oil return and (ii) to demonstrate the implication of structural break in volatility clustering estimation process. This paper tests for the presence of structural breaks in spot and future crude palm oil returns. Using daily data that span from January 1996 to August 2008, we test the existence of structural changes in tested crude palm oil series mean via the Bai and Perron procedure. Using the Inclan and Tiao Iterated Cumulative Sums of Squares (ICSS) algorithm procedures, we proceed to identify any structural changes in series variance. Based on the Bai and Perron test results, we found two structural changes in tested returns mean series located in late 1998 and 1999. Additionally, the Inclan and Tiao Iterated Cumulative Sums of Squares (ICSS) algorithm test results identified some regime changes in futures crude palm oil variance located in late 1996, late 2001 and early 2008. We provide some internal and external explanations for the cause of these structural shifts in both mean and variance. Then, the study continues to investigate the implication of structural breaks in crude palm oil volatility clustering estimation process. Initially, we estimate a Baba, Engle, Kraft, and Kroner model (BEKK model) without the structural break. Having identified the breaks in the mean and variance of both returns series, we model their relationship by incorporating those breaks in the volatility clustering procedure (using modified BEKK model). The volatility clustering finding show that the spot crude palm oil persistency parameters have slightly increased when structural breaks are taken into account in the estimated model. In contrast to the spot crude palm oil findings, the futures crude palm oil exhibits a lower persistency estimation when structural changes are considered. The results support the importance of structural breaks in this volatility clustering estimation, and failure to do so may lead to bias persistency parameter estimation.

**Key words:** Structural break, Bai and Perron test, IT ICSS test, CPO and FCPO.

### INTRODUCTION

Modelling structural breaks has taken centre stage in empirical macroeconomics and finance. This is evident from the ever-increasing number of publications that have discussed this issue in recent decades. The implications of failing to account for structural breaks in econometric modelling are many. Two of the well-known implications are: (Aggarwal, 1999) the tendency to erroneously support that time series behave as a non-stationary process rather than a stationary process in the preliminary unit-root diagnostic test (Zivot and Andrews, 1992) and (Andreou, 2002) a misspecified model, which could lead to an error in estimation and forecasts.

Because of these implications, the structural break identification test plays an important role in the econometric modelling process. There are many techniques available that researchers can use to identify structural breaks, for example, Bai and Perron (1998) developed a comprehensive test, which allows for the identification of multiple breaks in series means. The notion of a structural break is not strictly restricted to the mean specification of a series. In fact, the regime shift identification has extended into the series second moment specification (see Inclan and Tiao, 1994; Chu, 1995; Kokoszka and Leipus, 1998, 2000). The Inclan and Tiao (1994) procedure (IT procedure henceforth) is less preferred by some structural break researchers since this procedure is based on the Iterated Cumulative Sums of Squares (ICSS) algorithm, which caters for unconditional variance series. They argue that the fat tail characteristic exists in most economic and financial series and may make the procedure less suitable. However, Andreou and Ghysels (2002) highlight that the IT procedure has a higher power in detecting multiple breaks in large sample series compared to the Kokoszka and Leipus (1998, 2000) procedure. The IT test has less of a size distortion issue and smaller outlier problem when the sample size is large. Consequently, this IT procedure has been applied to many macroeconomic variables such as exchange rate (Rapach and Strauss, 2008), US interest rate (Bai and Perron, 2003), growth national

product (Fang, Miller and Lee, 2008) and in the securities markets (Aggarwal, Inclan and Leal, 1999). Generally, the empirical evidence highlights the importance of identifying and modelling these breaks in both the mean and volatility specifications in order to generate correct estimates of the model and its forecasts. On that basis, it is rudimentary to check for the existence of structural breaks in the series and to account for them in the modelling exercise. Hence, this study is interested in testing the presence of structural breaks in the mean and variance crude palm oil series, then providing an explanation of those detected breaks and, finally, testing the effect of modelling these breaks in the volatility clustering estimation process.

This paper extends the existing literature in a number of ways. First, it complements previous research on the issue of structural breaks with applications on financial and macroeconomic series from developed markets by considering the application of structural break tests on commodity return series from an emerging market. Second, although there is extensive evidence concerning the issue of structural changes in macroeconomic variables, very little attention has been given to agricultural commodity returns. However, the agricultural sector is intertwined with other sectors and constitutes a major contribution to economic activity for many emerging countries. Furthermore, the changes in the economic structure may not have an immediate and severe effect on other developed commodity markets. Additionally, Aggarwal *et al.*, (1999) highlight that some unexpected events only affect the world volatility movement and do not affect the emerging countries specifically. As such, the research posits that some unexpected events that may possibly affect the regime shift in more developed commodity markets may not affect the emerging commodity markets. Third, the identification of breaks in the mean and variance of the series returns would suggest the importance of a dynamic model specification that caters for these breaks in order to provide more precise persistency inference.

The remainder of the paper is organized as follows. Section 2 provides a literature survey on issues relating to structural breaks. Section 3 introduces the methodologies used to identify the existence of structural breaks in the series and the periods in which they occur. It then explains the volatility clustering model used. Subsequently, Section 4 briefly explains the data used in the study. The next section presents preliminary data analysis. Section 5 further discusses the findings of Bai and Perron, as well as IT ICSS and adjusted IT ICSS algorithm structural breaks tests and, ultimately, the BEKK-GARCH estimation. Section 6 will conclude the findings of this study.

#### **Literature Survey:**

The world has experienced a number of economic crises that affected many macroeconomic variables and financial series. These crises may alter the movement of economic series, especially macroeconomic variables such as GDP growth, inflation and exchange rates. Recent markets tend to be more volatile, caused by the response of market participants to the information (e.g. unexpected events) occurring in the markets. Sometimes the market is calmer but not all the time. There are various sources of volatility that may push the financial or economic series into different volatility regimes (from a high to low state volatility and vice versa). Hence, the affected movement may be translated into a higher or lower volatility experienced in those variables. Therefore, plausibly, many unexpected events can cause some unanticipated changes or shifts in these variables volatility.

Common unexpected events include global crisis, oil price shock, pre and post war effect, Asian Financial Crisis, regional revised exchange rate policy, and technology bubble, etc. Some highlight that the regime shift is due to internal monetary policy, government intervention, political stability, a country's economic situation or productivity capacity. However, the existing body of evidence documenting these structural breaks is mostly related to international events (global crisis, gulf war, etc.), and the national events (including political, social or financial atmosphere). Particularly, some of these national events caused a regime shift in volatility, and most were mainly concerned with international events (see Andreou and Ghysels, 2002). This empirical evidence also supports the significant events that may affect different types of countries in various ways. Certain world events may affect the developed countries more than the emerging countries. Interestingly, Aggarwal, Inclan and Leal (1999) infer that international events such as the Gulf war only caused a regime shift in Singapore, Japan, the US, the World index and the Emerging index variance, but did not affect the individual developing countries specifically. Generally, this omission of any possible breaks could affect the macroeconomic variables movement uniquely towards the developing countries rather than the more advanced countries.

Econometric perspective has empirically proved that structural breaks do influence the series behaviors and estimation accuracy. The preliminary effect indicates that ignorance of structural change may lead to falsely concluding the actual characteristic of the tested series distribution. According to Perron (1989, 1990), an inaccurate conclusion of having a unit root might be made when there is no allowance of structural change in the series trend function. This further makes the series appear to be stationary at a higher order. In addition, this erroneous finding is further worsened when the sequential cointegration test is carried out, and, finally, inference of a spurious existence of a cointegration relationship between tested series. Inclusion of the structural breaks in the unit root test hypothesis may be turned into rejecting the existence of the unit root at  $I(0)$  in the aforementioned series. To alleviate this, Zivot and Andrews, (1992) allow a break presence in their alternative random walk hypothesis testing. Also, much later, Vogelsang and Perron, (1998) introduced some flexibility

with a break in both the null and alternative hypotheses specified under the unit root test. Moreover, being less restrictive in the number of breaks, Perron (1997), and Lumsdaine and Papell (1997) established a test to cater for such flexibility in their alternative unit root hypothesis test. They emphasized that understating the amount of breaks existing in a series may lead to a misleading characteristic of the tested series.

