Testing for weak-form efficiency of Crude Palm Oil Spot and Futures Markets: New Evidence from a GARCH Unit Root Test with Multiple Structural Breaks

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Abstract

There is a sizeable literature that tests for weak-form efficiency in commodity and energy spot and futures prices. While many studies now allow for multiple structural breaks to address the criticism that conventional unit root tests have low power to reject the unit root null in the presence of structural change, the extant literature overlooks the fact that conventional unit root tests are biased in the presence of conditional heteroskedasticity. We apply a recently developed GARCH unit root test with multiple structural breaks to crude palm oil spot and futures prices and find much more evidence against weak-form efficiency than with tests that fail to allow for conditional heteroskedasticity. Our results point to the importance of allowing for heteroskedasticity when testing for efficiency in commodity and energy spot and futures prices.

Introduction

Fama (1970) proposed the concept of the efficient market hypothesis (EMH). He later suggested there are three categories of EMH; namely, weak-form efficiency, semi-strong-form efficiency and strong-form efficiency (Fama, 1991). Empirical testing of the EMH has focused on the weak form of the EMH. The weak-form EMH states that future prices cannot be predicted based on past prices, such that it is not possible for investors to use technical analysis to make supra-normal profits. While the EMH has been subject to much criticism (see Malkiel, 2003 for a review of the arguments), it endures as "the core of modern financial economics" (Wang & Wu, 2013, p.393).

A large literature exists that tests the weak-form EMH in commodity and energy futures markets (see Lim & Brooks, 2011 for a review). A subset of this literature tests the EMH in commodity and energy futures prices using unit root (or stationarity) tests (see eg. Elder & Jin, 2009; Elder & Serletis, 2008; Fernandez, 2010; Lee et al., 2006; Lee & Lee, 2009; Presno et al., 2014; Maslyuk & Smyth, 2008; Ozdemir et al., 2013; Sadorsky, 1999; Serletis, 1992). Findings have been mixed. Some studies have found commodity and energy spot and future prices to be stationary (Elder & Serletis, 2008; Lee et al., 2006; Lee & Lee, 2009; Sadorsky, 1999; Serletis 1992). Other studies have concluded that they are non-stationary, at the very least persistent or find mixed evidence of stationarity (Elder & Jin, 2009; Fernandez, 2010; Maslyuk & Smyth 2008; Ozdemir et al., 2013; Pindyck, 1999; Presno et al. 2014).

If spot and future prices are stationary, this implies that prices revert to their long-run mean. On the other hand, if spot and future prices contain a unit root, this implies that following a shock to the long-run growth path, there will be a permanent departure from the long-run equilibrium. If spot and future prices contain a unit root, this suggests that they contain a random walk and that it is not possible for investors to use technical analysis to make supra-normal profit. This supports the weak-form EMH. In these circumstances, an expert attempting to pick winners will do no better than an individual holding a randomly selected diversified portfolio, assuming a similar level of risk. Alternatively, if spot and future prices are mean reverting, this suggests that markets are not efficient and rejects the weak-form EMH.

The initial studies that tested the EMH in commodity and energy spot and futures markets using unit root tests employed conventional tests without structural breaks, such as the Augmented Dickey-Fuller (ADF) and Phillips-Perron tests. Over time, the econometrics has become progressively more advanced. For instance, the more recent literature has employed unit root tests with one or more structural breaks or fractional integration unit root tests. The point we make, and demonstrate, in this paper is a simple one. Despite the increasingly sophisticated array of unit root tests that have been applied to test the EMH in commodity and energy spot and futures markets, they all fail to take account of the existence of heteroskedasticity in the data. Failing to take this into account, biases the findings in favour of support for the EMH.

Most commodity and energy spot and futures market data is high frequency. Heteroskedasticity is particularly problematic in high frequency financial data. Heteroskedasticity will bias the findings of conventional unit root tests, which assume the existence of independent and identically distributed (iid) errors (Kim & Schmidt, 1993). Narayan and Liu (2013) show that in cases in which the unit root is the null, failure to take account of heteroskedasticity biases the test against rejecting the null.

The purpose of this paper is to show how failure to take account of heteroskedastity biases against rejecting the unit root null when testing the EMH in commodity and energy spot and futures markets. To do so, in addition to conventional unit root tests and unit root tests with structural breaks, we apply the recently developed Narayan and Liu (2013) generalised autoregressive conditional heteroskedasticity (GARCH) unit root test. The advantage of the Narayan and Liu (2013) test is that it allows for both heteroskedasticity in the data and two endogenous structural breaks.

