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Abstract

This paper sets out to date-stamp periods of historic oil price explosivity using the Generalized sup ADF (GSADF) test procedure developed by Phillips, Shi, and Yu (2013). The date-stamping procedure used in this paper is effective at identifying periodically collapsing bubbles; a feature found lacking with previous bubble detection methods. We set out to identify periods of oil price explosivity relative to the general price level and oil inventory supplies in the US since 1876 and 1920, respectively. The recursive identification algorithms used in this study identify multiple periods of price explosivity, and as such provides future researchers with a reference for studying the macroeconomic impact of historical periods of significant oil price build-ups.

Keywords:
Oil-prices, Date-Stamping Strategy, Periodically Collapsing Bubbles, Explosivity, Flexible Window, GSADF Test, Commodity Price Bubbles
JEL: C15, C22

1. Introduction

The occurrence of bubble episodes in asset markets have been studied extensively, both theoretically and empirically, and have spurred divergent

*The views expressed in this paper are those of the authors, and do not necessarily reflect that of the Bank of Israel.

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debates on its implications on rationality and market efficiency. Economists have long debated whether to reconcile bubble-like behaviour with rational expectations of future prices, leading to divergent views on suitable policy responses following its detection. To this end, various econometric techniques have been proposed for date stamping past bubble periods as well as suggesting mechanisms for early detection of its formation.[1]

This paper sets out to identify periods of mildly explosive behaviour of the oil price during the period January 1876 to January 2014. We do so using Phillips, Shi, and Yu (2013)'s recursive Generalized Sup Augmented Dickey-Fuller (GSADF) technique applied to test for significant deviations of the nominal price of oil from its prior levels relative to the general price level in the US and the US inventory supply stock. This technique allows the detection and date-stamping of periods where the price behaviour, relative to general prices and oil supply, resembles an explosive series.[2] In this study we define such explosivity as temporary regime shifts from unit-root non-stationarity towards periods where the root significantly exceeds unity, followed by reversion back to a martingale process. After date-stamping, we contextualize the identified periods of explosiveness in terms of contemporaneous events that may have contributed to said price surges.

Most applications of the techniques developed by Phillips et al. (2013) and used in this study, interpret such defined periods of explosiveness as bubble-periods. An asset price bubble can be defined theoretically as sustained price deviations from an identified fundamental value. We, however, apply caution as to the interpretation of our results, defining such periods as explosive as opposed to indicative of an oil price bubble.

Our caution in defining explosivity measured in this paper as bubbles follows for several reasons. Firstly, defining a fundamental level proves uniquely complicated for storable commodities. Similar studies into the explosiveness of commodity prices have typically made use of Pindyck (1993)'s convenience-yield in order to define the fundamental price of, e.g., oil. This is measured as the sum of discounted oil "dividends", which are in turn approximated for by the benefit to holding inventories per unit of commodity over a defined

[1] C.f. Gürkaynak (2008) for an in-depth assessment of the performance of various bubble detection techniques.

[2] Phillips and Magdalinos (2007) elaborate on the limit theory of mildly explosive behaviour, referred to in this paper merely as explosivity.

period to which a futures contract has been written on the underlying asset.[3] This can be thought of as analogous to the dividend earned on holding a share. In this study, as we lack longer dated futures contract data, we define the underlying fundamental levels of the oil price as relative to the general price level and the inventory supply level in the US (supply ratio hereafter).

We also apply caution to labeling the identified periods of explosivity as bubbles, as such periods might rather be indicative of adjustments from previously managed or manipulated pricing schedules toward a more fundamental level (whichever way defined). To infer exuberance, or bubble-like behaviour, would require the implicit assumption that the price was at its fundamental level prior to explosivity. This is clearly not plausible in the strongly manipulated oil price market for a commodity with a particularly hard to define fundamental level. Our interpretation thus of the oil price series is that it is non-linearly related to underlying fundamentals.

Despite our caution on interpretation, our results should still prove useful. This follows as the price of oil and its derivatives are an important input into nearly all spheres of modern economies. Regnier (2007), e.g., also shows that production prices for commodities closely track the oil-price, which would imply a significant impact on general price stability in the economy should the latter experience periods of explosivity. While commodity markets, and in particular the oil market, have well functioning derivative markets that allow effective hedging, large price fluctuations remain costly to households in the economy who participate chiefly in consuming oil derivative products in the form of fuel and gas. By identifying significant build-ups in the price of oil relative to other prices in the economy and relative to the supply, our results provide researchers with a reference to assess the macroeconomic impact of historical periods of oil price explosivity.

The paper is structured as follows: section 2 discusses the relevant literature and theory of asset pricing explosivity, while section 4 presents the data used in this study. Section 3 discusses the empirical methodology followed, while section 5 discusses the results. The dates identified by our GSDAF approach as representing periods of oil price explosivity is summarized in Tables 1 and 2.

[3] c.f. Lammerding et al. (2013) for a deeper discussion into this definition.

