HOW PERSISTENT ARE SHOCKS TO OIL PRICES?

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Abstract

Given that energy prices are known to contain structural breaks and are also characterized by volatility that changes over time we address this gap by adopting a novel unit root test due to Cavaliere, Harvey, Leybourne and Taylor (2011), that unifies these characteristics together. This paper aims to determine whether unit roots exist in benchmark crude oil prices allowing for the possibility of a structural break *and* non-stationary volatility. The literature is far from a consensus on the unit root properties of crude oil prices, which may result from low power of unit root tests, due to the presence of structural breaks and possible non-stationary volatility which seem to plague crude oil prices. We find that using a novel and more appropriate unit root test that allows for nonstationary volatility the conclusions about persistence in crude oil prices can be drastically different. In general, our findings suggest that the global economy experiences shocks which have a transitory effect on WTI and Brent oil prices, thereby reverting to a long-run trend whose path is determined by structural fundamentals.

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Introduction

The oil market is one of the largest and the most strategic commodity markets in the global economy. Oil prices have been a subject of much interest, particularly after the major oil shocks in the 1970s, 1980s and more recently in 2008. Such oil price shocks can have a huge impact on macroeconomic variables such as incomes, savings and current account balances. This would be particularly true for countries that are dependent on oil. Besides, the dynamic behaviour of crude oil prices contain important stochastic properties that have a bearing on financial activities such as forecasting, hedging, speculation, strategic planning and portfolio investment. The underlying dynamic properties of crude oil prices have further important implications because of the importance of oil for other sectors of the economy. There has been a vast number of studies that have shown how oil price movements can affect economic growth (Loungani 1986, Mork 1989, Lee et. al. 1995, Kilian 2008); inflation (Hamilton 1996, Cunado and Gracia 2003, Du et. al. 2010), impact on the stock market (Sadorsky 1999, Papapetrou 2001, Park and Ratti 2008), and explain exchange rate movements (Zhou 1995, Bergvall 2004, Chen and Chen 2007).

The crude oil market can be affected by exogenous shocks that could emanate from demand and supply shocks, or policies pertaining to the Organization of the Petroleum Exporting Countries (OPEC), and geopolitical risks. These exogenous shocks therefore motivate the study of investigating the time series properties of oil prices. We are generally interested to understand the nature of persistence of oil prices to exogenous shocks. A persistent increase in the crude oil price means that there is a positive terms-of-trade shock in an oil-exporting country. It can create a persistent real appreciation of the exchange rate (Chaudhuri and Daniel 1998) which puts decreasing pressure on the prices via less-expensive imports. However, the wealth effect of this kind of persistent change in the crude oil price can apply increasing pressure on prices (Ozdemir 2013). Clearly, the persistence of oil price shocks is a subject of interest to economists and policy makers and this paper makes an attempt to understand the nature of persistence using novel econometric methods.

A further scope of this study would help decide the order of integration of international oil prices. This would be a necessary step before investigating the effect of crude oil prices on economic variables with the help of statistical regressions. If oil prices are found to be non-stationary then there arises the possibility of spurious regressions. Policy makers would therefore need to exercise caution as they would be required to make inferences from correctly specified models that take into account the appropriate stochastic nature of the data generating process.

This study accordingly compares novel tests that take into account the underlying properties of the oil prices data. We focus on benchmark crude oils, being Western Texas Intermediate (WTI), Brent and Dubai/Oman[1]. In general, the conclusion from various studies so far are mixed about the underlying nature of persistence in benchmark crude oils. However, on balance, benchmark crudes are found to display a significant level of persistence, and thus for the policy maker, price shocks are likely to be long lasting rather than being short term transitory. Given the possibility of structural breaks and non-stationary volatility in crude oil prices, policy makers might consider whether these prices are more or less amenable to stabilization policies. This paper is structured as follows: the next section provides a brief critical review of the methodological issues that surround unit root tests; the following section outlines the literature review on oil price dynamics; this is followed by the section that describes the novel econometric methods that will be employed in this study; the next section describes the data and the empirical results; and finally the last section concludes.

Methodological Issues

The most common method to study the persistence of commodity prices is to use unit root tests. Unit root tests determine whether the price series is a trend or difference stationary process. If the commodity price series is a trend-stationary process, in other words prices are I(0), then shocks to prices would have transitory effects. On the other hand, if there is a unit root in the underlying price series, or prices are I(1), then shocks would have permanent effects.

Given the sample size chosen in empirical studies that cover a reasonably long monthly data set, it is likely that structural breaks may appear in the time series. Keeping this in consideration most of the recent studies have applied unit root tests with structural breaks. The standard unit root tests typically employed in empirical studies suffer from serious power and size distortions due to the asymmetric treatment of breaks by allowing for dummy variables in the alternative hypotheses but not in the null. As a result these unit root tests are subject to a spurious rejection problem when breaks are present under the unit

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[1] This benchmark began to incorporate Oman following a significant decline in the production of Dubai since the 1990s.

root null hypothesis. Essentially, the problem is the presence of nuisance parameters related to the trend function under the null hypothesis.[2] To address this problem, the most recent studies on oil price persistence have applied the minimum Lagrange Multiplier (LM) unit root test due to Lee and Strazicich (2003, 2004) with one or two structural breaks where breaks are allowed to appear in both the null and the alternative. [see Lee et. al. (2006), Postali and Pichetti (2006), Ghoshray and Johnson (2010)]. However, the recent developments in the field of unit root tests and structural breaks opens up potential shortfalls when applying the LM method, which can lead one to question the findings and subsequent implications of the most recent studies of oil price persistence based on this test.