To illustrate our point, we test for a unit root in monthly Malaysian Crude Palm Oil spot and futures (FCPO) contracts (one to nine months to maturity). Crude palm oil is a form of comestible vegetable oil, obtained from fruit of the oil palm tree. It has varied uses include being employed in cooking in Africa, Southeast Asia and South America and as an ingredient in processed foods and the production of biodiesel. Indonesia and Malaysia are the main oil palm producers, accounting for more than 80 per cent of global palm oil production in 2013-2014 (Phillip Futures, 2014). Bursa Malaysia Derivatives Berhad (BMD) is the main exchange on which FCPO are traded. At BMD, investors trade Malaysian Ringgit denominated FCPO contracts and this serves as the global benchmark for the palm oil industry (Phillip Futures, 2014).

Data

We examine crude palm oil prices[1] for ten time series (spot month contracts and one-month to nine-month contracts) for the period from January 1999 until June 2014. The data are at monthly frequency. Tables 1 and 2 give descriptive statistics for monthly spot and futures prices and returns. Figure 1 plots the time series for the monthly prices and returns for each series. The six-month contract has the highest average monthly price and the eight-month contract has the highest average monthly return. All series exhibit negative skewness and are not normally distributed. The final column of Table 2 reports the results of the ARCH LM test at lag 12. We report

[1] Data is extracted from Bursa Malaysia's website.

results at lag 12 given that we employ monthly data. The null hypothesis of no ARCH effect is rejected at the 5 per cent level for all lags up to lag 12. This suggests that it is important to take account of time varying volatility when testing the EMH.

Insert Tables 1 & 2; Fig. 1

Method

We first apply the conventional ADF unit root test without structural breaks. The null hypothesis is the existence of a unit root, or random walk, in prices. This provides a benchmark, with which to compare the effect of incrementally allowing for structural breaks and then structural breaks and heteroskedasticity in subsequent unit root tests. Given the ADF test is well known in the literature, we do not reproduce the details.

One of the main limitations of the ADF test is that it has low power to reject the unit root null in the presence of one or more structural breaks (Perron, 1989). A number of unit root tests with one or two structural breaks have been developed to address this issue. We employ the Narayan and Popp (2010) unit root test with two endogenous structural breaks. We employ both Narayan and Popp's (2010) Model 1 (two breaks in the intercept) and Model 2 (two breaks in the intercept and trend). In both cases, the null hypothesis is that the time series contains a unit root or exhibits a random walk. Narayan and Popp (2013) show that the Narayan and Popp (2010) test has better size properties and identifies the breaks more accurately, than its main two-break unit root rivals; namely, the Lumsdaine and Papell (1997) and Lee and Strazicich (2003) tests. The purpose of employing this test is to examine the effect of allowing for structural breaks, without accounting for heteroskedasticity, on whether the null is rejected. Thus, one can ascertain whether structural breaks alone are driving the results. The Narayan and Popp (2010) has been widely used so we do not reproduce the details.

Finally, we employ the Narayan and Liu (2013) GARCH unit root test with two endogenous breaks. Comparing the results from the Narayan and Popp (2010) and Narayan and Liu (2013) tests, we can ascertain the extent to which heteroskedasticity is biasing the findings with tests that do not accommodate it. Narayan and Liu (2013) is still in working paper form. Hence, we briefly outline the method here. Narayan and Liu (2013) relax the assumption of iid errors and propose a GARCH(1,1) unit root model that accommodates two endogenous breaks in the intercept in the presence of heteroskedastic errors. The null hypothesis is a unit root and the alternative is mean reversion. The test considers a GARCH (1,1) unit root model of the following form:

$$y_t = \alpha_0 + \pi y_{t-1} + D_1 B_{1t} + D_2 B_{2t} + \varepsilon_t \qquad (1)$$

Here,

$B_{it} = 1 \; for \; t > T_{Bi}$ otherwise $B_{it} = 0$, T_{Bi} are structural breakpoints, in which $i = 1, 2$. D_1 and D_2 are the structural break dummy variable coefficients.

ε_t follows the first order GARCH (1,1) model of the form:

$$\varepsilon_t = \eta_t \sqrt{h_t}, h_t = \kappa + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \qquad (2)$$

Here, $\kappa > 0, \alpha \geq 0, \beta \geq 0 \; and \; \eta_t$ is a sequence of iid random variables with zero mean and unit variance. To estimate Equations (1) and (2), Narayan and Liu (2013) use joint maximum likelihood (ML) estimation. Since the break dates (T_{Bi}) are unknown and have to be substituted by their estimates, a sequential procedure is used to derive estimates of the break dates. The unit root/random walk null hypothesis is tested with the ML t-ratio for π with a heteroskedastic-consistent covariance matrix.

