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DETECTING BUBBLES IN OIL MARKET USING SADF APPROACH: CASES OF WTI AND BRENT OIL FUTURES

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ABSTRACT

The paper analyzes the bubbles in oil markets using the SADF (*supremum* Augmented Dickey-Fuller) test. Weekly data of the prices of WTI and Brent Oil futures covering the period between April 1995 and April 2020 has been used. According to the results of both tests, the bubbles have been identified as some different historical episodes. The prices of WTI futures seem to have less period of bubbles rather than Brent Oil futures. Number of bubble episodes is also smaller for the price of WTI futures. SADF test results indicate that there are 236 weeks of the bubble in the price of Brent Oil futures and 98 for that of WTI futures.

Keywords: *SADF, bubble, Brent Oil futures, WTI futures*

JEL classifications: C5, Q41, Q47

1. INTRODUCTION

In economic theory, a bubble is when the cost of an asset is greater than its intrinsic value. Prices usually rise in a bubble when people show an extremely positive attitude toward an asset. When bubbles eventually burst, people are left with nothing when they have not made a sale of the asset in expectation of a price increase[1]. Next, the question arises whether it is difficult to determine bubbles beforehand or not. In fact, bubbles can only be detected as they burst. It is difficult to see them up to this point. Considering the close relationship of bubbles to the crises in financial markets, the detection of financial bubbles is of great importance. However, the challenges encountered in determining the presence of balloons pose an obstacle in taking measures for bubbles formation by regulators to the market by making necessary analysis. Since the importance of the subject in the literature is an indisputable fact, many studies have been carried out to determine the presence of bubbles.

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Traditional unit root and co-integration tests aimed at identifying such periods, as e.g. proposed by Diba and Grossman (1988), may not detect the existence of bubbles when they are periodically collapsing[2]. As Evans (1991) points out, "when seeking to identify multiple periodically collapsing bubbles within a single data set using stationarity tests, the process is greatly complicated and exposed to the possibility of identifying pseudo stationary behavior" [3].

To solve this problem, PSY (2011) and PWY (2011) developed right-tailed ADF testing procedures to detect and date stamp mildly explosive behavior of the financial assets. PSY, (2013) extended the methodologies of PWY, (2011) and PSY, (2011) in that it recursively identifies explosivity as rejecting the null hypothesis of unit-root non-stationarity for the right-tailed alternative of explosivity [4]. They found this strategy to significantly outperform previously used right-tailed ADF estimations in identifying multiple bubbles using Monte Carlo simulations. In particular, the PSY, (2013) approach overcomes the mentioned problem of detecting multiple episodes of periodically recurring explosivity.

Caspi et.al (2018) investigated the bubbles in oil market using GSADF approach. They found that there are speculative bubbles both in the real price and the price to supply ratio of oil during the period of 1876-2014[5]. Chi Wei-Su et.al (2016) applied the GSADF tests proposed by Phillips et al. (2013) to time-stamp speculative bubbles in the crude oil market from 1985 to 2016. The result indicates that there are explosive multiple bubbles in the WTI oil prices in 1990, 2005-2008 and 2015[6]. Ghassen El Montasser et.al (2015) tested for the existence of bubbles in the ethanol to gasoline price ratio in Brazil from 2000 to 2012 using SADF and GSADF tests. Results show the existence of two bubbles: one which has already happened; and another one which has been ongoing since 2010[7].

2. MODEL SPECIFICATION

"To detect the bubbles in time series, following regression equation is employed;

$$y_t = dT^{-\eta} + \theta y_{t-1} + \varepsilon_t, \varepsilon_t \sim^{iid} (0, \sigma^2), \theta = 1 \quad (1)$$

Where d is constant, T is the sample size, the parameter η is a coefficient that controls the magnitude of intercept and drift as $T \rightarrow \infty$. Solving equation (1) gives the following simplified equation;

$$y_t = d\frac{1}{T^\eta} + \sum_{j=1}^{t} \varepsilon_j + y_0 \quad (2)$$

Where if $\eta > 0$ the deterministic drift is small relative to a linear trend, when $\eta > 0.5$, the deterministic drift is small relative to the martingale component of y_t, and when $\eta < 0.5$, the standardized output $T^{-0.5} y_t$ behaves asymptotically like a Brownian motion with drift [8]."