Previously, in random walk hypothesis testing, it is crucial to detect any structural shift that exists in the series. If there is any, then the inclusion of those breaks may overwhelmingly reject the null hypothesis of the random hypothesis testing. What will happen to the non-linear estimation process (within the ARCH or GARCH framework) if we ignore these breaks? Deibold (1986) is among the first to argue the accuracy of the GARCH model in posturing the tested series volatility without structural changes. He highlights that the presence of structural breaks in volatility may wrongly estimate the volatility persistency parameters. Since then, more attention has been given to the seriousness of the non-inclusion of structural breaks in the volatility estimation process within macroeconomic variables. Rich empirical evidence testing the implication of structural breaks in macroeconomic variables includes GDP growth (see Fang and Miller, 2008; and Fang, Miller and Lee, 2008), exchange rates (Malik, 2003), interest rates (Gray, 1996 and Chan *et al.*, 1992), inflation rates (Benati and Kapetanious, 2002) and stock index (Aggrawal, Inclan and Leal, 1999) *inter alia*. Most evidence infers that the structural break may fallaciously overestimate the volatility persistency parameter. Furthermore, changes in regime is further claimed to improvise the forecasting performance as compared to model without (Hamilton and Susmel, 1994).

Apart from the consequences for omitting structural breaks in volatility clustering estimation results, it is also vital to detect the accurate structural number and dates (Pastor and Stambaugh, 2001). In considering these implications, the breaks identification test is an essential process before researcher can proceed any further in the volatility clustering estimation modelling procedure. Considering the critical process of the structural changes test identification, an overwhelming range of procedures has been introduced over the years. Quandt (1958, 1960) was among the pioneers to introduce a structural changes test (Sup F test) where the break is assumed to be unknown. The test is able to detect a structural break specified under its alternative hypothesis. Subsequently, another issue follows, whether single or multi structural breaks are raised, if we underestimate or overestimate the structural breaks, it will further influence the accuracy of the estimation process (Banerjee and Urga, 2005). The Sup F test has been further improvised by adding more structural breaks in its alternative hypothesis testing (refer Andrew, 1993). In light of multi structural breaks, see Andrew (1993) and Bai and Perron (1998, 2003) for mean regime shift procedure, while Inclan and Tiao (1994) (IT ICSS henceforth) and Sanso *et al.*, (2004) established the procedure within variance series. Many researchers have documented IT ICSS in inferring the presence of structural changes in stock market (Aggrawal, Inclan and Leal, 1999), exchange rate (Rapach and Strauss, 2008) and foreign exchange return (Malik, 2003). The aforementioned evidences focused only on structural changes in variance, but, Engle and Hyung (1999) and Fang, Miller and Lee (2008) concurrently adopted Bai and Perron and IT ICSS test in detecting the existence of any change in mean and variance tested series. Overall, the empirical evidence found some changes in mean or variance tested series. They also acknowledge the significant roles of these breaks in the persistency and forecasting estimation parameter results.

Generally, there are two issues that need to be addressed in most economic and financial second moment economic modelling process. First, the issue of including or omitting the structural break in the second moment modelling process. If there are some structural changes, another concern of equal significance arises, that of identifying the correct number of structural breaks in the tested series. If the series experience structural changes, without these changes, first we may conclude that the series is non-stationary at level. Second, when modelling the series of the second moment, the spurious persistency of variance estimated could possibly be achieved. When variance persistence is spuriously estimated, this leads to a subsequent effect, that is, less efficiency in forecasting activity (Rapach and Strauss, 2008). Additionally, Fang, Miller and Lee (2008) prove that modelling the second moment with breaks will transform the leptokurtic unconditional second moment into the mesokurtic conditional second moment. Understandably, it is considered prudent to examine any structural breaks experience by series before proceeding to the actual second moment modelling activities. Additionally, we are not interested to tackle the first issue where examining the structural break within unit root test but, more towards the implication of structural breaks within volatility estimation process.

### **Methodology:**

This section explains the techniques implemented in this research, begin with the structural break tests and end with the volatility clustering modeling specification. Let  $r_t = \ln(p_t / p_{t-1}) \times 100$  where  $r_t$  denotes return of crude palm oil (CPO henceforth) or crude palm oil futures (FCPO henceforth) at period  $t$ .  $p_t$  represents the CPO and FCPO prices at period  $t$  while  $p_{t-1}$  denotes the price at period  $t-1$ . Using CPO and FCPO returns, we test the presence of structural breaks in the series mean using Bai and Perron test; while, variance via IT ICSS and adjusted IT ICSS test. Ultimately, we modeled the structural breaks (*if any*) in both mean and variance

specification within BEKK-GARCH framework. Each of these tests is discussed in detail in the following sub-sections.

#### **Structural Break Test in Mean:**

The shift in the mean specification is identified by using the Bai and Perron (1998, 2003) (BP henceforth) test. They propose the linear model with  $m$  breaks (or  $m+1$  regimes):

$$y_t = x_t' \beta + z_t' \delta_j + u_t \quad t = T_{j-1} + 1, \dots, T_j \text{ as } j = 1, \dots, m+1 \quad (1)$$

where  $y_t$  denotes the dependent variable at period  $t$ , while  $x_t$  and  $z_t$  are vectors of covariates with dimension  $(p \times 1)$  and  $(q \times 1)$ , respectively. Note that  $\beta$  and  $\delta_j$  are the corresponding beta coefficients for  $x_t$  and  $z_t$ , respectively. Here,  $u_t$  represents the residuals at period  $t$ . The break points are treated as unknown with the convention that  $T_0 = 0$  and  $T_{m+1} = T$  being used. We set  $p=0$ , the model is considered a pure structural change model because all the coefficients are allowed to undergo a regime shift. The least-squares principle is employed to estimate the model.

To determine the number of breaks and their break dates, the BP test uses an efficient dynamic programming algorithm, which is discussed extensively in Bai and Perron (2003). The BP test procedure begins by testing for a single break, and then proceeds with two breaks and so forth. The optimal number of breaks ( $m-1$ ) is evaluated based on the optimal break that gives the lowest sum of squared residuals. BP (2003) also proposes another way of testing for multiple regime shifts in a series. The  $\sup F_T$  type test has a null of no structural break ( $m=0$ ) against an alternative of a fixed number of breaks ( $m=k$ ). The purpose of such a test is to allow the researcher to test for the null of no breaks against a priori knowledge on the number of breaks. In practice, the researcher may not possess any knowledge on the number of breaks and, thus, it is necessary to test for the absence of a break against some unknown number of structural breaks. In such a case, BP proposes using the double maximum tests. There are two types of double maximum test statistics; one is an equal-weight version and is referred to as a UD max  $F_T(M, q)$  and the other uses a proportional weight and is referred to as WD max  $F_T(M, q)$  with  $M=5$  and  $\varepsilon=0.05$ .

Finally, BP (1998) also discuss a test of  $m$  versus  $m+1$  breaks,  $\sup F(m+1|m)$ , which can be used as the basis of a sequential testing procedure. They also suggest using 5 as the maximum number of fixed breaks when performing this  $\sup F$  test. Since the number of observations is considerably high ( $T=3293$ ), we used 5% as the trimming  $\varepsilon$  value.

Based on the overall BP test result, if there is a structural change presence in both the CPO and FCPO series, we then modelled the mean equation as:

$$R_t = \alpha + D_j \quad (2)$$

where  $R_t$  represents the return for CPO or FCPO and  $\alpha$  is the mean intercept. Here  $D_j$  represents the dummy variable that accounts for the regime shift in mean for CPO and FCPO returns and it is defined as  $D_j = 1$  for  $t > \text{Structural break date}$  and zero otherwise.

#### **Structural Breaks Test in Variance:**

To identify for a possible break in the variance of both series, we adopt the iterated cumulative sum of squared residual algorithm (ICSS). According to Inclan and Tiao (1994), the ICSS algorithm conjectures that the second moment behaves in a monotonic fashion except when some perturbations occur to the series, which may alter the behaviour of the series to become non-stationary. The IT ICSS algorithm is able to estimate the existence of changes in variance using the following equation:

$$C_k = \sum_{t=1}^k \varepsilon_t^2 \quad (3)$$

where  $C_k$  represents the cumulative sum of squares of  $\varepsilon_t$  with  $\varepsilon_t$  comprising uncorrelated random variables that have zero mean and constant variance.