2. Literature Overview

The inflationary build-up of asset prices, more loosely defined as asset price bubbles, has long interested economists and led to the development of a vast literature aimed at explaining its existence and facilitating its timely detection and prevention . The difficulty in testing for the presence of bubbles lies in modeling its explosivity and labeling its occurrence. Traditional unit root and co-integration tests aimed at identifying such periods, as e.g. proposed by Diba and Grossman (1988), may not bear out the existence of bubbles when they are periodically collapsing.[4] 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 behaviour.

To overcome this problem, Phillips and Yu (2011), Phillips, Wu, and Yu (2011) and Phillips, Shi, and Yu (2013) (PY, PWY and PSY, respectively, hereafter) developed and subsequently improved on a convincing sequence of rolling right-tailed sup ADF testing procedures to detect and date stamp mildly explosive pricing behaviour. Homm and Breitung (2012) compared several widely used techniques for identifying bubbles and found that the PWY, (2011) strategy performs the best. PSY, (2013) extended the methodologies of PWY, (2011) and PY, (2011) in that it recursively identifies explosivity as rejecting the null hypothesis of unit-root non-stationarity for the right-tailed alternative of explosivity. 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 earlier mentioned problem of detecting multiple episodes of periodically recurring explosivity (a particularly useful feature, as in our study we identify several), and has since gained ground in its empirical applications (c.f. inter alia Bettendorf and Chen (2013), and Etienne et al. (2014)).

Most studies focussing on commodity price explosivity have sought to identify such periods using Pindyck (1993)'s convenience yield (c.f. inter alia Lammerding, Stephan, Trede, and Wilfling (2013), Gilbert (2010), Areal et al. (2014) and Shi and Arora (2012)). This cost-of-carry equation is then

[4] C.f. Branch and Evans (2011) for a detailed description of the rational price bubble literature; Gürkaynak (2008) also provides a thorough account of the broad literature on empirical tests for bubbles.

used to approximate the fundamental value of the oil price,[5] to which PSY, (2013)'s estimation procedures have been applied to identify significant deviations from it. Lammerding et al. (2013) separate the fundamental level from the unobserved "bubble" component by expressing the standard present-value model of discounted future oil dividends in state space form. They then approximate two distinct Markov Switching phases to distinguish between the stable and explosive phases of the bubble process. Their approach uncovers robust evidence of speculative bubbles present in oil price dynamics. Shi and Arora (2012) apply three different regime switching bubble-identifying procedures, finding evidence of a short-lived real oil price bubble between 2008 and 2009.

In these studies the authors use daily futures prices from contracts traded on the New York Mercantile Exchange (NYMEX) for West Texas Intermediate (WTI[6]) prices, and Inter-Continental Exchange (ICE) Futures Europe for Brent prices. The starting points are all after 1983 for WTI and 1989 for Brent crude prices due to data availability on futures contracts. As our study is based on prices dating back to 1876, we cannot use similar futures data to approximate a convenience yield. Our approach is then to use the US general price series data and oil inventories in the US as relative series to identify periods of unsustainable oil price build-ups. This is discussed in more detail in section 3.

3. Theoretical Framework and Methodology

The techniques used in this study build upon the work pioneered by Phillips and Yu (2011) and Phillips, Wu, and Yu (2011), and specifically the generalized form of the SADF (GSADF) technique as suggested by Phillips, Shi, and Yu (2013). The latter was designed to overcome the PY and PWY procedures lack of power in identifying a second bubble if it is dominated by the first. To do so, PSY develop in their paper a flexible moving sample test procedure that is able to consistently detect and date-stamp multiple bubble episodes and seldom give false alarms, even in modest sample sizes. The PSY approach achieves this by recursively implementing an ADF-type regression

[5] Intuitively, it approximates the fundamental value of oil from the current and expected discounted convenience yield that accrues from holding oil inventories.

[6] WTI (also known as Texas Sweet Light) is typically regarded as the reference oil type for the US.

test using a rolling window procedure. More specifically, we consider an ADF regression for a rolling interval beginning with a fraction r_1 and ending with a fraction r_2 of the total number of observations, with the size of the window being $r_w = r_2 - r_1$.

Let:

$$y_t = \mu + \delta . y_{t-1} + \sum_{i=1}^{p} \phi_{r_w}^{i} \delta . y_{t-i} + \epsilon_t \tag{1}$$

where μ, δ and ϕ are parameters estimated using OLS, and the usual $H_0 : \delta = 1$ then tested against the right sided alternative $H_1 : \delta > 1$.[7] The number of observations taken into account by 1 is $T_w = [r_w T]$, where [.] is the integer part. The ADF statistic corresponding to 1 is denoted by $ADF_{r_1}^{r_2}$

PSY, (2013) formulated a backward sup ADF test where the endpoint of the subsample is fixed at a fraction r_2 of the whole sample and the window size is expanded from an initial fraction r_0 to r_2. The backward sup ADF statistic is then defined as:

$$SADF_{r_2}(r_0) = sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \tag{2}$$

The generalized sup ADF (GSADF) is then constructed by repeatedly implementing the SADF test procedure for each $r_2 \in [r_0, 1]$. The GSADF can then be written as follows:

$$GSADF(r_0) = sup_{r_2 \in [r_0, 1]} SADF_{r_2}(r_0) \tag{3}$$

The rationale behind using a supremum of a recursively estimated ADF statistic is the observation that asset price bubbles generally collapse periodically, with conventional unit root tests then having limited power in detecting such bubbles (Evans, 1991). Homm and Breitung (2012) argued that the sup ADF test procedure delivers a fairly efficient bubble-detection technique when dealing with one or two bubble periods.