Results

Table 3 presents the results of the ADF unit root test applied to the ten price series. For all ten series (spot contract and one-month to nine-month contracts), the ADF test suggests that crude palm oil prices contain a random walk, supporting the EMH.

Insert Table 3

This finding provides a basis to proceed to examine whether allowing for structural breaks and accommodating heteroskedasticity makes any difference to the findings. As discussed above, the problem with the ADF test is that it is biased in the presence of structural breaks (Perron, 1989) and heteroskedaticity (Kim & Schmidt, 1993).

Insert Table 4

We adopt a sequential approach to examining the effects of structural breaks and conditional heteroskedasticity. We first apply the Narayan and Popp (2010) test, which allows for two structural breaks. The results of Narayan and Popp's (2010) Model 1 (M1) and Model 2 (M2) are presented in Table 4. The results of both Model 1 and Model 2 are consistent for spot contract and one-month to nine-month contracts. The Narayan and Popp (2010) test suggests that for all ten series, crude palm oil prices exhibit a random walk, supporting the EMH. Thus, on the basis of the Narayan and Popp (2010) test, we conclude it is not the presence of structural breaks per se that is driving the conclusion about whether there is a random walk.

Insert Table 5

We next apply the Narayan and Liu (2013) GARCH unit root test with two breaks to the ten price series. The results are reported in Table 5. In contrast to the findings for the earlier tests, there is evidence of mean reversion for seven of the ten price series at the 5 per cent level. Specifically, the EMH is rejected for one-month to five-month contracts, seven-month contracts and nine-month contracts. Spot prices as well as six-month and eight-month contracts still contain a unit root/random walk.

In terms of explaining why the Narayan and Liu (2013) test suggests that most prices are mean reverting, but six-month and eight-month contracts contain a unit root, it is of note that these two futures contracts have the highest average prices and returns (see Tables 1 and 2). Contracts are more likely to contain a unit root if the average price/returns are higher because shocks will generate larger movements from the long-run equilibrium path, resulting in greater degrees of persistence.

Given that the Narayan and Liu (2013) test differs from the Narayan and Popp (2010) test, it is worth briefly commenting on which test should be preferred. Both tests adopt the same approach to identifying the break dates so they have similar accuracy and power properties. The difference is that Narayan and Liu (2013) is preferable where there is heteroskedasticity in the data. Given that the ARCH LM test suggests that each of the ten series is heteroskedastic (see Table 1) we conclude that the findings from Narayan and Liu (2013) are to be preferred. That we find more evidence of mean reversion, when we allow for both conditional heteroskedasticity and structural breaks underlines the importance of taking account of heteroskedasticity when testing for a unit root in commodity and energy spot and futures prices.

The Narayan and Popp (2010) and Narayan and Liu (2013) tests suggest different break dates, but both are fairly internally consistent across series. The Narayan and Popp (2010) test identifies both breaks as occurring in the Global Financial Crisis (GFC) in 2008. The GFC contained the boom and bust of several commodities and financial bubbles (see Jiang et al. 2014 for a discussion). Specifically, in terms of crude palm oil, there was a significant decline in export prices for crude palm oil in the GFC. As a result, crude palm oil futures prices also declined through 2008. Crude palm oil futures prices in Malaysia fell from a high of RM4,500 per tonne in early March 2008 to about RM1,500 in November 2008. This is also reflected in Figure 1.

The Narayan and Liu (2013) test mainly identifies the first break as occurring in 1999 and the second break occurring in 2006. The first break is associated with the end of the Asian financial crisis (AFC). Crude palm oil exports in Malaysia rebounded strongly from the AFC and were a spur to growth in Malaysia in the aftermath of the crisis (Cheng, 2010). The second break in 2006 coincides with a couple of developments. The first was that in 2006 Malaysia introduced a National Biofuel Policy, which mandated an increase in palm oil content in biodiesel, increasing projected demand for palm oil. The second is that Malaysia and Indonesia, keen to create price stability for palm oil exports, signed a pricing pact in 2006, in which they manage supply and demand to prevent the price being set by non-producing countries.