Next, the procedure proceeds to calculate the centred cumulative sum of squares (refers to  $D_k$ ) using the following equation:

$$D_k = \frac{C_k}{C_T} - \frac{k}{T}, k = 1, \dots, T, \text{ with } D_0 = D_T = 0 \quad (4)$$

Note that  $D_k$  will display a constant variance up to a point when changes take place in the variance. Changes in the variance capture the structural breaks in the series volatility. However, in the event that there are no breaks in the variance series the  $D_k$  statistic will merge near to zero and vice versa. Further, the significance of those changes will be examined based on the critical value achieved from the null hypothesis of the static variance test against the alternative hypothesis of non-constant variance. A critical value of 1.36 within a 5% significant level is considered for this study. The  $D_k$  statistical test results can comfortably infer the existence of variance changes when the maximum of the absolute value of  $D_k$  is more than the critical value. Letting  $k^*$

represent the  $\max_k |D_k|$ , when the standardization distribution of  $\max_k |D_k|$  or  $\max_k \sqrt{(T/2)} |D_k|$  is situated outside the predetermined boundary, we can consider  $k^*$  as the turning point of variance changes. In the event of more than one change existing in the variance series, the IT ICSS algorithm is able to identify those multiple breaks via plotting the  $D_k$ .

Sanso, Arago and Carrion (2004) extended the IT ICSS algorithm and introduced the  $k_1$  test. Similar to the IT ICSS,  $k_1$  assumes that the residual series is an identical independent distribution with zero mean and constant variance. However, the  $k_1$  test is able to clear the existence of nuisance parameters produced by the IT ICSS test, where  $k_1$  is defined as:

$$k_1 = \sup_k |T^{-1/2} B_k| \quad (5)$$

where  $B_k = \frac{C_k - \frac{k}{T} C_T}{\sqrt{\hat{\eta}_4 - \hat{\sigma}^4}}$ , while  $\hat{\eta}_4 = T^{-1} \sum_{t=1}^T \varepsilon_t^4$  and  $\hat{\sigma}^4 = T^{-1} C_T$ . However, if the residual hold the

zero mean, normally, identically and independently random variable and  $E(\varepsilon_t^4) \equiv \eta_4 < \infty$ , thus  $k_1 \Rightarrow \sup_r |W^*(r)|$ .

Huge empirical evidence postulates most economic and financial series are having a leptokurtic distribution and some persistence in their conditional variance series. Hence, Sanso *et al.*, (2004) introduced  $k_2$  test that able to address this fat tails and persistency problem in those series. The adjusted statistic encompasses:

$$k_2 = \sup_k |T^{-1/2} G_k| \quad (6)$$

$$\text{where } G_k = \hat{\omega}_4^{-1/2} (C_k - \frac{k}{T} C_T) \quad (7)$$

The  $k_2$  test is able to solve both problems by clearly imposing the conditional heteroscedasticity and the disturbance's fourth moment properties via non-parametric adjustment based on the Bartlett kernel. Refer to equation 8,  $\hat{\omega}_4$  is a consistent estimator of  $\omega_4$  and the non-parametric estimator of  $\omega_4$  defined as follows:

$$\hat{\omega}_4 = \frac{1}{T} \sum_{t=1}^T (\varepsilon_t^2 - \hat{\sigma}^2)^2 + \frac{2}{T} \sum_{l=1}^m \omega(l, m) \sum_{t=1}^T (\varepsilon_t^2 - \hat{\sigma}^2)(\varepsilon_{t-l}^2 - \hat{\sigma}^2) \quad (8)$$

where  $\omega(l, m)$  represents the lag window and this lag window refers to the quadratic spectral  $[1 - l/(m+1)]$ . The bandwidth  $m$  is selected by Newey-West (1994) techniques. If the general assumption is satisfied, the  $k_2$  test will produce the same asymptotic distribution as in the IT ICSS test and, further, construct a finite sample critical value.

Referring to Sanso *et al.*, (2004), they recommend the  $k_2$  test as a powerful structural break test for variance. It is said that the test results are free from any size distortion and the procedure gives a more reliable number of breaks than the IT and  $k_1$  test. In addition, the non-normality features in most financial series may influence both IT and  $k_1$  to give a less accurate number of structural breaks than exist in these series variance. Hence, this study will implement the IT,  $k_1$  and  $k_2$  techniques to infer the presence of potential structural breaks in both CPO and FCPO returns. We then compare these three tests results and choose which test gives more sensible structural changes in both returns.

#### **Bekk-Garch Model:**

To investigate the implication of structural breaks in volatility clustering estimation process, we consider BEKK model developed by Engle and Kroner (1995) which allows capturing the behavior of conditional variance and covariance in two variables simultaneously. One of the advantages of the model is the ability of such model to maintain the positive definiteness of the estimated parameters. The BEKK-GARCH model without Structural Break defines as follows:

$$Y_t = \alpha + \varepsilon_t, \quad \varepsilon_t | I_{t-1} \approx N(0, H_t) \quad (9)$$

$$H_t = C^* C^* + \sum_{k=1}^K A_k^* \varepsilon_{t-1} \varepsilon_{t-1}' A_k^* + \sum_{k=1}^K G_k^* H_{t-1} G_k^* \quad (10)$$

where  $Y_t$  refers to returns for CPO or FCPO at period  $t$ . While,  $\alpha$  represents the constant term and  $\varepsilon_t$  is the residual term.  $I_{t-1}$  is the information given at period  $t-1$ . Then,  $H_t$  is the conditional variance and covariances. In

equation 10, where  $C^* = \begin{bmatrix} c_{ss} & c_{sf} \\ 0 & c_{ff} \end{bmatrix}$ ,  $A_k^* = \begin{bmatrix} a_{ss} & a_{sf} \\ a_{fs} & c_{ff} \end{bmatrix}$  and  $G_k^* = \begin{bmatrix} g_{ss} & g_{sf} \\ g_{fs} & g_{ff} \end{bmatrix}$ . While,  $\varepsilon_t = \begin{bmatrix} \varepsilon_{ss} \\ \varepsilon_{ff} \end{bmatrix}$  and

$$H_t = \begin{bmatrix} H_{ss} & H_{sf} \\ H_{fs} & H_{ff} \end{bmatrix}. K \text{ is the summation limit, which determines the model generality and } K \text{ is assumed to be } 1.$$

Next, based on the BP test and both ICSS test and adjusted ICSS test results, if the results strongly support the presence of breaks in both CPO and FCPO mean return and variances, we then consider the BEKK-GARCH model with Structural Break. The model can be estimated:

$$Y_t = \alpha_0 + \alpha_1 MD_t + \varepsilon_t, \quad \varepsilon_t | I_{t-1} \approx N(0, H_t) \quad (11)$$

$$H_t = C^* C^* + \sum_{k=1}^K A_k^* \varepsilon_{t-1} \varepsilon_{t-1}' A_k^* + \sum_{k=1}^K G_k^* H_{t-1} G_k^* + \sum_{k=1}^K C1_k^* D1_t C1_k^* \quad (12)$$

where  $MD_t$  is a the dummy break in the mean equation, while,  $D1_t$  is equal to 1 if  $t > k$  and zero otherwise,  $k$  equals the date of the break in the conditional mean (based on the breaks date given in BP tests). While,  $D1_t$  refers to the dummy variables in variance (the structural break date will be based on ICSS tests results). And  $C1^*$  is the  $N \times N$  matrices that represent the coefficient for the dummy variables for structural breaks (if any).

#### Data:

The data comprises of daily settlement prices for both CPO and FCPO for Malaysian commodity market. CPO prices are generated from Malaysia Palm Oil Board (MPOB) which represents the CPO spot commodity market. Meanwhile, FCPO prices are collected from Bursa Malaysia Derivative Berhad and Bloomberg databases. The study covers the period between 2<sup>nd</sup> January 1996 and 15<sup>th</sup> August 2008 that cater for prior Asian Financial Crisis until Global Financial crisis in 2007. Since its establishment in 80's, Malaysian CPO markets are considered as the most actively traded commodity derivative emerging market. A sustainable large global demand and growth in biodiesel technology spur the promising demand and made Malaysia as one of the world's top net exporters for CPO. Further, a consistently sound policy implemented by Malaysian government in improvising the production capacity has spurred the production of vegetable oil. FCPO is the first commodity futures product introduced in Malaysia's futures commodity market. It was much later that the crude palm oil kernel and the US denominated CPO futures is introduced.