[7]As mentioned by an anonymous reviewer, this process could also be re-estimated using a fractionally integrated mean process. This would entail estimating a right-tailed ADF test, with $\delta \rightarrow 1$ corresponding to a unit root, while $\delta > 1$ corresponds to explosivity. The benefit of this approach is that it incorporates long-memory into the process, and may yield more accurate results. This, however, remains an avenue for future methodological research using our approach. C.f. Cuñado, Gil-Alana, and Gracia (2007) for use of fractionally integrated estimation procedures to detect bubbles.

This process can be understood as a recursive regression process calculated by equation 1 using OLS with the initial fraction $r_w = r_0$, and then expanding the sample window forward until $r_w = r_1 = 1$, which is the full sample. The initial minimum fraction is selected arbitrarily while keeping in mind that we need to ensure estimation efficiency. This process is then repeated for each possible fraction, and an ADF statistic calculated as ADF_{r_k} for all values of $k \in (r_0, r_1)$. This procedure results in a sequence of ADF statistics. The supremum value of this sequence (SADF) can than be used to test the null hypotheses of unit root against its right-tailed (mildly explosive) alternative by comparing it to its corresponding critical values. Significant ADF statistics are indicated by $\delta_{r_1,r_2} > 1$, which we could then label as explosive (bubble) periods. The GSDAF approach defined above uses a variable window width approach, allowing starting as well as ending points to change within a predefined range $[r_0, 1]$, and thereby allowing the identification of several bubble periods consistently in a sample.

The procedure described above is used to test whether a certain time series exhibits explosive patterns, interpreted as bubbles, within a given sample. If the null hypothesis of no bubbles is rejected, the PSY procedure enables us, as a second step, to consistently date-stamp the starting and ending points of this (these) bubble(s). The starting point of a bubble is defined as the date, denoted as T_{r_e} (in fraction terms), at which the backward sup ADF sequence crosses the corresponding critical value from below. Similarly, the ending point of a bubble is defined as the date, denoted as T_{r_f} (in fraction terms), at which the backward sup ADF sequence crosses the corresponding critical value from above.

Formally, we can define the bubble periods based on the GSADF test by[8]

$$\begin{aligned} \hat{r_e} &= \inf_{r_2 \in [r_0, 1]} \left\{ r_2 : BSADF_{r_2} > cv_{r_2}^{\beta_T} \right\} \\ \hat{r_f} &= \inf_{r_2 \in [\hat{r_e}, 1]} \left\{ r_2 : BSADF_{r_2} > cv_{r_2}^{\beta_T} \right\} \end{aligned} \tag{4}$$

Where $cv_{r_2}^{\beta_T}$ is the $100(1-\beta_t)\%$ critical value of the sup ADF statistic based on $[T_{r_2}]$ observations. We also set β_t to a constant value, 5%, as opposed to letting $\beta_T \to 0$ as $T \to 0$. The BSADF(r_0) for $r_2 \in [r_0, 1]$ is the backward sup ADF statistic that relates to the GSADF statistic by noting

[8] For a more in-depth discussion of this process of bubble identification, refer to PSY, (2013).

that:

$$GSADF(r_0) = \sup_{r_2 \in [r_0,1]} \{BSADF_{r_2}(r_0)\} \tag{5}$$

We face several challenges dating historic oil price bubbles. Firstly, as we do not have sufficiently long dated forward price data, we cannot rely on estimates of the convenience yield for a fundamental level, as discussed in section 2. As such, we base our analysis on two measures: firstly that of defining periods of explosivity in the oil price relative to the general price level in the economy. We thus implicitly assume that the value of oil should keep some parity relative to other goods in the economy, at least in the short term. The second approach considers the nominal price of oil relative to the inventories held in the US, used as a proxy for the available supply of oil. This way we test for significant oil price deviations per unit of oil inventory in the US, which is more closely related to work done by Reitz and Slopek (2009), where the authors calculate a fundamental value of the oil price by assuming that it depends on excess capacity in oil production.

Another challenge faced in our estimation is dealing with the long period of virtual oil price stagnation between 1941 - 1973. Identifying periods of explosivity during this period for either of our measures would likely constitute general price inflation build-ups or oil supply shocks, as opposed to price fluctuations. As such, we caution the value of identifying episodes of explosivity during this period.

4. Data description

This study uses the monthly WTI crude oil price series for the period 1876 - 2014, obtained from the Global Financial database.[9] US CPI data, also obtained from the Global Financial database, is then used to calculate the real oil price for this period. Similar to PY, (2011), we approximate oil-supply from the US inventory of crude oil.[10] The inventory data is obtained from the US Department of Energy and is used throughout this paper as a proxy for the oil supply in the economy with the largest consumption of oil.

[9] Listed as WTI-Cushing, Oklahoma.

