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Analyzing Multiple Bubbles in the WTI Crude Oil Prices Using the GSADF Test

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ABSTRACT

Since most of the financial crisis caused by the bursting bubble of financial assets, the investigation of bubble behaviors and the early detection for the prevention of adverse economic consequences is important. This paper investigates whether multiple price bubbles exist in WTI crude oil prices on the basis of a recursive right tailed Generalized Supremum Augmented Dickey Fuller Test (GSADF) developed by Phillips, Shi and Yu (2015), as well as to determine date stamps of the price bubbles. In this regard, GSADF test performed by using weekly closing prices of the WTI spot prices for the period between 03.01.2016 to 13.12.2024 (468 observations). Empirical findings show that, although price inflations were detected in WTI crude oil prices during the analysis period, these price inflations did not turn into a price bubble because they did not last long.

Keywords: Price Bubbles, WTI Crude Oil, GSADF

JEL Code: C58, G10, E60

1. Introduction

The global oil market is the most important of the world energy markets because of oil's dominant role as an energy source. Crude oil is not just a commodity traded on the markets; it is a crucial factor that influences global energy prices, economic growth, employment, currency values, and international geopolitics. The price of crude oil is the most significant factor determining the prices of petroleum products. Fluctuations and bubbling behaviors in crude oil prices are monitored closely by governments, economists, and businesses alike, as they can have broad and lasting effects on the economy. Crude oil is still a major economic input factor and all economic recessions are associated with increases in oil prices. Crude oil is a fossil resource and its combustion is a major driver of climate change (Gronwald, 2016: 1).

Bubbles caused by excessive price inflation in financial asset or commodity prices and the explosion of these bubbles in the following periods threaten economic stability (Afşar and Doğan, 2019: 447). The rapid and continuous increases in asset or commodity prices suggest that there is a price bubble that is not considered rational. The price bubble is expressed as a situation where the actual value in the market increases rapidly and diverges from the fundamental value (Ghosh, 2016; Hepkorucu & Genç, 2019: 45; İskenderoğlu & Akdağ, 2019: 1085; Diba & Grossman, 1988: 520-530). If these two values are not equal, it means that risk and uncertainty are gradually increasing (Hu and Oxley, 2017: 420). Price bubbles are associated with a collapse following rapid increases in financial asset or commodity prices (Malkiel, 2010: 13).

Price bubbles are affected by demand-side shocks. After a while, investors start selling assets in their portfolios, thinking that asset prices have reached the highest level. This time, as a result of herd psychology operating in the opposite direction, asset prices are falling dramatically (Büyükduman, 2014: 83-84; Kansu, 2011: 22-26; Lind, 2009: 80). This process refers to the formation, growth and eventual explosion of the price bubble.

Traditionally, in order to detect bubbles in the prices of commodities, Chow and CUSUM tests are recommended, as well as variance, stationarity, unit root and/or cointegration tests. However, SADF (Supremum Augmented Dickey-Fuller) and GSADF (Generalized Supremum Augmented Dickey-Fuller) tests, proposed in Phillips, Wu & Yu (2011) and Phillips Shi & Yu (2015) studies, have been widely used determining price bubbles.

The recursive GSADF test, which analyzes the time series at a single level from beginning to end, examines in more detail and therefore contains more information than similar methods that take into account right-tailed distributions. This situation allows the analysis of the multi-price bubble structure in the whole time series (Hepkorucu & Genç, 2020: 47). GSADF method has a datestamping strategy that captures both the existence of price bubbles and the beginning and ending points of a bubble (Phillips, Wu & Yu, 2011: 212).

The main purpose of this study is to examine the presence of price bubbles in WTI crude oil prices with GSADF test, as well as to determine datestamps of the price bubbles. The remainder of this paper proceeds as follows. Section 2 attempts to review the relevant literature. Section 3 details the methodology. Section 4 describes the WTI crude oil prices data and presents the empirical results. Section 5 contains some concluding remarks.

2. Literature Review

Crude oil price bubbles have been a subject of extensive academic research, particularly due to their significant impact on the global economy. These bubbles are characterized by sharp increases in oil prices driven by speculative trading, followed by sudden declines when the bubble bursts.

One study by Pavlidis, Paya & Peel (2018) explores the presence of speculative bubbles in the crude oil market using market expectations of future prices. They extend methodologies for bubble detection and find no evidence of speculative bubbles during the period studied. This research highlights the challenges in identifying bubbles due to the unobservable nature of the fundamental price of oil.