Table 1 summarizes the statistical properties for both tested series. CPO has a wider range of return compared with FCPO. FCPO returns have exhibited a slightly higher standard deviation than CPO returns. Both returns have shown a non-symmetric distribution, where FCPO (CPO) return distribution being positively (negatively) skewed. The non-normality feature in both returns series were proved by the excess kurtosis and Jarque-Bera test results. The serial correlation and ARCH test with 9 and 15 lagged orders showed that both the CPO and FCPO returns have a strong autocorrelation and ARCH problem. With the non-normality and fat tail distribution characteristic, we employed the GARCH framework in modeling the volatility features in tested series.

**Table 1 :** Statistical Properties for CPO and FCPO returns.

|      | Mean   | Median | Max     | Min     | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Q(9)   | Q(15)  | Q <sup>2</sup> (9) | Q <sup>2</sup> (15) |
|------|--------|--------|---------|---------|-----------|----------|----------|-------------|--------|--------|--------------------|---------------------|
| CPO  | 0.0184 | 0.0000 | 15.2925 | -14.078 | 1.5019    | -0.0805  | 16.3897  | 24603.05    | 19.707 | 40.272 | 505.98             | 575.93              |
|      |        |        |         |         |           |          |          | 0           | -0.012 | 0      | 0                  | 0                   |
|      |        |        |         |         |           |          |          |             |        |        |                    |                     |
|      | Mean   | Median | Max     | Min     | Std. Dev. | Skewness | Kurtosis | Jarque-Bera | Q(9)   | Q(15)  | Q <sup>2</sup> (9) | Q <sup>2</sup> (15) |
| FCPO | 0.0196 | 0.0000 | 13.8469 | -10.016 | 1.6200    | 0.2265   | 9.5267   | 5872.988    | 25.332 | 30.779 | 446.84             | 600.81              |
|      |        |        |         |         |           |          |          | 0           | -0.001 | 0      | 0                  | 0                   |

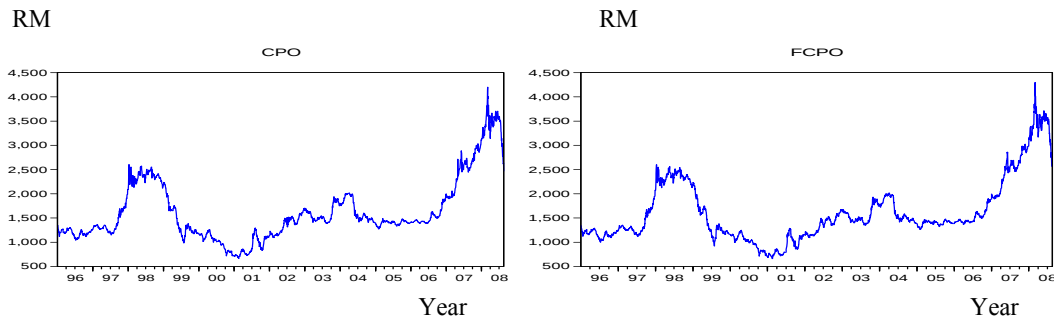
P-value are provided in parentheses for Jarque-Bera, Q(9), Q(15), Q<sup>2</sup>(9) and Q<sup>2</sup>(15).

Figure 1 presents both CPO and FCPO prices for the period between January 1996 and August 2008. These series tend to establish a homogeneous pattern, and we can assume these series are likely to move together. During the Asian Financial Crisis, crude palm oil prices recorded a steep hike from RM1,300 per metric tonne in mid 1997 to RM2,500 per metric tonne in early 1998. During the same period, the CPO production increased due to a good biological yield cycle during that particular year. Later, a tranquil movement in CPO and FCPO prices was registered after the Asian financial crisis, from 1999 up unto 2006. Another dramatic price movement was exhibited in early 2007 and thereafter the CPO price reached its peak at almost RM4,000 per metric tonne

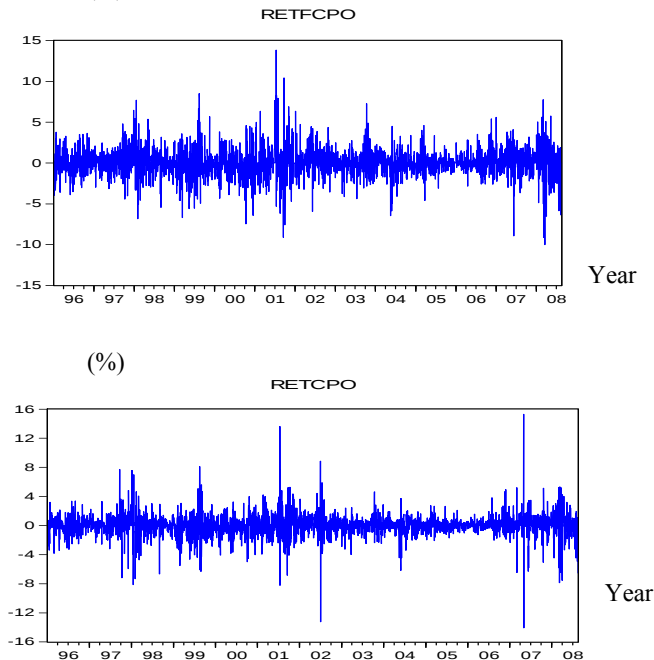
in early 2008. In spite of the global recession starting in early 2007, these prices were pushed up by a slower CPO production. The short supply was due to the weather conditions that affected the level of CPO production during that specific period. Furthermore, the lower production was also due to the seasonal downcycle during that year. The supply shortage continued into 2008, supported by the robust global demand for such commodities, boosting the price to the highest amount during that period.

Refer to volatility plotting in Figure 2, the CPO returns experienced the most turbulent period in 2001 and again in 2007. However, in 2007 a less volatile movement was reported for FCPO returns. A more uncertain movement was continuously exhibited in FCPO from 1997 up to its peak in year 2001. During the Asian financial crisis, both series experienced a highly volatile pattern, similarly, during the current global recession and commodity production pressure.

Based on the above evidence, we can conclude that both series, prices or returns, presented certain regime changes throughout 1999 to 2008. These changes were contributed from the local and external factors that directly or indirectly affect those series movements. The CPO prices and returns volatility were more affected by the sudden market condition from the United States than its own surrounding turbulence (such as the Asian Financial Crisis). For internal factors, the supply or production forces play a critical role in making this vegetable oil's price and returns more variable. While the demand function is less likely to make the returns more uncertain because of the strong consistent global demand for the vegetable oil. The current jump in crude oil prices made many countries search for an alternative source of energy such as biofuels and spurred the CPO demand curve. In addition, the CPO is also largely used in the food processing industry, especially in China and India, which strengthened the CPO demand over time.



**Fig. 1:** Plot for CPO and FCPO prices. (a) : Plot for CPO prices (b): FCPO prices. (%)



**Fig. 2:** Plot for CPO and FCPO returns. (a): Plot for CPO returns. (b): Plot for FCPO returns.

### **Empirical Result:**

#### **ICSS Tests Results:**

We adopted IT ICSS and adjusted ICSS ( $k_1$  and  $k_2$ ) tests and the results are presented in Appendix A. The IT ICSS results identified 41 breaks present in the CPO variance, while only 12 breaks were confirmed by the  $k_1$  ICSS test results. The similar variance break dates detected by both the IT and  $k_1$  ICSS tests were 14/04/1997, 19/09/1997, 02/01/1998, 10/03/1998, 08/09/1999, 01/10/2001, 05/08/2002, 25/03/2005 and 24/10/2005. In addition, the  $k_1$  test identified additional breaks 07/10/1996, 10/05/1999 and 02/08/1999. However, no structural breaks were reported under the  $k_2$  test.

