I Z A Institute of Labor Economics

Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 15666

The Determinants of Crude Oil Prices: Evidence from ARDL and Nonlinear ARDL Approaches

Leila Ben Salem
Ridha Nouira
Khaled Jeguirim
Christophe Rault

OCTOBER 2022

I Z A Institute
of Labor Economics

Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 15666

The Determinants of Crude Oil Prices: Evidence from ARDL and Nonlinear ARDL Approaches

Leila Ben Salem
LAMIDED University of Sousse

Ridha Nouira
LAMIDED and ISFF University of Sousse

Khaled Jeguirim
University of Monastir

Christophe Rault
Université d'Orléans, CESifo and IZA

OCTOBER 2022

ISSN: 2365-9793

IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

The Determinants of Crude Oil Prices: Evidence from ARDL and Nonlinear ARDL Approaches

This paper is an innovative attempt to empirically investigate the determinants of crude oil prices. The main objective is to distinguish between short- and long-term effects of some covariates on oil prices. The autoregressive distributed lag (ARDL) approach is applied to daily series spanning the period from January 2, 2003, to May 24, 2021, to analyze long-run relationships and short-run dynamics. The paper also focuses on the asymmetric effects of covariates and a nonlinear ARDL (NARDL) approach is used to explore this asymmetry. The use of an asymmetric error correction model with asymmetric cointegration provides new insights for examining the determinants of oil prices. All investigations of underlying oil price fluctuations are examined both before and in the COVID-19 pandemic. Our results, based on different econometric specifications, have key policy implications for policymakers both with and without COVID-19 potential considerations.

JEL Classification: C5, Q4, Q43

Keywords: crude oil price, ARDL, Nonlinear ARDL, symmetric and asymmetric, COVID-19

Corresponding author:
Christophe Rault
LEO, Université d'Orléans, CNRS UMR 7322
Faculté de Droit, d'Economie et de Gestion
Rue de Blois - B.P. 6739
45067 Orléans Cedex 2
France

E-mail: chrault@hotmail.com

1. Introduction

Oil prices have fluctuated significantly over the past few years and these fluctuations have continued to be of truly vast importance. Understanding the nature of the determinants of oil price volatility is crucial and can aid governments, organizations, and individuals in making decisions, planning, and forecasting.

One of the most challenging questions in this regard is to be able to distinguish between short- and long-term effects of some influences on oil prices. More specifically, if we recognize that some variables have a short-term effect on oil prices, can a change in these variables also affect oil prices also in the long term? For example, if the dollar exchange rate plays an important role in oil price fluctuations (as suggested by Alhajji (2004) among others), it is crucial to know if it has a short-run or a long-run effect, or both. In the same way, in cases where there is evidence of possible impacts, it is important to be able to compare dollar depreciation with appreciation effects.

Given these considerations this paper intends to contribute to the existing literature on the determinants of oil price fluctuations in two important ways. Firstly, we apply the autoregressive distributed lag (ARDL) approach (Pesaran *et al.*, 2001), which can catch the short-run and long-run impact of exogenous variables on oil prices. Moreover, the fact that ARDL allows for flexibility in the variables' order integration and can tolerate various lags in various variables, makes this method more interesting, adjustable, and practical. Secondly, and more importantly, we employ the nonlinear ARDL approach of Shin *et al.* (2014) to show that, in most cases, exogenous variables have short-run as well as long-run asymmetric effects on oil price variations. In comparison to other models, the NARDL model has the crucial advantage of having the ability to concurrently handle asymmetries and diverse cointegration patterns among series (see Kumar *et al.*, 2021, and Apergis and Cooray, 2015).

To be able to distinguish the above mentioned short- and long-run effects, we use daily data spanning the period from January 2, 2003, to May 24, 2021, which constitutes a reasonably large sample size. This period was characterized by strong fluctuations in the prices of energy due to the Iraq war, the financial crisis of 2008, and the recent coronavirus pandemic, which all drove down oil prices. COVID-19 is not only a global public health crisis but has also severely affected the oil market. Due to the very particular nature of this crisis, an empirical specific analysis with a model including a "COVID variable" was carried out, covering the period of this health and economic crisis. A model without this specific variable was estimated for the period before this crisis. In all cases, the study takes all these specific and more general factors into account in both the long term and short term and suggests the existence of nonlinearities or asymmetries related to them, which obviously has important policy implications.