Conclusion

A large literature has tested the EMH for commodity and energy spot and futures prices using unit root tests with varying degrees of econometrics sophistication. The results from these tests have been mixed in terms of support for the EMH. The point we make in this paper is that the existing literature that tests the EMH in commodity and energy spot and futures prices with high frequency data is likely to yield estimates biased in favour of the EMH because it fails to accommodate conditional heteroskedasticity. To illustrate our argument, we have applied unit root tests with and without structural breaks and/or that take account of conditional heteroskedasticity to spot month contracts and one-month to nine-month contracts for crude palm oil prices. The main finding is that the ADF test and Narayan and Popp (2010) test suggest that all ten series contain a random walk, while the Narayan and Liu (2013) GARCH unit root test with structural breaks suggests that 70 per cent of the series are mean reverting. In short, allowing for heteroskedasticity, means that we find much less evidence in support of the EMH than with conventional tests.

This finding has several implications. One is for ongoing debates about the validity of the EMH in financial markets (see eg. Malkiel, 2003). In terms of that debate, it might be argued that the results presented here put another nail in the coffin of the EMH. The results suggest that for commodity spot and futures prices applying a new class of unit root test that takes account of heteroskedasticity in high frequency data presents much more evidence against the EMH. This result is consistent with other recent applications of the Narayan and Liu (2013) test to high frequency stock price data (see eg Lean et al., 2015; Mishra et al. 2015; Narayan & Liu, 2013).

A second implication is for regulation of futures markets, particularly in Asia. Following the AFC (Wade, 1998), and again following the GFC (Kawai *et al.,* 2012), there have been calls to tighten the regulation of financial markets in Asia. This has occurred in Malaysia in derivatives markets, with the enactment of Malaysia's Capital Markets and Services (Amendment) Act 2011. Our finding that 70 per cent of the price series are mean reverting provides support for continued monitoring of crude oil futures on the BMD. The final implication is for investors. The finding that 70 per cent of the price series are mean reverting, suggests that investors should be able to use technical analysis to make supra-normal profits in these contracts.

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Table 1: Descriptive Statistic of Monthly Prices

Series	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
S0	7.5180	0.4206	-0.2388	2.2357	6.2951**
F1	7.5185	0.4164	-0.1853	2.1750	6.3397**
F2	7.5167	0.4119	-0.1439	2.1262	6.5588**
F3	7.5157	0.4088	-0.1185	2.0883	6.8775**
F4	7.5155	0.4064	-0.1036	2.0610	7.1663**
F5	7.5156	0.4048	-0.0936	2.0388	7.4316**
F6	7.5200	0.4005	-0.0692	2.0025	7.8595**
F7	7.5146	0.4058	-0.0981	2.0169	7.7890**
F8	7.5220	0.4011	-0.0592	1.9755	8.2429**
F9	7.5150	0.4046	-0.0944	2.0011	8.0089**

** denotes statistical significance at 5% significance level.

S0 is spot month contract, F1 is one-month futures contract, F2 is two-month futures contract, F3 is three-month futures contract, F4 is four-month futures contract, F5 is five-month futures contract, F6 is six-month futures contract, F7 is seven-month futures contract, F8 is eight-month futures contract, and F9 is nine-month futures contracts.

Table 2: Descriptive Statistic of Monthly Returns

Series	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Arch LM(12)
S0	0.0006	0.0927	-0.2317	4.6186	21.8501***	2.8832***
F1	0.0007	0.0909	-0.2680	5.1965	39.4034***	3.2881***
F2	0.0008	0.0896	-0.3587	5.2847	44.2011***	2.7363***
F3	0.0009	0.0879	-0.4224	5.4344	51.1830***	2.5392***
F4	0.0010	0.0867	-0.4829	5.5779	58.4139***	2.3505***
F5	0.0010	0.0855	-0.4963	5.5589	58.0680***	2.1465***
F6	0.0011	0.0904	-1.0336	11.1577	545.9115***	3.6473***
F7	0.0008	0.0874	-0.5753	7.3525	156.2331***	2.8364***
F8	0.0013	0.0882	-1.0796	11.5525	599.7646***	4.0164***
F9	0.0008	0.0861	-0.5853	7.1742	144.8740***	2.7614***

*** denotes statistical significance at 1% significance level.

S0 is spot month contract, F1 is one-month futures contract, F2 is two-month futures contract, F3 is three-month futures contract, F4 is four-month futures contract, F5 is five-month futures contract, F6 is six-month futures contract, F7 is seven-month futures contract, F8 is eight-month futures contract, and F9 is nine-month futures contracts.