By referring to the FCPO, the IT ICSS proved fewer breaks than posited in the CPO variance while similar break numbers were shown in the  $k_1$  test. There were 22 breaks for IT ICSS and 11 breaks in the variance series. However, only four breaks were recognized by the  $k_2$  test. All three tests have one similar structural date, which was 31/10/1996. In addition, both the IT and  $k_1$  consistently identified breaks on 31/10/1996, 20/10/1997, 26/12/1997, 12/02/1998, 08/09/1998, 01/04/2005, and 31/03/2006. However, the  $k_1$  further identified new structural changes in variance present on 02/07/2001 and 11/01/2008. Finally, one new structural change was detected from  $k_2$ 's four breaks, which was located on 18/03/2008.

Based on the findings, obviously most of the breaks occurred during the Asian Financial Crisis (within 1997 and 1998) and post Asian Financial Crisis in 1999 where the Malaysian government placed a capital control and pegged the Malaysian Ringgit against the US Dollar. Locally, the volatility during this period might be contributed from a generous growth in production that was due to a good biological cycle for the commodity. Another break was registered in October 2001, a few weeks after the terrorist attacks in the US. However, the structural change in the variance CPO return is not directly hurt by this event. The attack had an almost instantaneous affect on the US stock markets and contagiously towards the global stock markets volatility. This series variance changes tend to be influenced by domestic forces, which consist of CPO production shortage (lower biological cycle) and more markets towards the stock markets movement. In addition, the intense competition with other vegetable oil (soy oil, rapeseed oil and sunflower oil) producers who increased their production may have made the CPO market more volatile that year.

The lower production continued to be experienced in 2002, partly due to the low biological cycle of the CPO trees, and the unstable weather, which might have contributed to the supply shortage. These factors further pressured the CPO markets and explicitly translated into volatility in CPO returns. The oil price shocks in 2005 and 2006 further benefited the CPO producers. The popularity of the biofuel as another energy option increased the world CPO demand curve and pushed the price further. The downward supply in other vegetable oils and fats in 2005 made the CPO prices fluctuate more.

The final structural breaks in CPO variance were identified in March 2008, which were due to the global recession that was triggered by the US Mortgage Sub Prime crisis in early 2007. The global recession caused countries to implement measures to strengthen their liquidity and financial infrastructure. This pressure further translated into a downward trend in the oil and commodity prices, which includes CPO. In addition, the level of CPO production was very encouraging along with the great support from the world demand for such oil during that period. In addition, a weak production by other vegetable oil producers is believed to have further secured the CPO prices. Nevertheless, the current global turmoil has heightened the uncertainty in the movement of CPO prices, which overshadowed the good CPO demand forces.

#### **Bai and Perron Test Results:**

Table 2 and 3 summarize the BP test results for CPO and FCPO returns respectively. In Table 2, the sup  $F_T(1)$  test is virtually insignificant at all three levels of significance. However, a contradictory result was given when we tested at sup  $F_T(2)$ . The result exhibits two potential structural breaks in the CPO mean at the 5% level of significance. These two breaks were further validated via the sup  $F_T(m+1|m)$  test results. This indicates that the sup  $F_T(2|1)$  is significant at 10% and similarly suggests the existence of two changes in the mean tested series. In contrast, when referring to sequential procedure, the BIC and LWZ, these three tests unfailingly select no structural break. This is an inevitable result as the earlier sup  $F_T(1)$  test is statistically not significant; therefore, these three tests will definitely portray a similar result to sup  $F_T(1)$ . In sum, the existence of two breaks are strongly supported by the significant results in sup  $F_T(2)$ , sup  $F_T(2|1)$ , UD max and WD max tests. Intuitively, we can conclude that two significant structural changes exist in the CPO mean between January 1996 and August 2008.

Moreover, two structural breaks were located at 09/11/1998 and 28/07/1999. In order to verify the changes of mean that took place during these two break dates, we divide the observation into three sub-periods – 03/01/1996-06/11/1998 (SB 1), 09/11/1998-27/07/1999 (SB 2) and, finally, 28/07/1999-15/08/2008 (SB 3). Next, we included two dummy variables in the mean equation to cater for these two shift periods. Both the dummy coefficients are highly significant and further strengthen the structural shift in mean within these three sub-periods. The mean estimation model indicated a positive mean of 0.0788 and 0.0379 in the first and third sub-period, while a negative mean was reported in the second sub-period (-0.4693).

**Table 2:** CPO return (3 Jan 1996 – 15 Aug 2008).

| Specifications                      |                  |                       |       |                       |  |                       |  |                       |         |              |
|-------------------------------------|------------------|-----------------------|-------|-----------------------|--|-----------------------|--|-----------------------|---------|--------------|
| zt = {1}                            |                  | q = 1                 |       | p = 0                 |  | h = 164               |  | M = 5                 |         | ε = 0.05     |
|                                     |                  |                       |       |                       |  |                       |  |                       |         |              |
| Tests                               |                  |                       |       |                       |  |                       |  |                       |         |              |
| SupF <sub>T</sub> (1)               |                  | SupF <sub>T</sub> (2) |       | SupF <sub>T</sub> (3) |  | SupF <sub>T</sub> (4) |  | SupF <sub>T</sub> (5) | UDmax   | WDmax        |
| 3.9760                              |                  | 9.1476**              |       | 5.8430                |  | 5.8125                |  | 6.2259                | 9.1476* | 9.322*       |
|                                     |                  |                       |       |                       |  |                       |  |                       |         |              |
| SupF(2 1)                           |                  | SupF(3 2)             |       | SupF(4 3)             |  | SupF(5 4)             |  |                       |         |              |
| 10.0667*                            |                  | 3.7193                |       | 3.2390                |  | 2.9660                |  |                       |         |              |
|                                     |                  |                       |       |                       |  |                       |  |                       |         |              |
| Number of Breaks Selected           |                  |                       |       |                       |  |                       |  |                       |         |              |
| Sequential                          |                  | 0                     |       |                       |  |                       |  |                       |         |              |
| LWZ                                 |                  | 0                     |       |                       |  |                       |  |                       |         |              |
| BIC                                 |                  | 0                     |       |                       |  |                       |  |                       |         |              |
|                                     |                  |                       |       |                       |  |                       |  |                       |         |              |
| Structural Breaks Date              |                  |                       |       |                       |  |                       |  |                       |         |              |
|                                     |                  |                       |       |                       |  |                       |  |                       |         |              |
| SB 1:                               | 09/11/1998 (744) |                       | SB 2: | 28/07/1999 (931)      |  |                       |  |                       |         |              |
| Parameter Estimates with Two Breaks |                  |                       |       |                       |  |                       |  |                       |         |              |
|                                     |                  |                       |       |                       |  |                       |  |                       |         |              |
| α                                   |                  | D1                    |       | D2                    |  | Sub Period 1          |  | Sub Period 2          |         | Sub Period 3 |
| 0.0788                              |                  | -0.5481               |       | 0.5072                |  | 0.0788                |  | -0.4693               |         | 0.0379       |
| (0.0549)                            |                  | (0.1225)***           |       | (0.1137)***           |  | 03/01/1996 -          |  | 09/11/1998 -          |         | 28/07/1999 - |
|                                     |                  |                       |       |                       |  | 6/11/1998             |  | 27/07/1999            |         | 15/08/2008   |

Notes:

Standard errors are given in the parentheses

\*\*\* represents 1 % level of significance,\*\* represents 5 % level of significance and \* represents 10 % level of significance.

The supF<sub>T</sub>(k) tests with autocorrelation allowance in its disturbances. Further follow Andrews (1991) and Andrews and Monahan (1992), the covariance matrix with autocorrelation and heteroscedasticity is constructed adopting a quadratic kernel (an automatic bandwidth using AR(1) approximation). While, the errors are pre-whitened using VAR(1).