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The first equation is usually complemented with transitory dynamics in order to conduct tests for exuberance, just as in standard ADF unit root testing against stationarity [4]. "The recursive approach that we now suggest involves a rolling window ADF style regression integration based on such a system. In particular, suppose the rolling window regression sample starts from the r_1^{th} fraction of the total sample (T) and ends at the r_2^{th} fraction of the sample, where $r_2 = r_1 + r_w$ and $r_w > 0$ is the (fractional) window size of the regression [9]. The empirical regression model can then be written as

$$\triangle y_t = \hat{\alpha}_{r_1,r_2} + \hat{\beta}_{r_1,r_2} y_{t-1} + \sum_{i=1}^{k} \hat{\psi}_{r_1,r_2}^{i} \triangle y_{t-i} + \hat{\varepsilon}_t \ (3)$$

Where k is the lag length, for research purposes we choose Akaike Information Criteria (AIC). The number of observations in the regression is $T_w = [Tr_w]$, and r_w is the window size. The window size can be in range between r_0 and 1. The starting point r_1 of the sample sequence is fixed at 0, so the endpoint of each sample (r_2) equals r_w and changes from r_0 to 1. The ADF statistic based on this regression is symbolized by $ADF_{r_1}^{r_2}$ and for a sample that runs from 0 to r_2 is denoted by $ADF_0^{r_2}$ [10]. Testing for a bubble is based on a right-tail form of the standard unit root test where the null hypothesis indicates there is a unit root in a time series."

$$H_0: \hat{\beta}_{r_1,r_2} = 1$$

$$H_1: \hat{\beta}_{r_1,r_2} > 1$$

The SADF test is based on circular calculations of the ADF statistics with a fixed starting point and a window, where the initial size of the window is set by the user. "The estimation procedure goes as follows: The first observation in the sample is set as the starting point of the estimation window, r_1, i.e., $r_1 = 0$. Next, the end point of the initial estimation window, r_2, is set according to some choice of minimal window size, r_0 such that the initial window size is $r_w = r_2$. Finally, the regression is recursively estimated, while incrementing the window size, $r_2 \in [r_0, 1]$, one observation at a time. Each estimation yields an ADF statistic denoted as ADF_{r_2} [11]. In the last step, estimation will be based on the whole sample (i.e., $r_2 = 1$ and the statistic will be ADF_1)." SADF statistic is defined as;

$$SADF(r_0) = sup_{r_2 \in [r_0,1]} ADF_0^{r_2} \ (4)$$

SADF use a right tail form of the Augmented Dickey-Fuller unit root test where the null hypothesis is of a unit root and the alternative is of a *mildly explosive* process [11].

As PWY and PSY show, the SADF procedure can also be used, under general regularity conditions, as a date-stamping strategy that estimate the start and end of bubbles. In other words, if the null hypothesis of the test is rejected, one can estimate the start and end points of a specific

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bubble. PWY propose comparing each element of the estimated $ADFr_2$ sequence to the corresponding right-tailed critical values of the standard ADF statistic to identify a bubble starting at time Tr_2 [12]. The estimated starting point of a bubble is the first observation, denoted by Tr_e, in which $ADFr_2$ crosses the corresponding 95% critical value from below, while the estimated termination point is the first observation after Tr_e, denoted by Tr_f, in which $ADFr_2$ crosses below the 95% critical value[11]. Formally, the estimates of the bubble period are defined by

$$\hat{r}_e = inf_{r_2 \in [r_0,1]}\left\{r_2 : ADF_{r_2} > cv_{r_2}^{\beta_T}\right\} \quad (5)$$

$$\hat{r}_f = inf_{r_2 \in [\hat{r}_e,1]}\left\{r_2 : ADF_{r_2} < cv_{r_2}^{\beta_T}\right\} \quad (6)$$

Where $cv_{r_2}^{\beta_T}$ is the 100(1-β_T)% critical value of the standard ADF statistic based in [Tr_2] observations."

3. RESULTS

3.1 Descriptive statistics

Table 1 shows the descriptive statistics of variables. The average price of WTI and Brent Oil futures has been \$53.5506 and \$55.9514 respectively. Weekly prices of WTI futures reached its peak in June 2008 (\$145.29) and its minimum in December 1998 (\$10.79). On the other hand, weekly prices of Brent Oil futures saw its maximum in July 2008 (\$144.4900) and its minimum in December 1998 (\$9.82). According to the results of standard deviation, prices of Brent Oil futures have been more volatile than that of WTI. Both of distributions of the oil indicators are positively skewed and platykurtic.

Table 1: Descriptive statistics of variables

Statistics/Variable	WTI futures	Brent Oil futures
Mean	53.5506	55.9514
Median	50.6600	53.3500
Maximum	145.2900	144.4900
Minimum	10.7900	9.8200
Standard deviation	28.9585	32.6928
Skewness	0.4849	0.5031

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Kurtosis	2.2850	2.1584

The numerical methods include the skewness and kurtosis coefficients whereas normality test is a more formal procedure since it involves testing whether a particular data follows a normal distribution. There are more than 40 normality tests available in the statistical literature. However, the most commonly used normality test procedures are the Cramer-von Mises test, Anderson-Darling test, Shapiro-Wilk test, Shapiro-Francia test and Lilliefors test. The null hypothesis of all the tests mentioned above indicate that the data is normally distributed [13–17]. Probability values force us to reject null hypothesis in all tests. Thus, both prices of Brent Oil and WTI futures are not normally distributed.