In what follows, Section 2 provides a review of the theoretical and empirical literature dealing with factors influencing oil price volatility and used in this study. Section 3 presents the adopted research methodology. Empirical results are reported in Section 4, and Section 5 highlights some policy implications. Finally, Section 6 concludes the paper.

2. Background

Many studies have sought to analyze the main factors that can affect oil price. According to Polanco-Martínez and Abadie (2016), An *et al.* (2014), Liu *et al.* (2011), Kaufmann and Ullman (2009), Antoshin and Samiei (2006), and Quan (1992), speculation and the price of oil futures significantly affect spot oil prices. Such an association can be justified by the fact that high spot prices boost speculation in futures markets, leading to higher futures prices. Consequently, futures prices are followed by spot oil prices. The spot price will then increase in accordance with the futures price. This implies that the price of futures may dominate spot prices, and the formation of oil price would be more influenced by futures prices.

Furthermore, several research studies have demonstrated that the price of gold is another factor that influences oil prices (see Kanjilal and Ghosh 2017, Reboredo 2013, and Joy 2011). Indeed, gold and oil are both priced in US dollars and tend to rise and fall in tandem with each other. Even today, a significant percentage of oil revenues ends up being invested in gold. This increases the attractiveness of gold, as it acts as an inflation hedge.

Other studies have shown that the dollar exchange rate affects oil prices. According to Alhajji (2004), Coudert *et al.* (2008), Frankel (2003), Akram (2009), and Krichene (2005), when US dollar depreciates, net crude oil importing countries will increase their oil imports. This is because oil will then be considered cheaper in terms of national currency for oil importing countries. This increases the demand for oil, which increases the price of oil. Similarly, oil exporting countries may suffer a loss of revenue when the dollar depreciates. As a result, they must export more crude oil to purchase the same amounts of goods, which deteriorate their terms of trade. Oil exporting nations are thus forced to maintain oil price as high as possible in accordance with the depreciation of the dollar.

The OPEC basket is another factor that is a determinant of oil price. In fact, several research studies have demonstrated that OPEC production strategies influence oil prices. It can exercise market power and intervene to adjust prices voluntarily by decreasing or increasing its production to increase or decrease prices (see Kaufmann *et al.*, 2004 and Dees *et al.*, 2007).

Empirical models indicate that OPEC has a statistically measurable effect on real oil prices (see Loutia *et al.*, 2016, Brémond et al., 2012 and Kaufmann *et al.*, 2008).

Another factor that can influence oil prices is economic policy uncertainty. Baker *et al.* (2016) were among the main researchers who focused on policy uncertainty index, and its effect on the economy, particularly on investment and employment. Liang *et al.* (2020), Aloui *et al.* (2016) and Antonakakis *et al.* (2014) have focused on the effect of these indexes in oil markets and found a strong relationship between these two variables. It is likely that an increase (decrease) in economic policy uncertainty impact negatively (favorably) the economy. As a result, the oil demand and oil price will subsequently decrease (increase). Reboredo and Ugolini (2016) do not found a significant causal relationship between oil price and economic policy uncertainty. They argue that only in the context of the US economy, high economic policy uncertainty increased the shocks in the oil price. Degiannakis *et al.* (2018) suggested that financial and economic policy uncertainties in the US did not always affect oil price, but that it was dependent on time. Using monthly data for the period January 1997 to June 2018 and a different approach, Hailemariam *et al.* (2019) found that the relationship between oil price and economic policy uncertainty is also time-varying, but the overall effect is negative. Lin and Bai (2021) found that the oil price has a negative response to the uncertainty, although such a result differs depending on whether it is a question of economic policy uncertainty in oil importing or exporting countries.