**Table 3:** FCPO return (3 Jan 1996 – 15 Aug 2008).

| Specifications                      |  |                       |  |                       |  |                       |  |                       |         |              |
|-------------------------------------|--|-----------------------|--|-----------------------|--|-----------------------|--|-----------------------|---------|--------------|
| zt = {1}                            |  | q = 1                 |  | p = 0                 |  | h = 164               |  | M = 5                 |         | ε = 0.05     |
| Tests                               |  |                       |  |                       |  |                       |  |                       |         |              |
| SupF <sub>T</sub> (1)               |  | SupF <sub>T</sub> (2) |  | SupF <sub>T</sub> (3) |  | SupF <sub>T</sub> (4) |  | SupF <sub>T</sub> (5) | UDmax   | WDmax        |
| 4.2273                              |  | 8.8389**              |  | 7.5893*               |  | 5.8110                |  | 6.7800**              | 8.8389* | 9.0074       |
| SupF(2 1)                           |  | SupF(3 2)             |  | SupF(4 3)             |  | SupF(5 4)             |  |                       |         |              |
| 9.7387**                            |  | 3.9313                |  | 2.4722                |  | 2.4722                |  |                       |         |              |
| Number of Breaks Selected           |  |                       |  |                       |  |                       |  |                       |         |              |
| Sequential                          |  | 0                     |  |                       |  |                       |  |                       |         |              |
| LWZ                                 |  | 0                     |  |                       |  |                       |  |                       |         |              |
| BIC                                 |  | 0                     |  |                       |  |                       |  |                       |         |              |
| Structural Breaks Date              |  |                       |  |                       |  |                       |  |                       |         |              |
| SB 1:                               |  | 01/12/1998 (760)      |  | SB 2:                 |  | 30/07/1999 (933)      |  |                       |         |              |
| Parameter Estimates with Two Breaks |  |                       |  |                       |  |                       |  |                       |         |              |
| α                                   |  | D1                    |  | D2                    |  | Sub Period 1          |  | Sub Period 2          |         | Sub Period 3 |
| 0.0711                              |  | -0.5962               |  | 0.5681                |  | 0.0711                |  | -0.5251               |         | 0.043        |
| (0.0586)                            |  | (0.1360)***           |  | (0.1272)***           |  | 03/01/1996 -          |  | 01/12/1998-           |         | 30/07/1999-  |
|                                     |  |                       |  |                       |  | 30/11/1998            |  | 29/07/1999            |         | 15/08/2008   |

Notes:

Standard errors are given in the parentheses.

\*\*\* represents 1 % level of significance,\*\* represents 5 % level of significance and \* represents 10 % level of significance.

The supF<sub>T</sub>(k) tests with autocorrelation allowance in its disturbances. Further follow Andrews(1991) and Andrews and Monahan (1992), the covariance matrix with autocorrelation and heteroscedasticity is constructed adopting a quadratic kernel (an automatic bandwidth using AR(1) approximation). While, the errors are pre-whitened using VAR(1).

Empirical evidence infers that the futures market tends to move together with the spot market. With reference to the evidence, we conjectured that there is a tendency in the mean FCPO returns to undergo potential structural changes similar to the CPO returns. In Table 5.11, both the sup F<sub>T</sub>(1) and sup F<sub>T</sub>(4) exhibited similar insignificance at any 10%, 5% and 1% alpha value. However, when testing sup F<sub>T</sub>(k) at 2, 3 and 5, successfully the test highly rejects the null hypothesis of no structural breaks and accepts the existence of 2 and 5 potential structural shifts in FCPO mean returns at the 5% level of significance. The test results also show three breaks at the 10% level of significance. However, when referring to the sup F<sub>T</sub>(m+1|m) test, the results validated two structural breaks, but not for the other higher level than the supF<sub>T</sub>(2|1) test results. Meanwhile, a contrary result

was reported between UD max and WD max test results, where UD max is positively significant at 10%, but WD max is not significant. Unlike other tests, the sequential procedure, LWZ and BIC were found to establish a similar conclusion to the CPO return. There were no breaks reported under these three procedures. With similar reasons to the CPO return, the non existence of breaks identified was due to the trivial result given in the sup  $F_T(1)$ .

Summarizing all these related results, the sup  $F_T(2)$ , sup  $F_T(2|1)$  and UD max test supported the presence of two breaks in the FCPO mean return. Hence, we can comfortably accept the existence of two breaks, and proceed to include the two dummy variables, which represent these shifts in the FCPO mean estimation model. The break dates were on 01/12/1998 and 30/07/1999, which were less than a month away from the CPO returns breaks. Similar to CPO, we then demarcated the full sample period into three sub-periods consisting of 03/01/1996-30/11/1998, which represented sub-period 1, 01/12/1998-29/07/1999 for sub-period 2 and 30/07/1999-15/18/2008 for sub-period 3. Consistent with the CPO return, the evidence indicates the significance of both regime shifts in the FCPO mean estimation model. Moreover, the beta coefficient for dummy 1 was substantially reduced to 0.5962 during the second sub-period. Subsequently, the coefficient increased to 0.5681 for the respective sub-period. In conclusion, these findings infer the significance of two breaks affecting both the CPO and FCPO mean return between January 1996 and August 2008.

In relation to external factors, the breaks occurred within the post Asian financial crisis and, domestically, the CPO market performance was caused by a generous production in such oil during that period (Source: BNM Annual Report 1997/1998). Interestingly, the mean shift is much lower than the variance structural breaks occurring in both series. This is logical as both returns volatility are sensitive to external and internal events. The sensitivity may influence the trading reaction of producers and buyers (as hedgers, speculators or arbitragers), which may push the commodity prices either downwards or upwards.

#### ***Bekk-Garch Estimation:***

In this subsection we present the variance and covariances estimation for both series generated from BEKK-GARCH framework. Appendix B reports the parameter estimation results for both selected volatility models. The estimation for BEKK-GARCH without Structural breaks model presents in the first column, then a BEKK-GARCH with structural breaks in mean and variance estimation results in the second column. The first mean model's estimation failed to prove any significant results in its intercept. However, when structural breaks were taken into consideration in the mean model, the intercepts and those dummy variables (represent the structural breaks in mean) turned to be highly significant. Further, the variance estimation findings postulate quite similar results in the CPO series. Both variance estimation models' results virtually failed to find any significant results in either the variances lagged term (refer to  $G$  parameters) or in its residual terms (refer to  $A$  parameters). However, when we modelled the breaks in the FCPO variances series a slightly different conclusion can be made.

The findings indicate that the FCPO variance is highly related to the innovation of its own variances lagged term ( $G_f$  coefficient) but there is no evidence for its own residuals term. This evidence simply means that the movement of FCPO volatility is highly dependence on its previous volatility movement. Additionally, the FCPO volatility was not influenced by the FCPO own shock. Surprisingly, among four break dummy variables (refer to  $C1_f$ ,  $C2_f$ ,  $C3_f$  and  $C4_f$  coefficients) in the FCPO variance specification, only  $C4_f$  coefficient is proven to be strongly significant. This result proved that there is a significant structural break effect which located in the recent global financial crisis (18 March 2008) towards the current FCPO volatility movement. Nevertheless, when referring to the covariances estimation (see  $A_{sf}$ ,  $A_{fs}$ ,  $G_{sf}$  and  $G_{fs}$ ), both models demonstrate identical evidence that the CPO and FCPO covariances are highly influenced by both the residuals and variance lagged term. The study further examines whether there is any implication of structural break into volatility persistency. Considerable empirical evidence does support the crucial role of a break in volatility clustering modelling, which may overemphasize the actual variance persistency (Aggrawal, Inclan and Leal, 1999; Malik, 2003; Fang, Miller and Lee, 2008; and Fang and Miller, 2008). It is worth noting that the evidence was generated from a simple ARCH or GARCH framework. When we look at the persistency, the FCPO persistency is consistent with the existing body of literature where the structural break reduced the variance persistency (refer to  $A+G$ ) from 1.15 to 0.93. This finding has proved that without the structural break in modelling the volatility clustering process leads to inaccurate persistency estimation results.

In contrast to the FCPO, the CPO variance persistency merely increased (from 0.95 to 1.08) when we modelled the breaks in its mean specification, not in the CPO variance (since no breaks were reported in the  $k_2$  test result). It is noteworthy that this research applied a much more complex model, the BEKK model, as it was foreseen that the result may potentially provide a unique variance estimation feature rather than the other empirical evidence. In addition, the structural break BEKK model for the FCPO is able to overcome the serial correlation, but not for the CPO. Although the CPO failed to account for the serial correlation and ARCH effect, such results are still expected as the mean model is only run on the intercept not using the AR or MA mean model (used in Fang, Miller and Lee, 2008; and Fang and Miller, 2008). The finding asserts that when there is

any structural break, it is an important element to include in the volatility clustering modelling as it influences the accuracy of volatility parameters estimation.