To clarify, the LM tests suffers from the problem that it assumes structural breaks may exist in the data when the true data generating process may not contain any breaks at all. At an intuitive level, it seems more natural to be first able to ascertain if breaks are at all present before proceeding to conduct unit root tests allowing for such breaks. In the absence of breaks, these tests may suffer from low power and size distortions due to the inclusion of extraneous break dummies thereby potentially leading the researcher to estimate a differenced specification when a level specification is in fact more appropriate. Indeed, as stressed by Campbell and Perron (1991), proper specification of the deterministic components is essential in obtaining unit root tests with reliable finite sample properties.

Keeping in perspective the criticism on the minimum LM unit root test, this study has utilized a more robust method for determining structural breaks and unit roots to analyse benchmark crude oil prices. The structural break is determined by applying the novel method due to Kejriwal and Perron (2010). This method examines stochastic oil price dynamics utilizing econometric procedures that allows consistent estimation of the number of structural breaks in the benchmark crude oil price series while being agnostic about the order of integration of data, thereby avoiding the need for unit root pretesting. We adopt an intuitive to first determine if structural breaks exist at all before conducting unit root tests that allow for such breaks. The fact that the most recent studies adopt methods that do not test for the number of structural breaks suggests that those methods may have lower power in detecting deviations from the unit root if the researcher allows for more breaks than there actually are. Once the number of breaks are determined, we employ a novel test for unit roots due to Carrion-i-Silvestre et. al. (2009), hereafter CKP, that allow for structural breaks in both the null and alternative hypotheses.

It is well known that one of the problems with unit root tests is their low power in the presence of a structural break (Perron 1989). Therefore, in order to examine whether the crude oil prices are trend stationary or difference stationary we must take the possible presence of structural breaks into account. It needs to be noted that the tests by Perron (1989) are invariant to the magnitude of the trend break. The subsequent tests that endogenise the estimated break date (such as Perron 1997, Perron and Rodrigues 2003) are based around an estimator of the break fraction. This is not a problem if the estimator is consistent at a sufficiently fast rate, so that when a break occurs, the tests are near asymptotically efficient when based on quasi differenced (QD) detrending. However, when there is no structural break in the data, the break fraction estimator spuriously indicates a trend break thereby making the tests inefficient (Cavaliere et. al 2011). As a result, the power losses can be substantial (Elliot et. al. 1996). Harris et. al. (2009), propose a data dependent modification of the ordinary least squares break fraction estimator, which is obtained by first differencing the data which corrects .the above mentioned problem.

As highlighted by Cavaliere et. al. 2011, another problem with unit root tests is the possible presence of time varying unconditional volatility in the data. This has been flagged up in the literature (see for example, Busetti and Taylor 2003, Sensier and van Dijk 2004, Cavaliere and Taylor 2008) as a considerable drawback for a data series that displays simultaneous breaks in the trend and unconditional volatility.

Given the recent developments, the literature is far from a consensus on the unit root properties of crude oil prices, which may result from low power of unit root tests, due to the presence of structural breaks and possible non-stationary volatility which seem to plague crude oil prices. Bearing the fact that structural breaks and nonstationary volatility are highly plausible features of benchmark crude oil prices, we consider further investigations to better understand the time series properties of crude oil prices, which is the main contribution of this paper. We adopt a novel unit root test due to Cavaliere et. al (2011), CHLT hereafter, that allows for a possible trend break and nonstationary volatility. The nonstationary volatility could take the form of a single or multiple abrupt variance breaks, smooth transition variance breaks or a trending variance. It is expected that this study would lead to a significant improvement in the detection of unit roots in oil prices. This is inferred from the simulation results shown by CHLT which conclude a large impact on both power and size properties of the unit root tests for just a single break in volatility.

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[2] This problem is illustrated by Ghoshray et. al. (2014) where they explain the case of a single structural break.

Literature Review

This section reviews the literature that has examined the nature of persistence in energy prices. One of the earlier studies that examined the dynamic behaviour of oil prices is that by Pindyck (1980) highlighting that rising energy prices can impose a cost on the U.S. economy. Silvapulle and Moosa (1999) employ daily data reported by the New York Mercantile Exchange (NYMEX) and focus on Brent and WTI crude oil to examine the lead-lag effects in spot and future oil markets. They are unable to reject non-stationarity for both series using both the Augmented Dickey Fuller (Dickey and Fuller 1979, 1981) unit root test (hereafter ADF) and Kwiatkowski et. al. (1992) (hereafter KPSS) tests. Serletis and Rangel-Ruiz (2004) perform ADF and Philips and Perron (1989), (hereafter PP) tests on the U.S. Henry Hub, and Alberta Energy Company (AECO) Alberta Natural Gas and WTI crude oil price series in their study on the interconnectedness of the North American energy markets. Using daily observations over the period 1991 to 2001, they find all series to be nonstationary. Coimbra and Esteves (2004) use end of week, month and quarter observations on Brent crude spot prices in an assessment of the validity of the carry-over and market efficiency assumptions in macroeconomic forecasting. Using the ADF test they are unable to reject non-stationarity for the period January 1989 to December 2003, nor a partial sample from 1992 to 2003, excluding the Gulf War period from January 1992 to December 2003. Ewing and Harter (2000) examine monthly observations of Brent and Alaskan North Slope crude oil over the period 1974 to 1996 in order to study inter-market price convergence. Using the ADF and KPSS test they find both series to be non-stationary. Alizadeh and Nomikos (2004) use the ADF, PP and KPSS tests on weekly observations of UK Brent, WTI and Nigerian Bonny Crude futures in assessing the relationship between prices and tanker freight rates. They find all series to be non-stationary over the period 1993 to 2001.