Table 3: ADF Unit Root Test

	Level		First Difference	
Series	lag	t-statistics	lag	t-statistics
S0	0	-1.4457	0	-11.7462***
F1	0	-1.4267	0	-11.6171***
F2	0	-1.4151	0	-11.7206***
F3	0	-1.3923	0	-11.7974***
F4	0	-1.3735	0	-11.9369***
F5	0	-1.3550	0	-11.9648***
F6	0	-1.4569	0	-14.0824***
F7	0	-1.3939	0	-13.3119***
F8	0	-1.3999	0	-13.974***
F9	0	-1.3652	0	-13.3187***

*** denotes statistical significance at 1% significance level.

S0 is spot month contract, F1 is one-month futures contract, F2 is two-month futures contract, F3 is three-month futures contract, F4 is four-month futures contract, F5 is five-month futures contract, F6 is six-month futures contract, F7 is seven-month futures contract, F8 is eight-month futures contract, and F9 is nine-month futures contracts.

Table 4: Results of Narayan-Popp (2010) Two Break Unit Root Test

		M1				M2		
Series	t-stat	TB1	TB2	k	t-stat	TB1	TB2	k
S0	-1.9140	2008.07	2008.09	11	-2.8832	2008.07	2008.09	11
F1	-1.6126	2008.07	2008.11	11	-3.1814	2008.07	2008.11	12
F2	-1.5371	2008.07	2008.11	11	-3.0574	2008.07	2008.11	12
F3	-1.4813	2008.07	2008.11	11	-2.9822	2008.07	2008.11	12
F4	-1.4184	2008.07	2008.11	11	-2.9056	2008.07	2008.11	12
F5	-1.3817	2008.07	2008.11	11	-2.8824	2008.07	2008.11	12
F6	-1.6561	2008.08	2008.10	12	-2.8800	2008.08	2008.10	12
F7	-1.3616	2008.07	2008.11	12	-2.4334	2008.07	2008.11	12
F8	-1.6632	2008.08	2008.10	12	-2.8259	2008.08	2008.10	12
F9	-2.0915	2008.07	2009.03	0	-3.1198	2008.07	2008.11	0

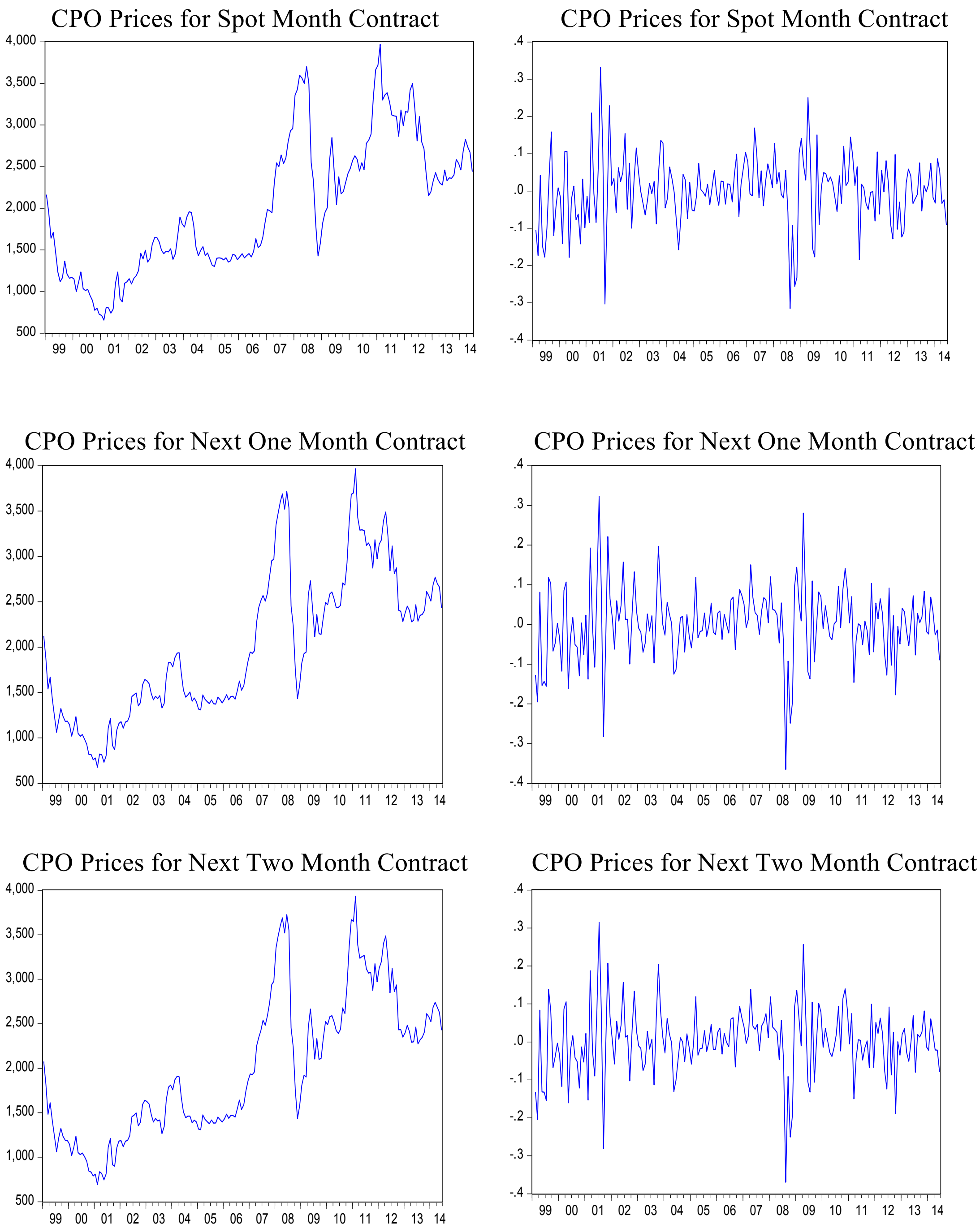
S0 is spot month contract, F1 is one-month futures contract, F2 is two-month futures contract, F3 is three-month futures contract, F4 is four-month futures contract, F5 is five-month futures contract, F6 is six-month futures contract, F7 is seven-month futures contract, F8 is eight-month futures contract, and F9 is nine-month futures contracts.