Table 2: Normality test results

Method	Brent Oil futures		WTI futures	
	Values	Probability	Values	Probability
Lilliefors	0.1225	0.0000	0.1065	0.0000
Cramer-von Mises	3.6973	0.0000	2.9693	0.0000
Anderson-Darling	28.0165	0.0000	21.1824	0.0000
Shapiro-Wilk	0.9293	0.0000	0.9449	0.0000
Shapiro-Francia	0.9302	0.0000	0.9456	0.0000

3.2 SADF test results

According to Table 3, p-value is less than 0.01 significance level, and we can reject null hypothesis of having a unit root. The prices of Brent-Oil and WTI futures have mildly explosive process or rational bubbles. Optimal lag length is chosen by Akaike Information Criteria (AIC). Test statistic has been calculated using Monte Carlo simulations in Eviews 10. The minimum window size is calculated as $0.01 + 1.8/\sqrt{T}$, where T is the sample size [9].

Table 3: SADF test results

Variable	t-Statistic	P-value	Lag-length	Sample size	Window size
Brent Oil futures	4.1019	0.0000	0	1305	78

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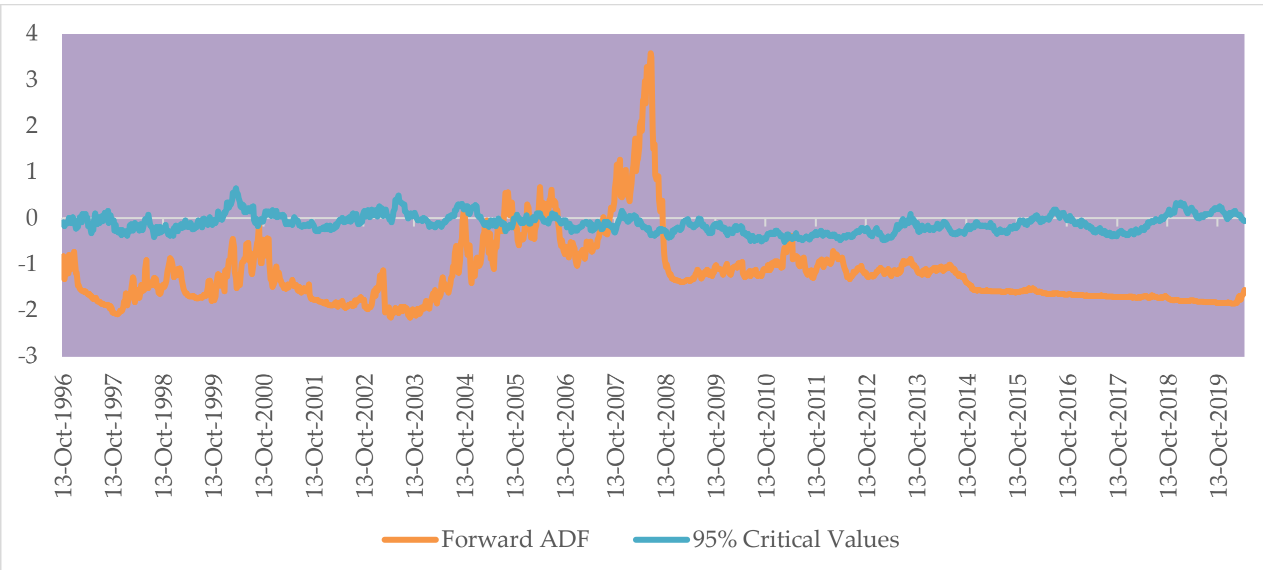
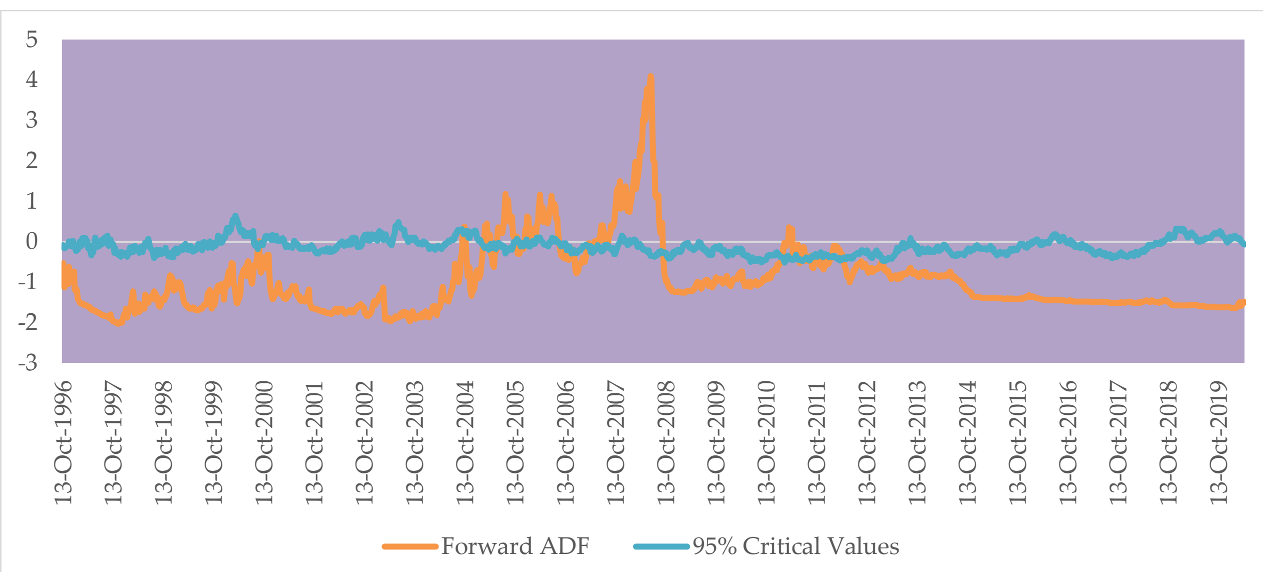
WTI futures	3.5777	0.0000	0	1305	78