Considering the literature that employs conventional unit root tests on long spans of data. Berck and Roberts (1996) examine 8 price series including coal, petroleum and natural gas using annual data from 1870 to 1991. All series were found to be non-stationary when applying the ADF and the Schmidt and Phillips (1992) (hereby SP) tests. Pindyck (1999) attempts to model non-renewable energy resources prices using a Kalman filter. Using data similar to that of Berck and Roberts (1996) spanning 1870 to 1996, Pindyck rejects stationarity for annual averages of producer prices for crude oil, bitumous coal and natural gas using the ADF test. Krichene (2002) analyses demand and supply elasticities in oil and gas markets using annual data over the period 1918 to 1999, and subsamples pre- and post- the 1973 oil price shocks. Using the ADF test on both real and nominal prices, oil and gas series were found to be non-stationary across the entire sample period. Over the period 1918 to 1973, oil was found to be stationary and gas non-stationary with both being deemed stationary over the period 1973 to 1999.

Fewer studies exist which test for stationarity allowing for either a single or two structural breaks, employing methods proposed by Perron (1989), Lumsdaine and Papell (1997), (hereafter LP), Zivot and Andrews (1992) (hereafter ZA) and Lee and Strazicich, (2003, 2004). Gulen (1997) examines fragmentation in the world oil markets using monthly price series of 13 branded crude spot and longer-term contract price spanning periods from 8 to 15 years. Using the Perron (1989) test with a break specified a priori to take into account the 1986 oil price crash, non-stationarity can be rejected for 4 of the 15 series using spot prices. Using contract prices rejection rises to 5 of the 15 series, two of which can only be rejected at the 5% level. An extension of this study, Gulen (1999) employs weekly data of the period 1991 to 1996. The Perron (1989) test is applied with a break in early 1994 and finds non-stationarity cannot be rejected for any series. Serletis (1992) published the first study on the temporal properties of oil prices with an endogenously specified structural break. Daily observations of crude oil, heating oil and unleaded gasoline are tested over the sample period 1983–1990. Both ADF and ZA are applied to the series. When accounting for a single endogenously specified break the unit root hypothesis is rejected for all three series. Sadorsky (1999) tests for a unit root in the U.S. producer price index of real crude oil prices as part of a study to determine the effect of oil shocks on real stock returns. Using monthly data over the period 1947–1996 the series is found to be non-stationary using both PP and ZA. Although the use of an aggregated price index may be appropriate in the context of the wider empirical question, it is possible that co-movements of components of the index might mask the true nature of the underlying series. Ahrens and Sharma (1997), using an extension of the data used by Berck and Roberts (1996), examine 11 commodity price series including coal, petroleum and natural gas using annual data from 1870–1990. Those series found to be non-stationary under the ADF and Leybourne and McCabe (1994) (hereafter LMC) tests are then re-tested using the Perron (1989) and Ouliaris et al., (1989), (hereafter OPP) tests to allow for the possibility of structural breaks. They find coal and petroleum to be stationary under the ADF test and petroleum stationary under the OPP test with a quadratic trend using Perron (1989) regardless of specified break date. Natural gas was found to be non-stationary under the ADF, OPP and Perron (1989) tests, with stationarity of petroleum, gas and coal rejected by the LMC test. Lee et al. (2006) employ the Lee and Strazicich (2004, 2003) tests with up to two breaks alongside the ADF, LP and SP tests employing the same series as Ahrens and Sharma (1997). Using the no-break SP and Lee and Strazicich (2003) tests, their results largely strengthen those of Ahrens and Sharma (1997) concluding petroleum prices to be stationary. The conclusion of unit roots in the study of Berck and Roberts (1996) is also reversed in the case of gas and coal.[3] Postali and Picchetti (2006) use the Lee and Strazicich (2004, 2003) test to find evidence of trend stationarity in crude oil prices in an attempt to assess the suitability of Geometric

Brownian Motion as a proxy for oil prices. Using an annual series of U.S. average crude oil prices from 1861 to 1944 and extended using price data for Arabian Light and UK Brent up to 1999, they reject the null of a unit root for the full samples and a range of subsamples spanning when allowing for trend and intercept breaks. In contrast, Maslyuk and Smyth (2008), employing weekly data spanning 1991–2004, are unable to reject the random walk hypothesis for spot and future price series of Brent and WTI using ADF, PP, SP or Lee and Strazicich (2004, 2003) tests. Mixed evidence is found by Ghoshray and Johnson (2010) who apply the single break ZA test and the two break LP and Lee and Strazicich (2003) tests to WTI and Brent. While Brent is found to be non-stationary, the null of a unit root is rejected in the case of WTI. Presno et. al. (2014) extend the work of Ahrens and Sharma (1997) applying two types of tests: one which allows for breaks and another that allows for smooth transitions. They find stationarity for almost all prices including petroleum.