### Conclusion:

In this study, we illustrate the structural changes analysis in the Malaysian CPO and FCPO market. Our analysis acknowledges the presence of structural breaks in the series mean and variance tested series. The investigation further adopts three structural breaks techniques – the Bai and Perron procedure for mean, and both IT and adjusted IT ICSS algorithm for variance. Finally, we investigate the implication of excluding structural breaks in the persistency parameters estimation results.

Our findings identified two structural changes in both CPO and FCPO return mean around late 1998 and 1999. In addition, the ICSS test results identified a significant number of regime changes in the variance series. IT ICSS and  $k_1$  test results substantiate more breaks for both series compared to  $k_2$  (similar to Sanso *et al.*, 2004). The three test results exhibited structural changes between 1997 and 1998, late 2001, 2002, between 2005 and 2006 and, finally, 2008. It is not an easy task to model all the breaks detected in IT and  $k_1$  test results. Therefore, for the purpose of the volatility modelling procedure we confidently select the breaks identified by the  $k_2$  test dated late 1996, late 2001 and early 2008 (only applicable to FCPO).

**Appendix A: ICSS Algorithm Results (Structural Breaks in Variance).**

|      | ICSS (IT)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | ICSS ( $k_1$ )                                                                                                                                                                                                    | ICSS ( $k_2$ )                                                          |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| CPO  | 05/11/1996 (220),16/04/1997 (336),19/09/1997 (448),13/10/1997(464),02/01/1998 (523),10/03/1998(570),04/08/199 (675), 31/08/1998 (694),10/09/1998 (702),27/01/1999 (801),26/07/1999(929),08/09/1999 (961),01/10/2000(1239),14/12/2000 (1292),26/06/2001(1430),11/07/2001 (1441),17/07/2001(1445),15/12/2001 (1532),01/07/2002(1694),03/07/2002 (1696),05/08/2002(1719),07/04/2003 (1894),19/09/2003(2013),21/11/2003(2058), 01/03/2004 (2129),09/04/2004 (2158),13/05/2004 (2182),04/06/2004(2198),25/03/2005 (2408),24/10/2005(2559),30/06/2006(2738) ,02/11/2006 (2827),30/04/2007 (2954),03/05/2007 (2957),24/05/2007(2972),20/06/2007 (2991),18/10/2007(3077),22/10/2007(3079), 10/01/2008 (3137),28/02/2008 (3172),02/04/2008 (3196),18/07/2008 (3273). | 07/10/1996 (199),16/04/1997 (336), 19/09/1997 (448), 02/01/1998 (523),10/03/1998 (570),10/05/1999(875), 02/08/1999 (934),08/09/1999 (961),01/10/2000(1239), 05/08/2002(1719),25/03/2005 (2408),24/10/2005 (2559). |                                                                         |
| FCPO | 31/10/1996 (217),15/09/1997 (444), 20/10/1997 (469),26/12/1997 (518),12/02/1998 (552),08/09/1998(700),20/01/1999(796), 01/07/1999 (912),27/08/1999 (953),03/10/2000 (1240),21/03/2001(1361),12/06/2001 (1420),02/10/2001(1500),14/12/2001(1553), 01/04/2005 (2413),03/10/2005 (2544),31/03/2006 (2673),27/10/2006(2823),28/02/2008 (3172),01/04/2008(3195),13/05/2008(3225), 18/07/2008 (3273).                                                                                                                                                                                                                                                                                                                                                             | 31/10/1996 (217),15/09/1997 (444),20/10/1997(469), 26/12/1997 (518),12/02/1998 (552),08/09/1998(700), 02/07/2001(1434), 16/01/2002(1576), 01/04/2005(2413), 31/03/2006(2673), 11/01/2008 (3138).                  | 31/10/1996 (217),02/07/2001 (1434),02/10/2001 (1500),18/03/2008 (3185). |

\* Position of the observation where the break is identified represents in the brackets.

Obviously the mean experienced some regime changes after the Asian financial crisis, however, the variance underwent a shift within the pre and during the crisis. In addition, external variance suffered more changes post-terrorist attack, during the oil price shock and recent global economic crisis. Based on internal events, the variance structural changes are attributable to the uncertain production level caused by a lower biological cycle for the palm trees, production level of other vegetable oil producers and weather volatility. Additionally, the changes in both CPO and FCPO mean are observed as a result of the outstanding production performance of crude palm oil. Ultimately, the volatility clustering finding gives very distinctive evidence where the CPO persistency parameters have slightly increased when structural breaks are taken into account in the estimated model. In contrast, the FCPO exhibits a lower persistency estimation when structural changes are considered. Similar to previous studies, our findings support the importance of testing these structural break identification techniques, in ensuring the accuracy of the volatility characteristic estimation results in any tested series.

## ACKNOWLEDGEMENT

We would like to thank Dr Sandy Suardi from the Faculty of Law and Management, La Trobe University, Australia for his contribution.

## Appendix B: Maximum Likelihood Estimation Results.

| Coefficient   | BEKK-GARCH  | BEKK-GARCH SB |
|---------------|-------------|---------------|
| $\alpha_{0s}$ | -0.020481   | -0.119361***  |
| $\alpha_{0f}$ | -0.002272   | -0.07920***   |
| $\alpha_{1s}$ |             | 0.09261***    |
| $\alpha_{1f}$ |             | 0.05591***    |
| $\alpha_{2s}$ |             | 0.02900***    |
| $\alpha_{2f}$ |             | 0.01156       |
| $C_s$         | -0.106206   | -0.11778      |
| $C_{sf}$      | 0.47601***  | 0.44783***    |
| $C_f$         | -0.000032   | -0.00162      |
| $C1_f$        |             | -0.00054      |
| $C2_f$        |             | -0.00070      |
| $C3_f$        |             | 0.00090       |
| $C4_f$        |             | 0.48649***    |
| $A_s$         | -0.28932    | 0.32757       |
| $A_{sf}$      | -1.01909*** | 1.10778***    |
| $A_{fs}$      | -0.68887*** | 0.63655*      |
| $A_f$         | 0.08844     | -0.14306      |
| $G_s$         | 0.18714     | -0.19100      |
| $G_{sf}$      | -0.42696*** | 0.36523*      |
| $G_{fs}$      | -0.26063*** | -0.19356**    |
| $G_f$         | -0.10775    | -0.29306***   |
| LR            | -10744.54   | -10752.35     |

Notes:

\*\*\* represents 1 % level of significance, \*\* represents 5 % level of significance and \* represents 10 % level of significance.

BEKK-GARCH represents the BEKK-GARCH without the structural break and the mean specification and variance specification are as follows:

**Mean Specification:**

$$Y_t = \alpha_0 + \varepsilon_t,$$

**Variance Specification:**

$$H_t = C^* C^* + \sum_{k=1}^K A_k^* \varepsilon_{t-1} \varepsilon_{t-1}' A_k^* + \sum_{k=1}^K G_k^* H_{t-1} G_k^*$$

And, BEKK-GARCH SB represents the BEKK-GARCH with structural breaks in mean and variance specification.

The specification as follows:

**Mean Specification:**

$$Y_t = \alpha_0 + \alpha_1 MD1_t + \alpha_2 MD2_t + \varepsilon_t,$$

Where:

MD1<sub>t</sub> = 1 for t > 09:11:1998 otherwise 0 and MD2<sub>t</sub> = 1 for t > 28:07:1999 otherwise 0 for CPO

MD1<sub>t</sub> = 1 for t > 01:12:1998 otherwise 0 and MD2<sub>t</sub> = 1 for t > 30:07:1999 otherwise 0 for FCPO

**Variance Specification:**

$$H_t = C^* C^* + \sum_{k=1}^K G_k^* H_{t-1} G_k^* + \sum_{k=1}^K A_k^* \varepsilon_{t-1} \varepsilon_{t-1}' A_k^* + \sum_{k=1}^K C1_k^* D1_t C1_k^* + \sum_{k=1}^K C2_k^* D2_t C2_k^* + \sum_{k=1}^K C3_k^* D3_t C3_k^* + \sum_{k=1}^K C4_k^* D4_t C4_k^*$$

Where:

D1f=1 for  $t > 31:10:1996$  otherwise 0, D2f=1 for  $t > 02:07:2001$  otherwise 0, D3f=1 for  $t > 02:10:2001$ , and D4f=1 for  $t > 18:03:2008$  for FCPO.