[10] Department of Energy, Monthly Energy Review, series: US Crude Oil ending stocks non-SPR (thousands of barrels).

Figure 1 plots the logarithmic scale of the deflated price of oil for the period 1876 – 2014, as well as the US CPI series. The rescaling of the real price controls for level distortions by approximating the relative changes in prices. From the figure it is clear that the real oil price has shown considerable variation both before and after the largely stagnant price period between 1941 – 1973.[11] Over the two subsamples, 1876 - 1940 and 1973 - 2014, the real price of oil averaged respectively \$16.78 and \$23.97. The period after 1973 was much more volatile (with standard deviations after the stagnant price period double what it was before), with oil cartel influence and supply shocks causing great fluctuations in the real price of oil. As can be seen too from the figure, aggregate prices in the US rose steadily after the 1970s, displaying a generally stable upward trend. This is important, as our interpretation of real oil price explosivity would have been distorted if, e.g., there were periods of significant deflation and oil prices remained stagnant.[12]

Next we consider figure 2, depicting the logarithmic transform of the nominal price supply ratio, as well as the level quantity of oil inventories in the US (in 1000s) since 1920. From the figure it follows that the ratio declines sharply after 1920, largely as a result of a sharp increase in the US oil supply. Thereafter we see the supply ratio remain largely flat until mid 1973, after which the price of oil rises significantly. Thereafter we see several periods of significant build-ups in the ratio series. During this period, oil supply initially also rises, but thereafter remains largely flat without any significant periods of sustained decline. This again is important as periods of decline might similarly as before distort our interpretation of oil price explosivity.

Therefore, as we do not find any periods of significant explosivity for either the inventory supply or the inflation series that corresponds to a reduction in the respective series which are contemporaneous with our identified periods of oil price explosivity, we the latter periods as being driven by significant oil price increases.[13]

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[11]In December 1941 the Wartime Price and Trade Board announced a complete control of all oil prices would come into force. This control was subsequently lifted in 1973.

[12]This follows as CPI is the denominator in the real price ratio, and such a scenario could imply labeling periods of explosivity despite the nominal price of oil potentially remaining flat.

[13]Results for the CPI and inventory supply GSADF tests are omitted for the sake of brevity, but can be requested from the authors.

Figure 1: Logarithm of Real Oil Price: 1920 - 2014

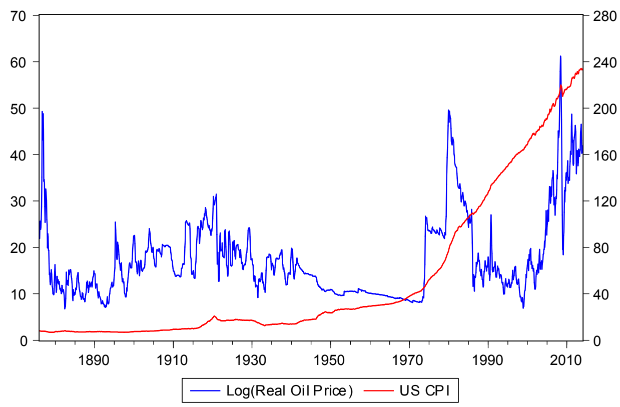
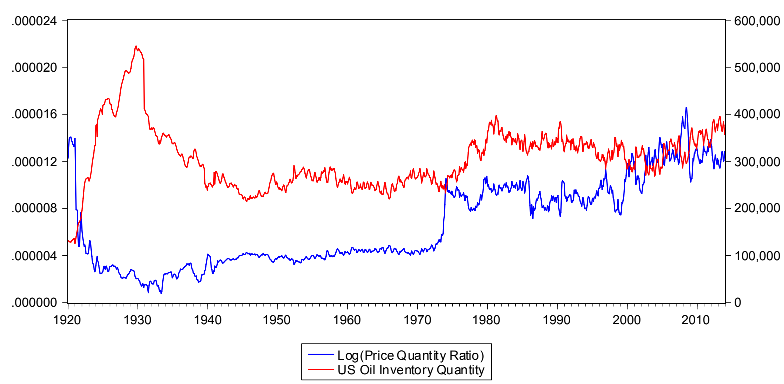


Figure 2: Logarithm of Nominal Oil Price and US oil Inventories: 1920 - 2014



5. Empirical results

In order to motivate the use of our GSADF analysis, we first conduct unit root tests on both the real price and the price ratio series for the full sample and sub-sample periods. The Augmented Dickey-Fuller (ADF) test suggests that for both series the unit root hypothesis cannot be rejected for the full sample, as shown in Table B.4. However, for the sub-samples between 1876 – 1941 and 1920 – 1973 for the two series respectively, we reject the hypothesis. This result may, however, be as a result of the ADF test being biased in the presence of structural breaks. Considering Table B.5, where we control for breaks in each series for both the intercept and the trend using the Zivot–Andrews test, we find that the two sub-samples are indeed I(1), but only at the 1% level. We then employed both the Lumsdaine and Papell (1997) and the minimum–LM Lee and Strazicich (2003) tests, which both allow for two endogenous breaks in the respective series, in order to establish whether there is a unit root in the data for both these sub-periods.[14] The results are reported in Tables B.6 and B.7, and show that indeed the series are I(1) for both sub-samples when we account for multiple breaks in the data. These findings are consistent with Hamilton (2009, p.3)'s discussion on the unpredictable unit root behaviour of the price of oil.