In summary, the empirical evidence is mixed. Despite an increasing amount of studies finding evidence to the contrary, it remains weighted in favour of non-stationarity in benchmark crude oil prices. The choice of the sample period and the frequency of the data can have a bearing on the results. Ambiguous results are likely when the data considered is of higher frequency as it is likely to exhibit fat tails and volatility clustering (Boswijk and Klaassen, 2005). Further, one could argue that in order to solve the low power of the unit root test, researchers increase the power by obtaining more observations. This can be possible by either considering a longer span, or employing data recorded at a higher frequency. However, Shiller and Perron, (1985) and Campbell and Perron (1991) have argued that increasing the frequency does not lead to higher power. They state that the power of the unit root test depends on the span of the data chosen rather than the frequency of the observations. However, the value of long sample periods of 50–140 years, as employed by studies considering annual data may be questioned, given the typical time horizon in oil and gas field investment of three decades (Maslyuk and Smyth, 2008). Conversely, short sample periods of high frequency data are unlikely to capture the long lags in energy investment cycles and social adjustment to energy price changes caused by the long lead times and substantial capital expenditures involved in energy commodity exploitation. Keeping in perspective these considerations, we have relied on monthly data that covers the period of interest which we believe sufficient to track the nature of persistence in benchmark crudes.

Numerous studies have concluded that oil prices are characterised by high volatility (see Narayan and Narayan (2007) and references within). Kang et. al. (2009) investigate the nature of volatility and have fitted GARCH models on the benchmark crudes, being Brent, Dubai/Oman and WTI. Li and Thompson (2010) consider the volatility of monthly prices of crude oil between 1990 and 2008. They find long persistence in the variance of oil price shocks concluding that oil prices show a deterministic trend.

Given that energy prices are known to contain structural breaks and are also characterized by volatility that changes over time we address this gap by adopting a novel unit root test due to CHLT, that unifies these characteristics together. This paper aims to determine whether unit roots exist in benchmark crude oil prices allowing for the possibility of a structural break *and* non-stationary volatility.

Econometric Methods

This section describes the various novel econometric methods to be applied in this study. We start by first making use of the Inclan and Tao (1994) method and the more recent method due to Sanso et. al. (2004) to examine whether the price series are characterised by nonstationary volatility. We also detect whether breaks are present in the data or not by making use of the Perron and Yabu (2009) method. The advantage of this procedure is that we can be completely agnostic of the underlying order of integration of the price series. If we obtain evidence of a structural break, we then use the sequential procedure due to Kejriwal and Perron (2010) to investigate the possibility of further breaks. Given the number of breaks, we apply the CKP test of unit roots that accommodates multiple breaks. We then proceed to apply the novel unit root test due to CHLT that allows for the possibility of a structural break and more importantly, non-stationary volatility. The following briefly describes each of these econometric procedures.

Procedure to test for nonstationary volatility

In order to test the null hypothesis of constant unconditional variance, Inclan and Tiao (1994) proposed to use the statistic given by:

$$IT = \sup |\sqrt{T/2D_k}\,|$$

where $D_k = \frac{C_k}{C_T} - \frac{k}{T}$

and $C_k = \sum_{t=1}^{k} \varepsilon_t^2$, $k = 1,2, \dots, T$ is the cumulative sum of squares.

Under the assumption that $\varepsilon_t \sim iidN(0, \sigma^2)$ the asymptotic distribution of the test is given by:

$$T \Rightarrow \sup |W^*(r)|$$

Where $W^*(r) \equiv W(r) - rW(1)$ is a Brownian Bridge, $W(r)$ is a standard Brownian motion and the notation $\Rightarrow$ stands for weak convergence of the associated probability measures.

The Inclan and Tiao (1994) method has two drawbacks being: (a) it does not allow for conditional heteroscedasticity and (b) it ignores the fourth moments. Sanso et. al. (2004) takes into account these features and produces a correctly sized test (κ) at the expense of a slight loss of power in comparison to the Inclan and Tiao method. Sanso et. al. (2004) recommend to use both the tests to check for nonstationary volatility.