Another study by Yu & Zhang (2021) investigates the sharp changes in oil prices since 2004, which exhibited bubble-like behavior. They employ a continuous-time dynamic system to isolate the contributions of speculative bubbles and fundamentals to oil price movements. Their findings suggest that while oil prices showed episodes of instability, there was no conclusive evidence of speculative bubbles.

Zhang & Wang (2015) also contribute to this field by using the Markov Regime Switching Model to analyze the WTI crude oil price bubble process. Their research provides insights into the nonlinear dynamics of oil prices and the potential for regime shifts that could indicate bubble behavior. These studies collectively underscore the complexity of detecting and understanding crude oil price bubbles, emphasizing the interplay between market fundamentals and speculative activities.

Caspi et.al. (2018) sets out to date-stamp periods of historic oil price explosivity using the GSADF test procedure. The recursive identification algorithms used in this study identify multiple periods of price explosivity. Empirical results suggest the presence of multiple periods of significant explosivity in both the real price and the price-supply ratio of oil.

Ben Douissa & Azrak (2024) aims to investigate the existence of bubbles and their contagion effect in crude oil and stock markets of oil-exporting countries Gulf Cooperation Council (GCC) from 2016 to 2021. he authors use Generalized Sup augmented Dickey–Fuller (GSADF) and Backward Sup augmented Dickey–Fuller (BSADF) to significantly identify multiple bubbles stock and oil markets with precise dates. The authors find empirical evidence of downwards bubbles in crude oil prices and in all GCC stock indexes (except the Saudi stock index) during the corona virus disease 2019 (COVID-19) outbreak.

3. Methodology

The regression model used in determining price bubbles can be written as follows (Phillips, Shi & Yu, 2015: 1047):

$$y_t = dT^{-\eta} + \theta y_{t-1} + \varepsilon_t,\ \varepsilon_t \sim^{iid} N\left(0, \alpha^2\right),\ \theta = 1 \tag{1}$$

Here; d is the intercept term, T is the number of observations, the coefficient η is constant and $T \to \infty$ is the localization-confinement coefficient which controls the magnitude of drift, and y_{t-1} means a delayed value of the respective asset series; ε_t represents the error term with constant variance that has mean 0. In the Phillips, Shi and Yu approach, the null hypothesis (H_0) assumes that the asset price follows a random walk process with an asymptotically negligible shift, while under the alternative hypothesis (H_1), it shows the existence of a bubble in prices (Ceylan et al., 2018: 266-267). When equation (1) is solved, the following equation is obtained, which gives the deterministic shift $\frac{dt}{T^{\eta}}$:

$$y_t = d\frac{t}{T^{-\eta}} + \sum_{j=1}^{t} \varepsilon_j + y_0 \tag{2}$$

Here, with $\eta > 0$, the drift is small compared to a linear trend. If $\eta > 1/2$, the drift is small relative to the martingale component of y_t. In the case of $\eta < 1/2$, the standardized $T^{-\frac{1}{2}} y_t$ output treats asymptotically like Brownian motion involving drift. In the study, $\eta > 1/2$ case, in which the magnitude level of y_t is the same as the pure random walk has been discussed.

The recursive approach includes an ADF-style regression with drift windows for stationarity testing. The regression with a drift window starts from the r_1^{th} portion of the total sample (T) and ends at the r_2^{th} portion. Where $r_2 = r_1 + r_w$ ve $r_w > 0$ is the partial window size of the regression. The empirical regression model, including $H_0 : \hat{\beta} = 1$ ve $H_1 : \hat{\beta} > 1$ can be written as:

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

Here, k (temporary) is the number of delays. $T_w = [Tr_w]$ is the base function showing the integer part $[.]$, including the total number of observations. This is shown $ADF_{r_1}^{r_2}$ in the form of ADF statistics based on regression. Thus, it is understood that this type of floating window regression is used especially for multiple bubble detection. Asymptotic critical values of GSADF test statistics are determined by Monte Carlo simulations.

The GSADF test is based on recursively repeated ADF test regressions on subsamples of the total number of observations. The window size (r_w) spreads from r_0 (the smallest sample window size) to 1 (the largest sample window size) and expresses the total sample size. The r_1 (starting point of the sample) is fixed at 0. The window size is equal to r_w, with r_2 at the sample ending point. The sample starting point r_1 changes between r_0 to 1. It is shown as the ADF statistics of a sample ranging from 0 to r_2 (Zeren & Esen, 2018: 441). Figure 1 below shows the GSADF process in the context of floating windows in the sample range (Caspi, 2013: 6)