Recently, the price of oil has fallen dramatically due to the COVID-19 pandemic, with marked effects from its onset. For instance, in April 2020, the price of crude oil from the North Sea (Brent) in euros fell sharply to €17 on average per barrel, its lowest level since June 1999. Several studies argue that this pandemic indirectly influenced the trend of crude oil prices in early 2020 (see Baldwin and Di Mauro, 2020; Fernandes, 2020; Arezki and Nguyen, 2020; Algamdi *et al.*, 2021). They found a negative relationship between the reported number of new daily COVID-19 infections and crude oil prices. Greater economic problems are associated with a fall in current and potential future demand for oil, resulting in lower oil prices. In other words, because of the reduction in economic activity due to the restrictions imposed in different countries of the world, demand for oil fell sharply.

One feature that unites the research described above and others in the literature is the assumption that all these factors (dollar exchange rate, gold price, OPEC basket, economic policy uncertainty) affect oil price in a linear manner. Kumar (2017) had identified a non-linear and asymmetric interactive mechanism between oil and gold prices. Similarly, the appreciation of the dollar could affect oil prices to a different extent in absolute terms than depreciation;

generally asymmetric impacts are amplified because of the slipping rigidity in oil prices. Kumar *et al.* (2021) identify empirical evidence about the presence of asymmetries among crude oil, exchange rate and stock market in Indian context. This study is part of this research perspective, examining the potential asymmetric effects of several oil price determinants. It also serves as the first examination of the effects of all these factors before and after the COVID-19 pandemic.

To be able to distinguish between short-term and long-term effects, we use the ARDL approach on a fairly long investigation period with daily observation frequencies. The period of study is sufficiently broad to account for the fundamental patterns of oil price evolution and the short-term accidental fluctuations that have marked crude oil prices. Furthermore, we use the nonlinear autoregressive distributed lag approach (NARDL) to examine the potential presence of asymmetries during the period of study.

The novelty of this study is that it examines the evolution of the oil price considering several factors that have been separately or partially integrated in other studies. Our approach, which has been used in other works (*e.g.,* Kumar *et al.*, 2021), distinguishes between short- and long-run interactions during the period in question, including COVID-19, allowing for a unique comparative investigation of the importance and significance of the factors examined and the COVID effect in a single study framework. This article thus sheds light on the relative importance of the factors analyzed. The length of the study period and the frequency of observations also distinguish our study and provide more robust results. We describe the data, the models and explain the procedures in the following section.

3. Methodology

We explore in this section the relationship between crude oil prices and some variables considered to be determinants of oil price, such as futures price, gold price, OPEC basket price, dollar exchange index and economic policy uncertainty, over January 2003 to December 2019 period. Then, we add the variable COVID-19 to the model to investigate the effect of the COVID pandemic on crude oil prices over the January 2020 to May 2021 period. The data for WTI crude oil prices series (West Texas Intermediate) and futures prices are taken from the Energy Information Administration (EIA). The OPEC basket series is taken from the OPEC website. The other series (gold price, dollar exchange index) are taken from the Bloomberg database. The EPU index (Baker *et al.*, 2016) is used to measure economic policy uncertainty. The data for the COVID series (global number of new infections per day) are derived from the World Health Organization website. All data sources and definitions can be found in the appendix[a]. Descriptive statistics and the correlation matrix between variables are provided in Appendix Table 2 and Table 3. These tables reveal that most of the variables are at high risk since their standard deviation is very high. Also, there is a strong positive correlation between oil price and future and OPEC variables, and a strong negative correlation between oil price and dollar exchange rate.

We start by defining the long-run reduced form specification as follows:

$$OP_t = \alpha + \beta_1\, gold_t + \beta_2\, Exusd_t + \beta_3\, futures_t + \beta_4\, OPEC_t + \beta_5\, EPU_t + \beta_6\, COVID_t + \varepsilon_t \qquad (1)$$

where *OP* is the crude oil price, *gold* is the gold price per ounce in US Dollars ($), *Exusd* is the dollar exchange rate, *OPEC* is the OPEC reference basket price, *futures* is the futures price of oil, EPU is the economic policy uncertainty index, *COVID* represents the global number of new cases of COVID-19 reported per day, and ε_t is a white noise error term.