Procedure to detect Structural Breaks

Perron and Yabu (2009) propose a novel method to detect a break in the trend function based on a Feasible Quasi Generalized Least Squares (FGLS) method. First, the following auto regression on the error term in a trend equation is estimated:

$$\hat{u}_t = \alpha\hat{u}_{t-1} + \sum_{i=1}^{k}\varphi_i u_{t-i} + e_{tk}$$

where the lag length k is chosen using the Bayesian Information Criteria (BIC). The estimate of α is obtained using OLS, denoted $\tilde{\alpha}$. Perron and Yabu (2009) use a bias corrected version of $\tilde{\alpha}$, denoted by $\tilde{\alpha}_M$, to improve the finite sample properties of the tests, proposed by Roy and Fuller (2001). In the next step, Perron and Yabu (2009) calculate the super-efficient estimator of α given by:

$$\tilde{\alpha}_{MS} = \begin{cases} \tilde{\alpha}_M & \text{if } |\tilde{\alpha}_M - 1| > T^{-1/2} \\ 1 & \text{if } |\tilde{\alpha}_M - 1| \leq T^{-1/2} \end{cases}$$

Using a super-efficient estimate is crucial for obtaining nearly identical limit properties in the I (0) and I(1) cases. The estimate $\tilde{\alpha}_{MS}$ is then used to construct the quasi differenced regression

$$(1-\alpha_{MS}L)y_t = (1-\tilde{\alpha}_{MS}L)x'_{L1,t}\Psi + (1-\tilde{\alpha}_{MS}L)u_t\,; \qquad t = 2,3,\ldots\ldots\ldots,T$$

$$y_t = x'_{L1,1}\Psi + u_1$$

where $\Psi = (\mu_0, \beta_0, \mu_1, \beta_1)'$. The resulting estimates from the regression are denoted as $\tilde{\Psi}^{FG} = \left(\tilde{\mu}_0^{FG}, \tilde{\beta}_0^{FG}, \tilde{\mu}_1^{FG}, \tilde{\beta}_1^{FG}\right)'$. The Wald test $W_{QF}(\lambda_1)$ for a particular break function λ_1, where the subscript QF denotes the Quasi Feasible GLS is given by

$$W_{QF}(\lambda_1) = \frac{\left(\tilde{\beta}_1^{FG}(\lambda_1)\right)^2}{\sqrt{\left(\tilde{h}_v(\lambda_1)\right)\left[(X^{a'}X^a)^{-1}\right]_{44}}}$$

Where $X^a = \left\{x_{L1,1}, (1-\tilde{\alpha}_{MS}L)x_{L1,2}, \ldots\ldots, (1-\tilde{\alpha}_{MS}L)x_{L1,T}\right\}'$. The quantity $\tilde{h}_v(\lambda_1)$ is an estimate of (2π times) the spectral density function of $v_t = (1-\alpha L)u_t$ at frequency zero. If $|\tilde{\alpha}_{MS}| < 1$, a kernel-based estimator given by

$$\tilde{h}(\lambda_1) = T^{-1}\sum_{t=1}^{T}\hat{v}_t^2(\lambda_1) + 2T^{-1}\sum_{j=1}^{T-1}k\left(j,\tilde{l}\right)\sum_{t=j+1}^{T}\hat{v}_t(\lambda_1)\hat{v}_{t-j}(\lambda_1)$$

is employed where $\hat{v}_t(\lambda_1)$ are the least squares residuals. The function $k\left(j,\tilde{l}\right)$ is the quadratic spectral kernel and the bandwidth $\tilde{l}$ is chosen according to the plug-in method put forward by Andrews (1991) using an AR(1) approximation. When $\tilde{\alpha}_{MS} = 1$, the estimate suggested is an autoregressive spectral density estimate that can be obtained from the regression:

$$\hat{v}_t = \sum_{i=1}^{k}\xi_i\hat{v}_{t-i} + e_{tk}$$

where the lag length k is again chosen using the BIC. Perron and Yabu (2009) consider the Mean, Exp, and Sup functionals of the Wald test for different break dates. They found that with the Exp functional, the limit distribution in the I(0) and I(1) cases are nearly identical. They recommend the following statistic to determine the structural break:

$$ExpW = \log\left[T^{-1}\sum_{\lambda_1\in\Lambda_1}\exp\left(\frac{1}{2}W_{QF}(\lambda_1)\right)\right]$$

In the spirit of Perron and Yabu (2009), Kejriwal and Perron (2010) propose a sequential procedure that allows one to obtain a consistent estimate of the true number of breaks irrespective of whether the errors are I(1) or I(0). The first step is to conduct a test for no break versus one break. Conditional on a rejection, the estimated break date is obtained by a global minimization of the sum of squared residuals. The strategy proceeds by testing each of the two segments (obtained using the estimated partition) for the presence of an additional break and assessing whether the maximum of the tests is significant. Formally, the test of one versus two breaks is expressed as:

$$ExpW(2|1) = \max_{1\le i\le 2}\left\{ExpW^{(i)}\right\}$$

where $ExpW^{(i)}$ is the one break test in segment i. We conclude in favour of a model with two breaks if $ExpW(2|1)$ is sufficiently large.