Our results for the right tailed ADF tests for explosivity are summarized in Tables B.3 in the appendix. The output suggests significant right tail deviations from unit root-behaviour for both series and for each of the sub-samples, except for the ratio series during 1920 – 1941. Explosivity identified for this period should thus be interpreted with caution.

Next, we set out to date-stamp the periods of price explosivity of the oil price relative to the general price level and US inventory supplies. The periods of real oil price and price supply ratio explosivity identified using the GSDAF approach of PSY, (2013), are summarized in Tables 1 and 2 below.

[14] For the sake of brevity, we omit a deeper discussion into these tests.

Table 1: Real Oil Price Explosivity

Sample : 1876M01 2014M03		
Included observations: 1659		
Starting Date	Ending Date	Duration (Months)
1895M01	1895M05	5
1899M11	1900M03	4
1909M11	1911M01	15
1912M11	1914M02	16
1946M05	1948M10	30
1951M01	1952M10	22
1964M07	1964M11	5
1966M02	1966M07	6
1970M06	1970M11	6
1973M10	1977M03	41
1979M04	1982M03	36
1986M02	1986M07	6
2007M10	2008M08	11

Table 2: Nominal Price and Inventory Quantity Ratio Explosivity

Sample : 1920M01 2014M02		
Included observations: 1129		
Starting Date	Ending Date	Duration (Months)
1949M02	1949M06	5
1973M09	1984M12	136
1985M07	1985M12	6
2005M07	2005M10	4
2006M04	2006M08	5
2007M07	2008M09	15

The real oil price shows, prior to the stagnant price period, several episodes of real oil price build-up. The first price spike identified in 1895 coincides with the loss of oil production in the Appalachian fields and a cholera epidemic in Baku in 1894 (Hamilton, 2011, p. 4). The slight oil price spike in 1900 could also likely be attributed to the documented surge in demand for the new uses of oil apart from *fabricating illuminants* at the time.[15]

Following the Great Depression in 1929, oil demand declined sharply, coupled with large oil discoveries at the time. The nominal price of oil slid dramatically following the Depression in 1931, plumetting over 160% from its peak in April 1929 of $24.2 to $9.19 in July 1931. Prices then rose moderately thereafter as output continued a slide downward from its peak in 1930.

The period after 1940 saw global oil prices and supply remain largely stagnant, despite accelerating demand following World War II. The supply ratio GSADF results suggest two periods of explosivity, although this was entirely production driven and as such not a price phenomenon. Nominal oil prices did rise somewhat during 1945 – 1947, while significant oil disruptions followed in 1952 – 1953, which was contemporaneous with the Korean conflict and Iranian efforts to nationalize their oil industry. While these events, coupled with the Suez Crisis of 1956 – 1957, caused some global concern on oil markets and despite the general unrest and uncertainty, the quantity of oil produced did not change much during this period. During the late 1960s, modest price increases could again merely be attributed to broader inflationary pressures, according to Hamilton (2011), as real prices remained flat.

The 1970s and early 1980s were, in contrast, periods of great global stagflation. It also saw great oil shocks emanating from OPEC's oil embargo and the Yom Kippur War in 1973, which arguably ushered in a decade of dramatic oil price increases and supply fears. The Iranian revolution in 1979, the Iran/Iraq conflict in 1980 – 1981, and further unrest in the Middle East during this period, added to the surge in prices. As noted in Hamilton (2011), the shifting of a world petroleum market centered in the Gulf of Mexico to one centered in the Persian Gulf during this period, contributed to unprecedented price and supply swings in the global market for oil.

Our results indicate that the supply ratio shows a protracted period of price explosiveness during this period, spanning September 1973 to April 1986. This significant duration could also be motivated by the sustained period of global commodity price inflation feeding through into generally higher oil prices. The real price GSADF suggests two protracted periods of explosiveness during this time (for the periods 1973M10 – 1977M03 and

[15]E.g. Petroleum gained in use for commercial and industrial heating, as well for rail and motor vehicle transportation (Hamilton, 2011).

1979M04–1982M03[16]), followed by a sharp real price correction in mid 1986 after a significant oil price collapse in late 1985 (for a more detailed overview of oil prices and supply during this period, see Hamilton (2011) and Barsky and Kilian (2002)).

Our estimates suggest no further periods of explosiveness during the 1990s for either of our measures following the turbulent two decades preceding it. A period of stability in oil prices and output ensued, coupled with low global inflation and high growth. The period of low and stable oil prices (with the real oil price reaching a historic low of $ 6.92 in December 1998) ended in early 1999, as world petroleum consumption increased and the real price of oil rose nearly threefold by February 2000. This was followed by another decline in 2001, following the DotCom bubble and subsequent recession in the US. After the start of the second Persian Gulf war in early 2002 and the US deployment of troops to the region, Middle East tensions drove the oil price up once again, precipitating a sustained build-up in the real price of oil for much of the rest of the decade. This was driven, in large part, by surging global demand for oil, as energy hungry and rampantly growing China added to the already bulging global oil glut. Fears of Middle East production shortage continued throughout the decade, as conflicts in the Niger delta, terrorist attacks in the Persian Gulf, further Arab/Israeli unrest and also the financialization of commodities,[17] contributed to a massively inflated oil price. Our GSADF results suggest real oil price explosivity for the period October 2007 –August 2008, with real prices surging 47% (55% nominal) during this time.