Table 5: Results of Narayan and Liu (2013) Two Break GARCH(1,1) Unit Root Test

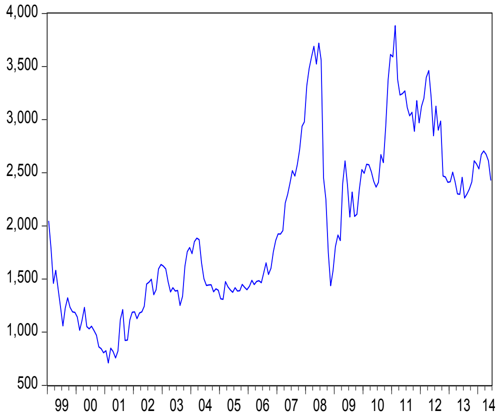
Series	t-stat	TB1	TB2
S0	-3.1638	Nov 2006	Jan 2010
F1	-8.3274**	Mar 1999	Nov 2006
F2	-8.9836**	Nov 2001	Oct 2006
F3	-8.4381**	Mar 1999	Oct 2006
F4	-7.8392**	Mar 1999	Oct 2006
F5	-7.5097**	Mar 1999	Oct 2006
F6	-3.2746	Mar 1999	Apr 2007
F7	-9.3578**	Mar 1999	Dec 2006
F8	-2.2834	Mar 2007	Jul 2008
F9	-9.3119**	Mar 1999	Dec 2006

Notes: The 5% critical values for the unit root test statistics are obtained from Narayan and Liu (2013) [Table 3]. ** denotes statistical significance at 5% significance level.
S0 is spot month contract, F1 is one-month futures contract, F2 is two-month futures contract, F3 is three-month futures contract, F4 is four-month futures contract, F5 is five-month futures contract, F6 is six-month futures contract, F7 is seven-month futures contract, F8 is eight-month futures contract, and F9 is nine-month futures contracts.

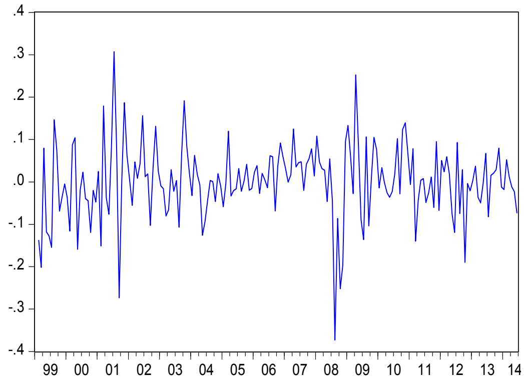
Figure 1: Time Series Plot for FCPO Monthly Prices and Returns



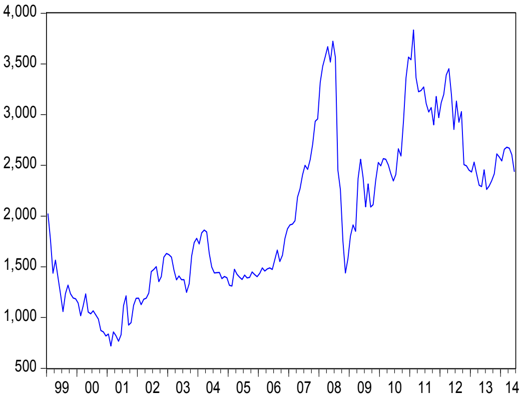
CPO Prices for Next Three Month Contract