Procedure to test for Unit Roots with Structural Breaks

Consider a trend equation where the estimates of the break fractions λ_i and the regression parameters are obtained by minimizing the sum of squared residuals from a quasi-differenced regression. The sum of squared residuals evaluated at these estimates is denoted $S(\alpha(\hat{\lambda}), \hat{\lambda})$, where $\alpha(\hat{\lambda}) = 1 - \frac{c(\hat{\lambda})}{T}$. The feasible point optimal statistic is then given by:

$$PT - GLS = \frac{S(\alpha(\hat{\lambda}), \hat{\lambda}) - \alpha(\hat{\lambda})S(1, \hat{\lambda})}{s^2(\hat{\lambda})}$$

Where $s^2(\hat{\lambda}) = s_{ek}^2 / [1 - b(1)]^2$ and $s_{ek}^2 = (T-k)^{-1}\sum_{t=k+1}^{T}\hat{e}_{tk}^2$; $\hat{b}(1) = \sum_{j=1}^{k}\hat{b}_j$. Both $\hat{b}_j$ and $\hat{e}_{tk}$ are obtained using OLS estimation of the following equation:

$$\Delta\tilde{y}_t = b_0\tilde{y}_{t-1} + \sum_{j=1}^{k} b_j\Delta\tilde{y}_{t-j} + e_{tk}$$

Where $\tilde{y}_t = y_t - \hat{\Psi}_2' x_{Li,t}(\hat{\lambda})$; $x_{Li,t}(\hat{\lambda}) = \{1, t, DU_{it}(\hat{\lambda}), DT_{it}(\hat{\lambda})\}$; i denotes the number of breaks; and $\hat{\Psi}_2'$ is the OLS estimate of the quasi differenced regression (4).

Carrion-i-Silvestre et al. (2009) also consider extensions of the M-class of tests analysed in Ng and Perron (2001). These extensions involve the inclusion of multiple structural breaks, building on the work of Perron and Rodriguez (2003). The statistics computed by Carrion-i-Silvestre et al. (2009) are similar to Ng and Perron (2001) where the null hypothesis is that of a unit root against the alternative of stationarity with the symmetric treatment of structural breaks in the null and alternative hypothesis. These statistics are computed as follows:

$$MZA = \left[T^{-1}\tilde{y}_T^2 - s^2(\lambda)\right]\left(2T^{-2}\sum_{t=2}^{T}\tilde{y}_{t-1}^2\right)^{-1}$$

$$MSB = \left(T^{-2}\sum_{t=2}^{T}\tilde{y}_{t-1}^2\right)^{1/2} \Big/ s^2(\hat{\lambda})$$

$$MZT = \left[T^{-1}\tilde{y}_T^2 - s^2(\lambda)\right]\left(4s^2(\hat{\lambda})T^{-2}\sum_{t=2}^{T}\tilde{y}_{t-1}^2\right)^{-1/2}$$

where $s^2(\hat{\lambda})$, $\tilde{y}_t$ and $c(\hat{\lambda})$ have already been defined. The computation of the critical values of these powerful unit root tests are described by Carrion-i-Silvestre et al. (2009). Simulation evidence presented in Carrion-i-Silvestre et al. (2009) shows that the tests allowing up to two breaks have good finite sample power when the data generating process is driven by one or two breaks. Given that these tests exploit information regarding the presence of breaks these tests have better power than those based on search procedures.

Procedure to test for Unit Roots with a possible structural break and nonstationary volatility.
CHLT consider the following model

$$P_t = \alpha + \beta t + \gamma DT(\lambda) + \varepsilon_t; \quad t = 1,2, \dots\dots, T.$$
$$\varepsilon_t = \rho_T \varepsilon_{t-1} + \eta_t; \quad t = 2,3, \dots., T.$$
$$\eta_t = C(L)e_t$$
$$e_t = \sigma_t z_t$$

Equation (1) allows for the possibility of a structural break in the trend; where γ denotes the break magnitude, λ denotes the unknown break fraction, so that the break point is given by $\lfloor \lambda T \rfloor$. CHLT assume the initial condition satisfies $T^{-1/2}\varepsilon_1 \xrightarrow{p} 0$. Two further assumptions are made: First, the lag polynomial satisfies $C(z) \neq 0, \forall\ z \leq 1$ and $\sum_{j=0}^{\infty} jc_j < \infty$; $z_t \sim IID(0,1)$; $E|z_t|^r < K < \infty$ for some $r \geq 4$; $\sigma_t = \omega(t/T)$ where ω is non-stochastic and strictly positive. Secondly, as $T \to \infty$, the lag truncation parameter p in the QD detrended ADF test satisfies the condition $1/p + p^3/T \to 0$.

Consider the case where a break occurs at λ. The M-statistics evaluated by CHLT are given by:

$$MZ_a(\tau, c) = \frac{T^{-1}\varepsilon_t^2 - s_{AR}^2(p)}{2T^{-2}\sum_{t=2}^{T}\varepsilon_{t-1}^2}$$

$$MSB(\tau, c) = \left[\frac{T^{-2}\sum_{t=2}^{T}\varepsilon_{t-1}^2}{s_{AR}^2(p)2T^{-2}}\right]^{1/2}$$

$$MZ_t(\tau, c) = MZ_a(\tau, c) \times MSB(\tau, c)$$

Where $s_{AR}^2(p)$ is an autoregressive estimator of the non-normalised spectral density at frequency zero of η_t.

Data and Empirical Results

The data used in this analysis are the three benchmark crude oils being WTI, Brent and Dubai/Oman which were obtained from the *International Financial Statistics*. These are free market price indices with monthly frequency spanning from January 1985 to July 2013. The span is chosen so that we can include the Dubai/Oman price which is available from 1985 on a monthly basis alongside the other two benchmarks being WTI and Brent. Also, during 1985 there was a marked shift in the OPEC pricing policy.