The ratio estimates, in contrast, pick up price explosivity earlier, labeling periods between July and October 2005, April and August 2006, and July 2007 and September 2008 (with the ratio increasing by approximately 16%, 13% and 75% respectively, during these periods). Despite several supply shocks during this period, global oil production and US inventories remained relatively stable throughout the 2000s, implying the latter periods identified could reliably be classified as significant price surges relative to supply.

[16]The real and nominal price increases were 91% and 148%, and 53.9% and 108%, respectively, for these periods of explosivity

[17]Khan (2009), e.g., shows that the daily trading volume of oil futures to world oil demand were at 14.7 in 2008, up from approximately 4.5 in 2002. Also see Lombardi and Van Robays (2011) for a discussion on the amplification effect of financialization on the oil price during this time.

Several sources document the underlying factors to these buil-ups of the oil price seen during the periods identified, including Sornette et al. (2009), Bekiros and Diks (2008), Khan (2009), Lombardi and Van Robays (2011), Areal et al. (2014) and Hamilton (2011). Hamilton (2009) suggests that speculative trading could be regarded as a major factor to the increasing price level of commodities in the 2000s, even without any dramatic changes in inventories (as indeed seen during the periods identified), given that the short term price elasticity of oil demand is nearly zero. Kilian and Murphy (2014), however, contends that speculation among oil traders was not the main driver of the price surge, stating that the build-up was rather a result of the earlier mentioned global surge in demand for oil during this period. This latter view is echoed by most other studies mentioned in this paper, which identified similar commodity price bubbles during this period.

In conclusion, although the debate as to the exact causes of the abovementioned periods of explosivity remain open, the impact of such oil price surges are widely accepted. Periods of oil price explosivity are generally regarded as disruptive to production (particularly in industries with high energy needs), consumer demand and price stability in oil-importing countries. More research is needed into the macroeconomic impact that such periods have on the price stability of modern economies, and how and whether policymakers should intervene in smoothing such disruptions. Our estimates can thus be used to serve as a benchmark for analysing the impact of such periods.

6. Conclusion

The aim of this paper is to provide a basis for effectively labelling historic periods of oil price explosivity between 1876 - 2014. We make use of Phillips, Shi, and Yu (2013)'s right-tailed recursive GSADF approach in order to approximate the starting and ending points of historic oil price explosivity. The GSADF procedure provides an effective means of identifying such periods by recursively adjusting the moving window estimation sample for the right-tailed sup ADF testing procedures. Phillips et al. (2013) show in their paper the ability of these techniques to identify multiple periodically collapsing bubbles in a longer dated series. The detection strategy is based on a right-tailed variant of the standard Augmented Dickey Fuller (ADF) test, with the alternative of a mildly explosive series. The GSADF statistics are compared to the corresponding calculated critical values, after which we date-stamp these periods using the backwards sup ADF (BSADF) statistic.

Although the technique provides an efficient and consistent basis for identifying such periods of departures from a unit root process, it provides no causal understanding of such periods. We also apply caution in not defining in our study such periods as displaying market exuberance, or bubble episodes, as is done in most other similar applications. As we lack historical data on derivatives in order to calculate a convenience yield, we consider periods of significant oil price build-ups relative to aggregate price levels and US oil inventory supplies, respectively.

Our results suggest the presence of multiple periods of explosivity in both the real price and the price supply ratio of oil. In particular, the period after the generally stagnant price period between 1941 – 1973 displays significantly more explosiveness than before. We find that during the late 1970s and early 1980s, several periods of prolonged oil price build-ups ensued. We also find, for both measures, that in the build-up to the global financial crisis, oil prices experienced explosiveness (as confirmed by many other studies). The supply ratio indicates that prices were significantly above their past stationary levels with respect to supply even well before then, between 2005 and 2006.

In summary, our study provides a concise estimate of the periods where historical oil prices deviated significantly from general price- and US inventory supply levels, since 1876 and 1920, respectively. Although the debate as to the exact causes of the identified periods of explosivity remain open, the impact of such oil price surges are widely accepted as being disruptive to ordinary economic activity.