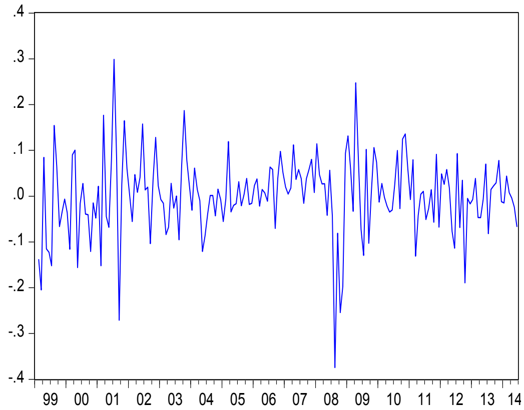
CPO Prices for Next Three Month Contract



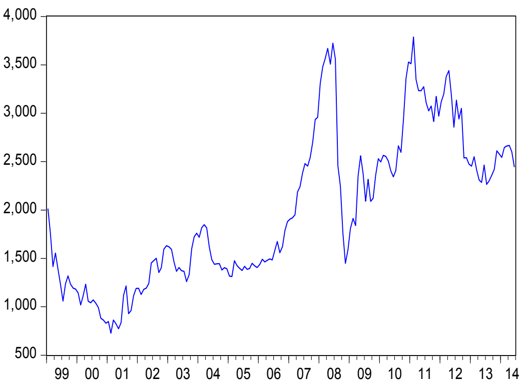
CPO Prices for Next Four Month Contract



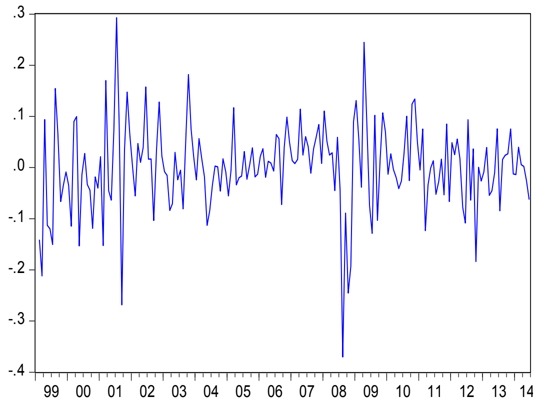
CPO Prices for Next Four Month Contract



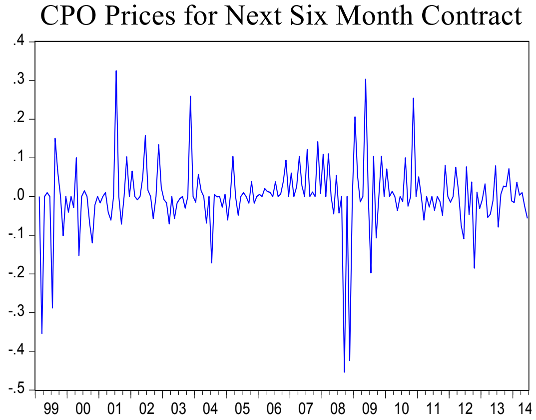
CPO Prices for Next Five Month Contract

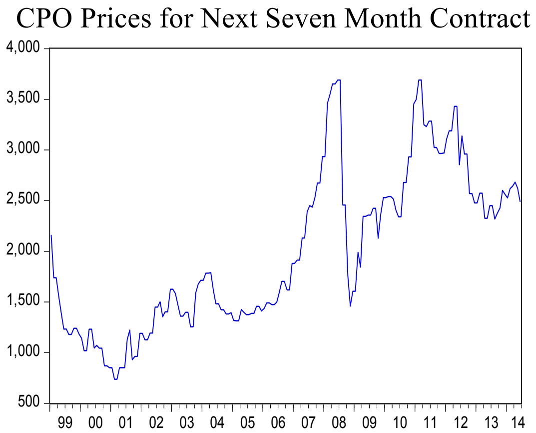


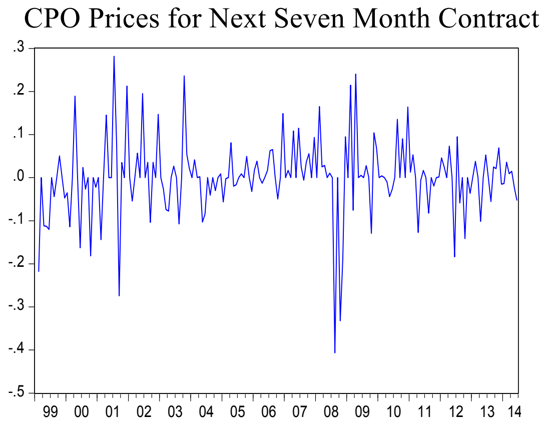
CPO Prices for Next Five Month Contract

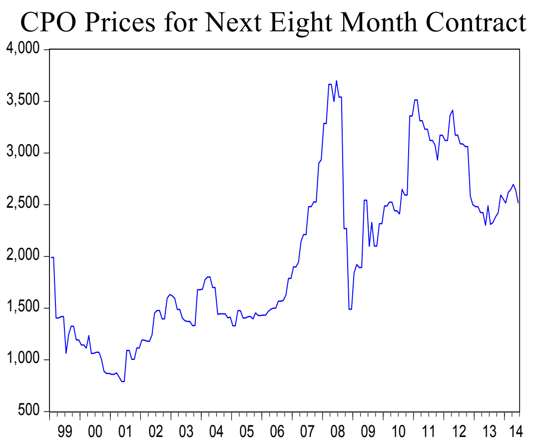


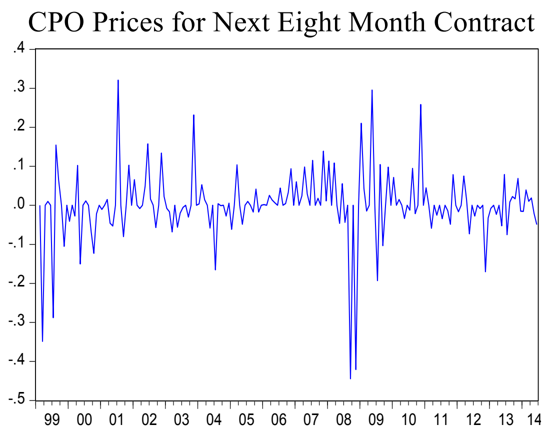

CPO Prices for Next Six Month Contract
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14

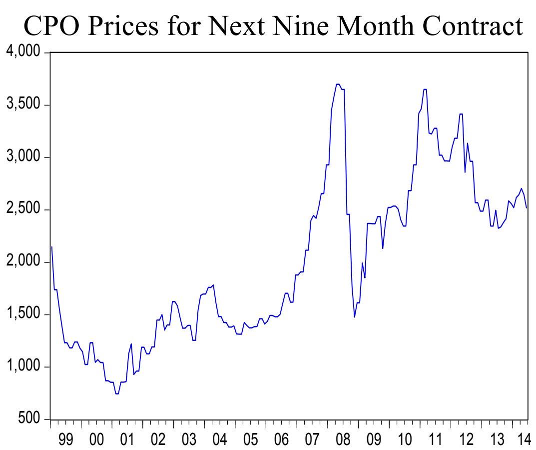

CPO Prices for Next Six Month Contract
.4
.3
.2
.1
.0
-.1
-.2
-.3
-.4
-.5