Following Graph 1 and Graph 2 visualize critical values sequence and forward ADF sequence obtained by employing Monte Carlo simulation.

Graph 1: Critical value and ADF sequence (WTI futures)



Graph 2: Forward ADF and 95% critical values sequence (Brent Oil futures)



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3.3 Date-stamping the bubbles

Bubble periods are periods where green line (forward ADF sequence) is above blue line (95% critical value sequence) in Graph 1 and 2. Table 4 shows that there were 236 weeks of bubble in prices of Brent Oil futures. The longest periods of bubble are observed in 2005, 2006 and 2008.

Table 4: Bubble periods (Brent Oil futures)

Beginning of bubble	End of bubble	Period of bubble (in weeks)
September 3, 2000	September 10, 2000	1
October 3, 2004	October 17, 2004	2
February 20, 2005	April 3, 2005	6
April 10, 2005	April 17, 2005	1
May 22, 2005	May 29, 2006	53
June 5, 2005	October 30, 2005	21
December 18, 2005	February 5, 2006	7
February 12, 2006	September 3, 2006	29
November 19, 2006	November 26, 2006	1
December 3, 2006	December 10, 2006	1
March 25, 2007	April 8, 2007	2
April 15, 2007	April 22, 2007	1
April 29, 2007	September 28, 2008	74
February 13, 2011	June 12, 2011	17
June 19, 2011	July 24, 2011	5
August 14, 2011	September 4, 2011	3
January 29, 2012	April 22, 2012	12

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Table 5 shows that there were 98 weeks of bubble in prices of Brent Oil futures. The longest periods of bubble are observed in 2006 and 2008. The prices of WTI futures seem to have less period of bubbles rather than Brent Oil futures. Number of bubble episodes is also smaller for the price of WTI futures.

Table 5: Bubble periods (WTI futures)

Beginning of bubble	End of bubble	Period of bubble (in weeks)
March 6, 2005	March 13, 2005	1
March 20, 2005	March 27, 2005	1
July 17, 2005	October 2, 2005	11
December 25, 2005	January 1, 2006	1
January 8, 2006	January 29, 2006	3
April 2, 2006	August 20, 2006	20
July 1, 2007	July 22, 2007	3
August 26, 2007	September 28, 2008	57
April 17, 2011	April 24, 2011	1

4. CONCLUSION

The unusual price movements in the oil markets have made it important to develop new methods to understand this market. In the study, it was aimed to give information to the finance professionals who invested in or intend to invest in these markets by investigating the existence and duration of the balloons in the prices of WTI and Brent Oil futures, which have the highest trading volume in the oil market. Weekly data of the prices of WTI and Brent Oil futures covering the period between April 1995 and April 2020 has been used. According to the results of both tests, the bubbles have been identified as some different historical episodes. Evidence obtained by SADF method developed by Philips et al. (2015) results indicate that there are 236 weeks of the bubble in the price of Brent Oil futures and 98 for that of WTI futures. Balloon times lasting from 1 week to 57 weeks are among the remarkable findings.

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