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Appendix A. Graphs

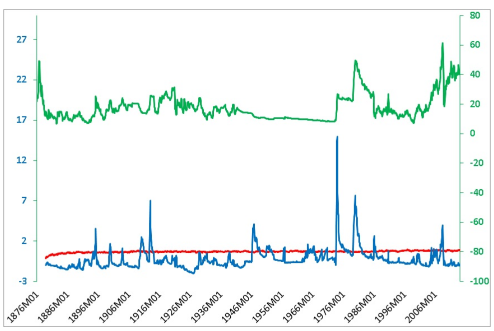

Figure A.3: Real Oil Price, 1876 - 2014:
— Real Oil Price
— BSADF
— 95% Critical Values

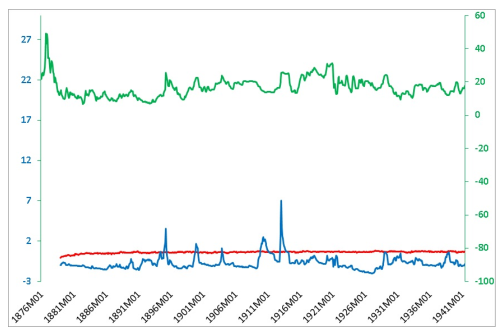

Figure A.4: Real Oil Price, 1876 - 1941:
— Real Oil Price
— BSADF
— 95% Critical Values

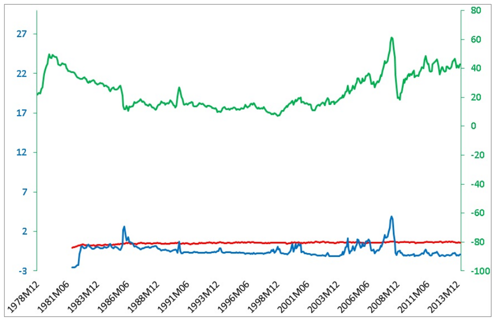

Figure A.5: Real Oil Price, 1978 - 2014:
— Real Oil Price
— BSADF
— 95% Critical Values

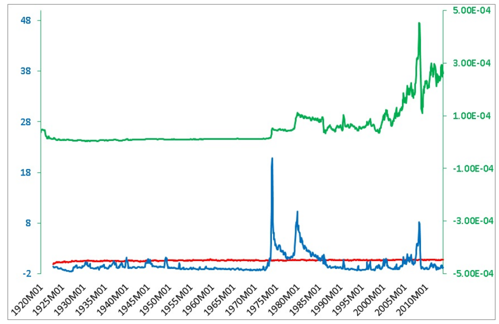

Figure A.6: Price to Supply, 1978 - 2014:
— Real Oil Price
— BSADF
— 95% Critical Values

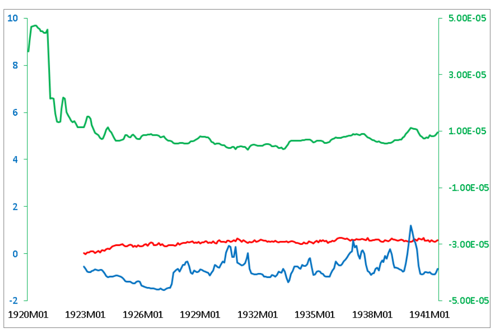

Figure A.7: Price to Supply, 1920 - 1941:
— Real Oil Price
— BSADF
— 95% Critical Values

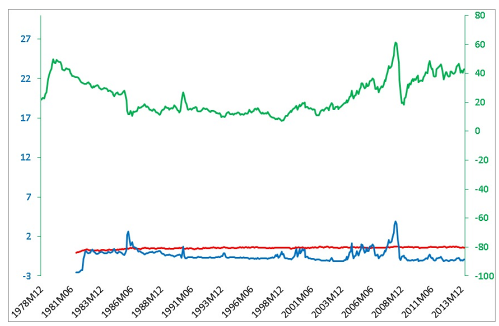

Figure A.8: Price to Supply, 1978 - 2014:
— Real Oil Price
— BSADF
— 95% Critical Values

Appendix B. Tables

Table B.3: Right Tailed Augmented Dickey–Fuller Tests for Explosivity

Right Tailed ADF Tests			
Sample : 1876M01 2014M03			
Included observations: 1659			
H_0: Real Oil Price has a unit root			
Lag Length: Fixed, lag=0		t-Statistic	Prob.*
Window size: 36			
		14.9630	**0.0000**
GSADF	99% level	3.3605	
Test critical values:	95% level	2.8731	
*Right-tailed test	90% level	2.5790	

Right Tailed ADF Tests			
Sample : 1876M01 1941M06			
Included observations: 786			
H_0: Real Oil Price has a unit root			
Lag Length: Fixed, lag=0		t-Statistic	Prob.*
Window size: 36			
		6.9968	**0.0000**
GSADF	99% level	3.0450	
Test critical values:	95% level	2.5009	
*Right-tailed test	90% level	2.2439	

Right Tailed ADF Tests			
Sample : 1978M12 2014M03			
Included observations: 424			
H_0: Real Oil Price has a unit root			
Lag Length: Fixed, lag=0		t-Statistic	Prob.*
Window size: 36			
		3.9460	**0.0000**
GSADF	99% level	2.0251	
Test critical values:	95% level	2.2271	
*Right-tailed test	90% level	2.8835	

Right Tailed ADF Tests			
Sample : 1920M01 2014M02			
Included observations: 1129			
H_0: Price Ratio has a unit root			
Lag Length: Fixed, lag=0		t-Statistic	Prob.*
Window size: 36			
		20.8414	**0.0000**
GSADF	99% level	3.1018	
Test critical values:	95% level	2.6244	
*Right-tailed test	90% level	2.3995	