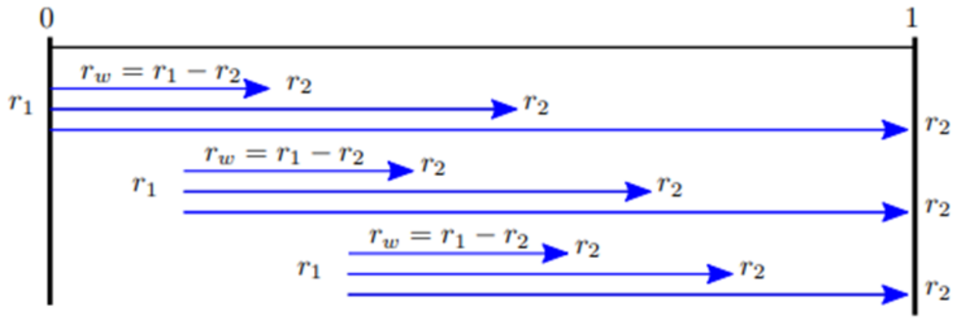

Figure 1. GSADF Test Process Sampling Range [0,1]

In the GSADF test, the sample starting point is not fixed and is shifted over the starting and ending points. Thus, it becomes possible to detect multiple bubbles with the GSADF test. Nonlinear structures and structural breaks also take into account by GSADF (Evrim Mandacı & Çağlı, 2017: 66).

The GSADF test statistic is defined as the largest ADF statistic in all applicable r_1 and r_2 ranges in this double iteration, and GSADF (r_0) is shown as follows (Phillips, Shi & Yu: 2015: 1049; Enoksen et.al., 2020: 142):

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} \left\{ ADF_{r_1}^{r_2} \right\} \qquad (4)$$

As previously shown in equation (1), the limit distribution of the GSADF test statistic, where W is a standard Wiener process and $r_w = r_2 - r_1$ can be written as follows:

$$= \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} \left\{ \frac{\frac{1}{2} r_w \left[W(r_2)^2 - W(r_1)^2 - r_w \right] - \int_{r_1}^{r_2} W(r)dr \left[W(r_2) - W(r_1) \right]}{r_w^{\frac{1}{2}} \left\{ r_w \int_{r_1}^{r_2} W(r)^2 dr - \left[\int_{r_1}^{r_2} W(r)dr \right]^2 \right\}^{\frac{1}{2}}} \right\} \qquad (5)$$

If the GSADF test statistics calculated with the help of equation (4) and therefore equation (5) are greater than the critical values calculated as a result of Monte Carlo simulations, the null hypothesis claiming that there are no financial bubbles is rejected (Çelik, Akkuş & Gülcan, 2019: 943). The rejection of the null hypothesis indicates the existence of rational bubbles in price series (Gökçe & Güler, 2020: 996).

Actually if T is small, then r_0 should be large enough to allow sufficient observation for the initial prediction. If T is large, r_0 may be smaller so that the GSADF test can detect an early burst / bubble event. A rule in simple functional form in the form of $r_0 = 0{,}01 + \frac{1{,}8}{\sqrt{T}}$ is proposed for the selection of the appropriate window size based on extensive simulation findings. When r_0 (the minimum window size) gets smaller, the critical value of the GSADF test statistic increases (Phillips, Shi & Yu, 2015: 1050).

After detecting the presence of bubbles, the formation periods of the bubbles are determined using retrospective SADF (Backwards sup ADF - BSADF) statistics series. BSADF statistical sequences are obtained using right-tailed ADF tests for samples of a backward expanding structure. BSADF and GSADF statistics can be represent as follows (Caspi, 2013: 7):

$$\left\{ BSADF_{r_2}(r_0) \right\}_{r_2 \in [r_0, 1]} \tag{6}$$

$$GSADF(r_0) = \sup_{r_2 \in [r_0, 1]} \left\{ BSADF_{r_2}(r_0) \right\} \tag{7}$$

By comparing the BSADF sequences with the set of right-tailed critical values the dates of formation of the bubbles are determined (Ceylan et al., 2018: 267).

4. Data and Empirical Results

Between 2011 and 2012, oil prices declined due to uncertainty among OPEC countries, low demand caused by the Eurozone debt crisis, and concerns about potential supply disruptions. Prices hit their lowest point between 2014 and 2016, continuing to fall as economic growth slowed and OPEC policies changed. Furthermore, U.S. sanctions on Iran limited oil exports and heightened unrest. In February 2020, oil prices dropped again due to concerns over the economic impact of the corona virus, with China, the world's second-largest oil consumer, experiencing an even greater economic effect (Khan et.al., 2021: 2).