## REFERENCES

- Aggarwal, R., C. Inclan and R. Leal, 1999. Volatility in Emerging in Stock Markets. *Journal of Financial and Quantitative Analysis*, 34: 33-55.
- Andreou, E. and E. Ghysels, 2002. Detecting Multiple Breaks in Financial Market Volatility Dynamics. *Journal of Applied Econometrics*, 17(5): 579-600.
- Andrew, D.W.K., 1993. Test for Parameter Instability and Structural Change with Unknown Change Point. *Econometrica*, 62: 821-856.
- Bai, J. and P. Perron, 1998. Estimating and Testing Linear Models with Multiple Structural Changes. *Econometrica*, 66: 47-78.
- Bai, J. and P. Perron, 2003. Computation and Analysis of Multiple Structural Change Models. *Journal of Applied Econometrics*, 18: 1-22.
- Bailie, R.T. and R.J. Myers, 1991. Bivariate GARCH Estimation of the Optimal Commodity Futures Hedge. *Journal of Applied Econometrics*, 6(2): 109-124.
- Banerjee, A. and G. Urga, 2005. Modelling Structural Breaks, Long Memory and Stock Market Volatility: On Overview. *Journal of Econometrics*, 129: 1-34.
- Bekaert, G., C. Harvey and R. Lumsdaine, 2002. The Dynamics of Emerging Market Equity Flows. *Journal of International Money and Finance*, 21(3): 295-350.
- Beltratti, A. and C. Morana, 2006. Breaks and Persistency: Macroeconomic Causes of Stock Market Volatility. *Journal of Econometrics*, 131: 151-177.
- Benati, L. and G. Kapetanios, 2002. Structural Breaks in Inflation Dynamics. Unpublished Manuscript. University of London.
- Chan, K.C., G.A. Krolly, F.A. Longstaff and A.B. Sanders, 1992. An Empirical Comparison of Alternative Models of the Short-Term Interest Rate. *The Journal of Finance*, 47(3): 1209-1227.
- Chaudhuri, K. and Y. Wu, 2003. Random Walk versus Breaking Trend in Stock Prices: Evidence from Emerging Markets. *Journal of Banking & Finance*, 27: 575-592.
- Chu, C.J., 1995. Detecting Parameter Shifts in GARCH Models. *Econometric Reviews*, 14: 241-266.
- Deibold, F.X., 1986. Comments on Modelling the Persistence of Conditional Variance. *Econometric Reviews*, 5: 51-56.
- Engle, R.F. and K.F. Kroner, 1995. Multivariate Simulations Generalized Arch. *Econometric Theory*, 11(1): 122-150.
- Fang, W. and S.M. Miller, 2008. The Great Moderation and the Relationship between Output Growth and Its Volatility. *Southern Economic Journal*, 74(3): 819-838.
- Fang, W., S.M. Miller and C.S. Lee, 2008. Cross-Country Evidence on Output Growth Volatility: Nonstationary Variance and GARCH Model. *Scottish Journal of Political Economy*, 55(4): 509-540.
- Floros, C. and D.V. Vougas, 2004. Hedge Ratios in Greek Stock Index Futures Market. *Applied Financial Economics*, 14: 1125-1136.
- Ford, J.L. W.C. Pok and S. Poshakwale, 2005. Dynamic vs Static Stock Index Futures Hedging: A Case of Malaysia. <http://bham.au.uk>.
- Granger, C.W. and N. Hyung, 1999. Occasional Structural Breaks and Long Memory. Discussion Paper. No 99-14. University of California.
- Gray, S.F., 1996. Modeling the Conditional Distribution of Interest Rates as a Regime-Switching Process. *Journal of Financial Economics*, 42: 27-62.
- Hamilton, J.D. and R. Susmel, 1994. Autoregressive Conditional Heteroscedasticity and Changes in Regime. *Journal of Econometrics*, 64: 307-333.
- Inclan, C. and G.C. Tiao, 1994. Use of Cumulative Sums of Squares for Retrospective Detection of Changes of Variance. *Journal of the America Statistical Association*, 89: 913-923.
- Kokoszka, P. and R. Leipus, 2000. Change Point Estimation in ARCH Models. *Bernoulli*, 6: 1-28.
- Kokoszka, P. and R. Leipus, 1998. Change Point in Mean of Dependent Observations. *Statistic and Probability Letters*, 40: 385-393.
- Kroner, K.F. and J. Sultan, 1993. Time-Varying Distributions and Dynamic hedging with Foreign Currency Futures. *Journal of Financial and Quantitative Analysis*, 28(4): 535-551.
- Lastrapes, W.D., 1989. Exchange Rate Volatility and US Monetary Policy: An ARCH Application. *Journal of Money, Credit and Banking*, 21: 66-77.

- Liew, K.Y. and R.D. Brooks, 1998. Returns and Volatility in the Kuala Lumpur Crude Palm Oil Futures Market. *The Journal of Futures Markets*, 18(8): 985-999.
- Lumsdaine, R. and D. Papell, 1997. Multiple Trend Breaks and the Unit-Root Hypothesis. *Review of Economics and Statistics*, 79(2): 212-218.
- Malik, F., 2003. Sudden Changes in variance and Volatility Persistence in Foreign Exchange Markets. *Journal of Multinational Financial Management*, 13: 217-230.
- Mili, M. and F. Abid, 2004. Optimal Hedge Ratios Estimates: Static vs Dynamic Hedging. *Finance India*, 18: 655-670.
- Nelson, C.R. and C.I. Plosser, 1982. Trends and Random Walks in Macroeconomics Time Series. *Journal of Monetary Economics*, 10: 139-162.
- Pastor, L. and R.F. Stambugh, 2001. The Equity Premium and Structural Breaks. *Journal of Finance* : 1207-1239.
- Perron, P., 1989. The Great Crash, the Oil Price Shocks, and the Unit Root Hypothesis. *Econometrica*, 57(6): 1361-1401.
- Perron, P., 1990. Testing for a Unit Root in a Time Series with Changing Mean. *Journal of Business & Economic Statistics*, 8: 153-162.
- Perron, P., 1997. Further Evidence on Breaking Trend Functions in Macroeconomic Variables. *Journal of Econometrics*, 80(2): 355-385.
- Perron, P., 2005. Dealing with Structural Breaks. *Palgrave Handbook of Econometrics: Econometric Theory* 1.
- Quandt, R.E., 1958. The Estimation of the Parameters of a Linear Regression System Obeying Two Separate Regimes. *Journal of the American Statistical Association*, 53: 873-880.
- Quandt, R.E., 1960. Tests of the Hypothesis that a Linear Regression System Obeys Two Separate Regimes. *Journal of the American Statistical Association*, 55: 324-330.
- Rapach, D.E. and J.K. Strauss, 2008. Structural Breaks and GARCH Models of Exchange Rate Volatility. *Journal of Applied Econometrics*, 23: 65-90.
- Rapach, D.E. and M.E. Wohar, 2006. Structural Breaks and Predictive Regressive Models of Aggregate US Stock Returns. *Journal of Financial Econometrics*, 4(2): 238-274.
- Rappoport, P. and L. Reichlin, 1989. Segmented Trends and Nonstationary Time Series. *The Economic Journal*, 99: 168-177.
- Roche, M.J. and K. McQuinn, 2003. Grain Price Volatility in a Small Open Economy. *European Review of Agricultural Economics*, 30(1): 77-98.
- Sanso, A., V. Arago and J.L. Carrion, 2004. Testing for Changes in the Unconditional Variance of Financial Time Series. *DEA Working Paper 5*, <http://www.ideas.repec.org>.
- Vogelsang, T. and P. Perron, 1998. Additional Tests for a Unit Root Allowing for Breaks in the Trend Function at an Unknown Time. *International Economic Review*, 39(4): 1073-1100.
- Yang, W. and D.E. Allen, 2004. Multivariate GARCH Hedge Ratios and Hedging Effectiveness in Australian Futures Markets. *Accounting and Finance*, 45: 301-321.
- Zivot, E. and D.W.K. Andrews, 1992. Further Evidence on the Great Crash, the Oil Price Shock and the Unit Root Hypothesis. *Journal of Business and Economic Statistics*, 10: 251-270.