Right Tailed ADF Tests			
Sample : 1920M01 1941M06			
Included observations: 258			
H_0: Price Ratio has a unit root			
Lag Length: Fixed, lag=0		t-Statistic	Prob.*
Window size: 36			
		1.2066	**0.3680**
GSADF	99% level	2.5859	
Test critical values:	95% level	2.0408	
*Right-tailed test	90% level	1.7865	

Right Tailed ADF Tests			
Sample : 1978M12 2014M03			
Included observations: 423			
H_0: Price Ratio has a unit root			
Lag Length: Fixed, lag=0		t-Statistic	Prob.*
Window size: 36			
		5.4255	**0.0000**
GSADF	99% level	2.9019	
Test critical values:	95% level	2.2689	
*Right-tailed test	90% level	2.0426	

Table B.4: Augmented Dickey–Fuller Tests

Null Hypothesis: Real Oil Price has a unit root			
Exogenous: Constant			
Lag Length: 24 (Automatic based on SIC, MAXLAG=24)			
Sample: 1876 – 2014			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.7955	0.3831
Test critical values:	1% level	-3.43415	
	5% level	-2.8631	
	10% level	-2.56765	

Null Hypothesis: PQ Ratio has a unit root			
Exogenous: Constant			
Lag Length: 2 (Automatic based on SIC, MAXLAG=19)			
Sample	1929:1-1973:9		
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-7.14177	0.0000
Test critical values:	1% level	-3.44031	
	5% level	-2.86582	
	10% level	-2.56911	

Table B.5: Zivot-Andrews Unit Root Tests

Zivot-Andrews Unit Root Test (Real Oil Price)	
Sample: 1876 – 1941	
Allows Intercept and Trend Breaks	
Breaks Tested for 1886:04 to 1932:02	
Including 5 Lags of Difference	
Selected by User	
Sig_Level	Crit_Value
1%(**)	-5.34
5%(*)	-4.8
Breakpoint	TestStat
1898:05:00	-4.72211

Zivot-Andrews Unit Root Test (PQ Ratio)	
Sample: 1876 – 1941	
Allows Intercept and Trend Breaks	
Breaks Tested for 1928:06 to 1965:09	
Including 5 Lags of Difference	
Selected by User	
Sig_Level	Crit_Value
1%(**)	-5.34
5%(*)	-4.8
Breakpoint	TestStat
1939:01:00	-5.16921*

Table B.6: Lumsdaine-Papell Unit Root Tests

Lumsdaine-Papell UR Test (Real Oil Price)		
Sample: 1876 – 1941		
Observations 786		
Breaks in Intercept and Trend		
Breaks at 1886:08 1921:01		
Estimated with fixed lags 0		
Sig_Level	Crit_Value	
1%(**)	-7.19	
5%(*)	-6.75	
10%	-6.48	
Variable	Coefficient	T-Stat
Y1	-0.0712	-5.7193
D(1886:08)	0.3064	1.1677
DT(1886:08)	0.0135	3.2468
D(1921:01)	-0.598	-2.8039
DT(1921:01)	-0.003	-2.1587
Constant	1.7492	4.1448
Trend	-0.0108	4.1448

Lumsdaine-Papell UR Test (PQ Ratio)		
Sample: 1920 – 1973		
Observations 258		
Breaks in Intercept and Trend		
Breaks at 1938:12 1946:12		
Estimated with fixed lags 0		
Sig_Level	Crit_Value	
1%(**)	-7.19	
5%(*)	-6.75	
10%	-6.48	
Variable	Coefficient	T-Stat
Y1	-0.0564	-5.135
D(1938:12)	0	0.7217
DT(1938:12)	0	-0.07
D(1946:12)	0	0
DT(1946:12)	0	0
Constant	0	1.0399
Trend	0	1.0399

Table B.7: Lee-Strazicich Unit Root tests

Lee-Strazicich Unit Root Test (Real Oil Price)		
Sample: 1876 – 1941		
Observations 791		
Trend Break Model with 2 breaks		
Estimated with fixed lags 0		
Variable	Coefficient	T-Stat
S1	-0.0545	**-4.6892**
Constant	-0.0648	-0.5276
D(1886:08)	0.1018	0.0736
DT(1886:08)	0.1507	1.0777
D(1921:12)	-3.5227	-2.5448
DT(1921:12)	-0.1579	-1.3825
Critical Values: LS test		
	1% level	-6.32
	5% level	-5.71
	10% level	-5.33

Lee-Strazicich Unit Root Test (PQ Ratio)		
Sample: 1920 – 1973		
Observations 263		
Trend Break Model with 2 breaks		
Estimated with fixed lags 0		
Variable	Coefficient	T-Stat
S1	-0.0381	**-2.2343**
Constant	0	-3.2753
D(1928:01)	0	-0.0317
DT(1928:01)	0	2.7963
D(1939:08)	0	0.0385
DT(1939:08)	0	0.2811
Critical Values: LS test		
	1% level	-6.32
	5% level	-5.71
	10% level	-5.33