West Texas Intermediate (WTI) is a grade of crude oil that is produced in the United States and serves as a critical benchmark for oil pricing both domestically and internationally. It is one of the most traded oil types in the world and is often used as a reference point for pricing other crude oils. WTI is characterized by its light weight and low sulfur content.

In the study, the existence of speculative price bubbles in WTI crude oil prices since 2016 and the bubble formation dates were determined by the right-tailed GSADF unit root test proposed by Phillips, Shi & Yu (2015), as well as to determine date stamps of the price bubbles. In this regard, GSADF test performed by using weekly closing prices of the WTI spot prices for the period between 03.01.2016 to 13.012.2024 (468 observations). The data are taken from EIA (U.S. Energy Information Administration) database.

The empirical findings of the study have been interpreted by presenting them with the help of tables and graphics. The appropriate window size for the WTI crude oil price series was calculated with the $r_0 = 0{,}01 + \frac{1{,}8}{\sqrt{T}}$ formula and was determined as 44.

The usual descriptive statistics for WTI crude oil price series are summarized in Table 1. According to Table 1, while the maximum and minimum values are 120.43 and 3.32 respectively, the volatility (standard deviation) value is also high (18.61338). The coefficient of skewness (0.258041) is positive and there is a right skewed distribution. The kurtosis coefficient is

3.183133 and close to critical value for a normal distribution. Additionally, by Jarque-Bera statistics and corresponding p-value we accept the null hypothesis that WTI crude oil price series are well approximated by the normal distribution.

Table 1. *Descriptive statistics of WTI crude oil price series*

	WTI
Observation	468
Mean	63.50201
Minimum	3.320000
Maximum	120.4300
Standard Deviation	18.61338
Skewness	0.258041
Kurtosis	3.183133
Jarque-Bera	5.847623
(Prob.)	(0.053729)

Source: *Author's calculations.*

From the descriptive graph presented in Figure 1, several increase periods can be observed especially in 2018, 2020, 2021 and 2022. These graphical expositions show that WTI crude oil price series exhibit price bubbles.

Figure 1. *Weekly closing prices for WTI crude oil price series*

In the WTI crude oil price series, it is important to determine whether the upward trends experienced especially in 2018, 2020, 2021 and 2022 are price bubbles, as well as the start and end dates of the bubble. In this context, the GSADF method can offer an "early warning" tool (Ceylan et al., 2018: 268).

Table 2 shows the GSADF test statistics given in equation (4) and equation (5) for the WTI crude oil price series. Critical values are obtained with 2000 trials based on Monte Carlo simulations according to the appropriate window size (Gökçe & Güler, 2020). Accordingly, (468-44) x2,000 = 848,000 regressions were estimated. The GSADF test statistic is significantly greater than the critical value at 99% confidence level. Statistically, it has been understood that there are price bubbles in the WTI crude oil price series for the period of 03.01.2016 to 13.012.2024.

Table 2. *GSADF Test Statistic Results*

Variable	GSADF Test Statistic	Test Critical Values	Window Size	Lags	Price Bubbles
WTI Crude Oil	3,324657*	2.867929 (99%) 2.235735 (95%) 2.010294 (90%)	44	0	YES

Source: *Author's calculations.*

According to Table 1, one can specify that the WTI crude oil prices contains explosive sub-periods. The null hypothesis that H_0: $r = 1$ at 1% significance critical value is rejected because the GSADF test statistic (3.324657) is greater than the critical value (2.867929).

After determining the existence of price bubbles, the number of bubbles formed during the analysis period and the start-end dates of the bubbles can be observed with the BSADF method as explained before. The critical value of the BSADF sequence indicates the starting point of the price bubble, and the crossing downwards indicates the ending point of the price bubble. In addition, the larger the part of the BSADF sequence that remains above the critical value, the higher the impact of the speculative price bubble on the market will be.

In Figure 2, the BSADF series estimated from WTI crude oil price series, are compared with the critical value series obtained at 95% confidence level. The start and end dates of speculative price bubbles are shown in shades. The WTI crude oil prices, the 95% critical value, the GSADF statistic are represented by upper, middle and bottom curves, respectively. The shadows are sub-periods with bubbles.