We first determine whether the prices chosen in this study show any evidence of nonstationary volatility and structural breaks. To determine whether there is any evidence of a break in variance we employ the popular test due to Inclan and Tiao (1994) and the more recently developed test due to Sanso et.al. (2004). Both the tests show evidence of nonstationary volatility with breaks in variance. Interestingly we find the preponderance of breaks in variance to be centred around 1999 and 2004 for all the three benchmark crudes. The results are shown in Table 1 below.

[Table 1 about here]

The break in variance at around mid-1999 corresponds to a turning point when oil prices tumbled to a low and then experienced an upturn. The crude oil prices started to tumble from 1997. In December 1997, OPEC increased its quota by 2.5 million barrels per day (that is, 10 percent) to 27.5 million barrels per day with effect from January 1998. However, economic growth in Asian economies stagnated and. in 1998 Asian Pacific oil consumption declined for the first time since 1982. The combination of lower consumption and higher OPEC production sent prices into a downward spiral and continued down through December 1998. Prices began to recover in early 1999. In April, OPEC reduced production by another 1.719 million barrels. As usual not all of the quotas were observed, but between early 1998 and the middle of 1999 OPEC production dropped by about three million barrels per day. The cuts were sufficient to move prices above $25 per barrel. With growing U.S. and world economies, the price continued to rise throughout 2000 to a post 1981 high. In 2000 between April and October, three successive OPEC quota increases totalling 3.2 million barrels per day were not able to stem the price increase. Prices finally started down following another quota increase of 500,000 effective November 1, 2000. The break in variance observed around 2004 During much of 2004 the spare capacity to produce oil was less than a million barrels per day. A million barrels per day is not enough spare capacity to cover an interruption of supply from most OPEC producers. In a world that consumes more than 80 million barrels per day of petroleum products that added a significant risk premium to crude oil price and was largely responsible for prices in excess of $40-$50 per barrel. The reason for this sharp break in variance as well as trend may be due to the loss of production capacity in Iraq and Venezuela combined with increased OPEC production to meet growing international demand led to the erosion of excess oil production capacity. For instance, in mid-2002 there were more than six million barrels per day of excess production capacity and by mid-2003 the excess was below two million. A further break in variance is found for the Brent crude oil in November 2010. This date immediately precedes February 2011, when prices jumped as a consequence of the loss of Libyan exports in the face of the Libyan civil war. Concern about additional interruptions from unrest in other Middle East and North African producers continues to support the price volatility in this period.

For structural breaks we employ the Kejriwal and Perron (2010) test. The advantage of employing this procedure is that we can be agnostic about the underlying order of integration of the price series. The results are contained in Table 1 above. Applying this test we find that for all the three benchmark crudes we find evidence of a single structural break. The break date is found to be around mid-2004 for WTI and Brent, while for Dubai the break date is in early 2002. Based on this result, we can conclude that studies which allow for two structural breaks such as the Lee and Strazicich (2003) test risk the problem of lowering the power of the unit root test by including an extra unnecessary break.

The break in trend for WTI and Brent occurs around the same time when we find a break in variance. For the Dubai crude benchmark, the break date is February 2002. In 2001, a weakened US economy and increases in non-OPEC production put downward pressure on prices. In response OPEC once again entered into a series of reductions in member quotas cutting 3.5 million barrels by September 1, 2001. In the absence of the September 11, 2001 terrorist attacks, this would have been sufficient to moderate or even reverse the downward trend. In the wake of the attack, crude oil prices plummeted. Under normal circumstances a drop in price of this magnitude would have resulted in another round of quota reductions. Given the political climate OPEC delayed additional cuts until January 2002. It then reduced its quota by 1.5 million barrels per day and was joined by several non-OPEC producers including Russia which promised combined production cuts of an additional 462,500 barrels. This had the desired effect with oil prices moving into the $25 range by March 2002 leading to a change in trend.

Accordingly, we employ a unit root test due to CKP that allows us to incorporate a single structural break in the unit root null and a break in the stationary alternative hypotheses. The results of the unit root test with structural break are found in Table 2 below.

[Table 2 about here]

We find that the null hypothesis of a unit root cannot be rejected for all three of the benchmark crudes. Comparing the estimated statistic using the M type tests described in the econometric methods section, we find that the critical values are greater in absolute terms thereby leading us to conclude that using this M type test we conclude that the oil prices are all I(1). This implies that the shocks to the benchmark crude oils are permanent in nature.

However, as argued earlier, none of these tests so far account for nonstationary volatility which is clearly present in the benchmark crude oil price data. When we run the tests due to CHLT that allow not only for the possibility of a structural break but also for non-stationary volatility which is a closer representation of actual benchmark crudes, we find that two out of the three benchmark crudes (Brent and WTI) reject the null hypothesis of a unit root at the 1% significance level and the Dubai/Oman price is rejected at the 10% level. This result allows us to conclude that all these crudes actually have a transitory response to a shock. These results are contained in Table 3 below.