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14

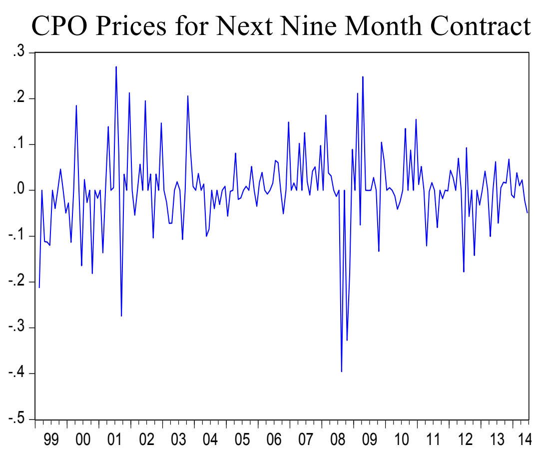

CPO Prices for Next Seven Month Contract
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14


CPO Prices for Next Seven Month Contract
.3
.2
.1
.0
-.1
-.2
-.3
-.4
-.5
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14


CPO Prices for Next Eight Month Contract
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14


CPO Prices for Next Eight Month Contract
.4
.3
.2
.1
.0
-.1
-.2
-.3
-.4
-.5
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14


CPO Prices for Next Nine Month Contract
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14


CPO Prices for Next Nine Month Contract
.3
.2
.1
.0
-.1
-.2
-.3
-.4
-.5
99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14