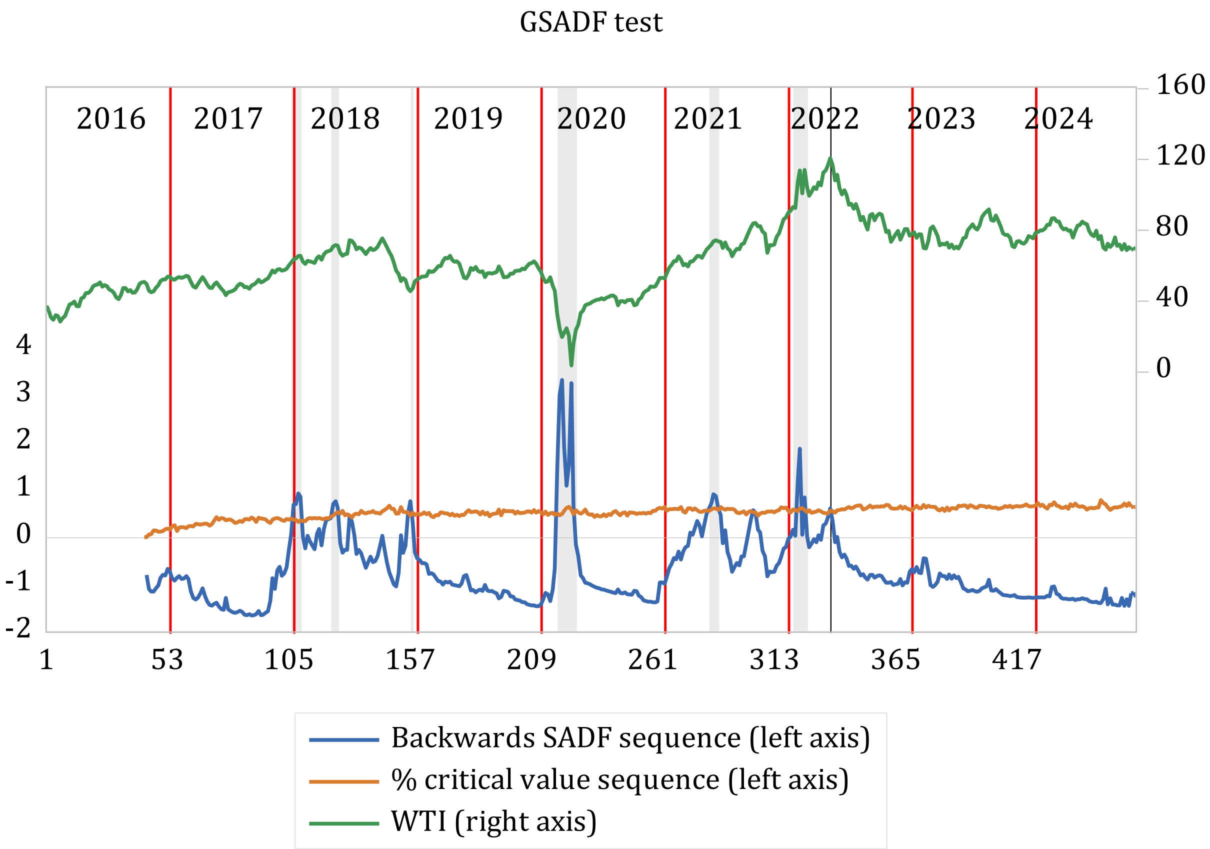

Figure 2. *GSADF test of the WTI crude oil prices*

Not every price inflation is considered a bubble. In fact, Philips et al., 2015 and Gonzalez et al., 2017 state that price inflation must last at least 6 months to be considered a bubble.

Accordingly, long-term (6 months or longer) extreme price behaviors (price exuberance) that can be defined as bubbles could not be determined during the analysis period.

In Figure 2, price inflations above the threshold value are shaded. The first price inflation originates on March 13, 2020, and bursts on May 08, 2020 which is a duration of nearly nine weeks (approximately 2 months). The second price inflation begins on February 18, 2022, and collapses on April 1, 2022 which is a duration of nearly 7 weeks (approximately 1.5 months). However, these price inflations cannot be considered as bubbles.

5. Conclusion

Asset prices can fluctuate greatly due to speculative movements. This study investigates whether multiple price bubbles exist in WTI crude oil prices, as well as to determine date stamps of the price bubbles. In this regard, by using weekly closing prices of the WTI crude oil prices for the period between 03.01.2016 to 13.012.2024, a recursive right tailed Generalized Supremum Augmented Dickey Fuller Test (GSADF) proposed by Phillips, Shi and Yu (2015) performed.

When the price increases seen in 2018, 2020, 2021 and 2022 were examined as price bubbles, it was determined that there were price increases that occurred especially in the first half of 2020 and 2022 and lasted for approximately 2 months each. However, since the price inflations did not last at least 6 months, they were not considered as price bubbles. Accordingly, although price inflations were detected in WTI crude oil prices during the analysis period, these price inflations did not turn into a price bubble because they did not last long.

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