[Table 3 about here]

We can therefore conclude, that the presence of non-stationary volatility in the crude oil prices can have a crucial impact on the results of unit root tests which are considered to be quite novel in the sense that the allow for the symmetric treatment of structural breaks, such as the CKP tests. We find that using a unit root test such as the CHLT that allows for a possible structural break as well as nonstationary volatility can lead to conclusions about persistence in crude oil prices to be drastically different from the CKP test.

Our findings have strong implications for investment decisions. We might presume that the finding where novel tests employed lead to reject the unit root hypothesis is due to the presence of transitory shocks to the crude oil price series. If indeed this is true, and considering the approximate investment horizon of 30 years in oil fields, it would imply that we cannot quite ignore the mean reverting components. Indeed the neglected volatility in the data reverses the results obtained by popular unit root tests applied on oil price data. This may not be unsurprising given the evidence by Hamilton (1996) where he highlights that the uncertainty of so called persistence, which may be a result of nonstationary volatility in oil prices, may delay irreversible investment decisions and, as such, a negative price shock may not confer a positive effect on the economy. Also, the fact that possibly too many breaks (two instead of one) were incorporated in the studies by Maslyuk and Smyth (2008) thereby concluding that the oil prices contain a unit root, which is likely to be a result of a low power of the tests by using extraneous dummy variables. Thus in the case where we are able to reject the unit root hypothesis in the presence of possible structural break and nonstationary volatility, this does not necessarily imply a rejection of weak form efficiency, but emphasizes the role structural breaks might play when assessing if a the crude oil price series is trend or difference stationary (Serletis, 1992) and that oil price volatility adds to the complexity. We might then conclude that despite our finding of trend stationarity for two out of the three benchmark crudes, the expert may not outperform the uninformed well diversified investor.

Conclusions

This paper examines and discusses the temporal properties of the benchmark crude oils. The results have significant consequences for energy related econometric analysis, forecasting, investment decisions and macroeconomic policy-making besides the implications for stabilization policies. Given the new find of transitory shocks in two leading benchmark crude oil prices allowing for the possibility of a structural break and non-stationary volatility, policy makers would need to exercise caution whether these energy commodities are less amenable to stabilization policies. For example, after the oil price shock in the early 1970s, the price controls imposed by the US government may not have been necessary if the prices were to revert back to the long term trend. Similarly, the OPEC production quotas of the early 1980s may have been redundant if the oil prices were to exhibit a deterministic trend. The finding of a deterministic trend provides support for the optimal depletion models of Hotelling (1931). We find that using a novel and more appropriate unit root test that allows for nonstationary volatility the conclusions about persistence in crude oil prices can be drastically different. In general, our findings suggest that the global economy experiences shocks which have a transitory effect on WTI and Brent oil prices, thereby reverting to a long-run trend whose path is determined by structural fundamentals. However beyond the economic rhetoric, identifying the correct time series process remains a crucial issue for the macroeconomic policy maker.

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TABLES

Table 1: Structural Breaks in Variance

	Tests for break in variance		**Sequential Test for Structural Breaks**	
	Inlan Tiao Test	**Kappa 2**	**Kejriwal Perron 0|1**	**Kejriwal Perron 1|2**
WTI	Oct 1999, July 2004	Oct 1999, July 2004,	2.70* (Jun 2004)	-0.22
Brent	Oct 1999, Feb 2004, Nov 2010	Oct 1999, Feb 2004, Nov 2010	9.05*(Apr 2004)	-0.21
Dubai	Aug1999, Apr 2004	Aug 1999, Apr 2004,	16.05* (Feb 2002)	0.34

*denotes rejection of the null hypothesis at the 10% significance level.

Table 2 CKP Test on Benchmark Oil Prices

	MZa statistic				**MSB statistic**				**MZt statistic**			
	stat	Bootstrapped Crit. Val.			stat	Bootstrapped Crit. Val.			stat	Bootstrapped Crit. Val.		
		1%	5%	10%		1%	5%	10%		1%	5%	10%
WTI	-16.907	-28.340	-20.899	-17.327	0.172	0.133	0.155	0.170	-2.904	-3.749	-3.219	-2.928
Brent	-11.285	-28.114	-20.792	-17.226	0.210	0.133	0.155	0.170	-2.372	-3.738	-3.212	-2.920
Dubai	-9.604	-28.114	-20.792	-17.226	0.228	0.133	0.155	0.170	-2.187	-3.738	-3.212	-2.920

Table 3 CHLT Test on Benchmark Oil Prices

	MZa statistic				**MSB statistic**				**MZt statistic**			
	stat	Bootstrapped Crit. Val.			stat	Bootstrapped Crit. Val.			stat	Bootstrapped Crit. Val.		
		1%	5%	10%		1%	5%	10%		1%	5%	10%
WTI	-42.034[a]	-34.029	-24.688	-20.367	0.109[a]	0.121	0.141	0.153	-4.563[a]	-4.123	-3.481	-3.206
Brent	-38.128[a]	-34.687	-24.466	-21.093	0.114[a]	0.119	0.143	0.152	-4.341[a]	-4.163	-3.497	-3.234
Dubai	-21.420	-38.497	-24.983	-21.533	0.151[c]	0.114	0.141	0.152	-3.242	-4.387	-3.511	-3.252

[a] denotes rejection of the null hypothesis at the 1% significance level, [c] denotes rejection of null hypothesis at the 10% level.