In the empirical specification without the *COVID* variable, the coefficient β_6 is set equal to zero. Otherwise, the expected sign of β_6 is negative because of the reduction in economic activity caused by the COVID-19 pandemic.

Furthermore, oil and gold prices are both quoted in US dollars and tend to rise and fall with each other. Thus, the expected sign of this variable is positive.

A decline in the dollar exchange rate reflects a depreciation of the US dollar against a basket of currencies of U.S. trading partners.[b] Oil price and dollar exchange rate tend to rise and fall inversely. Indeed, on the demand side, when the U.S. dollar depreciates, countries will increase their oil imports since oil is then considered cheaper. This increases the demand for oil, which increases oil prices. On the supply side, the dollar's depreciation reduces the purchasing power of exporting nations, which in turn leads them to reduce supply and thus increase oil prices as a compensatory measure. We expect an estimate of β_2 to be negative.

The expected sign of the futures variable to be positive. Indeed, high spot prices raise speculation in futures trading markets, which drives up futures prices. As a result, the spot price will rise in accordance with the increase in the futures price.

[a] The data of this study is available from the corresponding author.
[b] The currency basket consists of the euro, Japanese yen, British pound, Canadian dollar, Swedish krona, and Swiss franc.

The OPEC reference price is a weighted average of the prices of just over a dozen OPEC-produced crude oil blends. OPEC can exercise market power and intervene to adjust spot oil price. It has often attempted to keep the price of the OPEC basket between upper and lower bounds by increasing or decreasing production. Bentzen (2013) used daily data including spot crude oil prices and the OPEC basket price to show that OPEC influences oil prices from a benchmark basket in order to regulate and control world oil market conditions through its strategies, production, behaviors and interventions. We expect an estimate of β_4 to be negative.

The expected effect of policy uncertainty (EPU) through the estimation of β_5 is negative. This is because an increase in policy uncertainty negatively affects the components of the economy (investment, employment, growth). Oil demand and prices are expected to decline accordingly.

Coefficient estimates discussed above are long-run estimates. However, these variables may also have short-term effects on oil prices. Wang and Cheuh (2013) have proved that a clear short-term relationship between oil price and gold price exists. Recently, Mensi *et al.* (2020) showed that COVID-19 has negatively influenced the price of oil in the short term. Following the approach of Pesaran *et al.* (2001), we re-write equation (1) in an error-correction format to properly assess the short-term effects of exogenous variables. This leads to the following equation:

$$\begin{aligned}\Delta OP_t = c &+ \sum_{i=1}^{n} \varphi_{1i}\, \Delta OP_{t-i} + \sum_{i=1}^{n} \varphi_{2i}\, \Delta gold_{t-i} + \sum_{i=1}^{n} \varphi_{3i}\, \Delta Exusd_{t-i} \\ &+ \sum_{i=1}^{n} \varphi_{4i}\, \Delta futures_{t-i} + \sum_{i=1}^{n} \varphi_{5i}\, \Delta OPEC_{t-i} + \sum_{i=1}^{n} \varphi_{6i}\, \Delta EPU_{t-i} \\ &+ \sum_{i=1}^{n} \varphi_{7i}\, \Delta COVID_{t-i} + \lambda_1 OP_{t-1} + \lambda_2 gold_{t-1} + \lambda_3 Exusd_{t-1} \\ &+ \lambda_4 futures_{t-1} + \lambda_5 OPEC_{t-1} + \lambda_6 EPU_{t-1} + \lambda_7 COVID_{t-1} + u_t \qquad (2)\end{aligned}$$

Again, in the model with the COVID variable, the coefficients φ_{7i} $(i = 1, \cdots, n)$ and λ_7 are restricted to zero.

The ARDL approach has recently gained a lot of attention from researchers due to its advantages over other traditional cointegration approaches. Among its advantages are that the ARDL model may be used with limited sample size as well as in cases where variables in level are integrated of order 0, or of order 1. Furthermore, the ARDL model allows for the simultaneous estimation of both long-run and short-run parameters. The estimations of short-run effects are in fact derived from $\lambda_2, \cdots, \lambda_7$ coefficients linked to first-differenced variables. The long-run effects are deduced by the estimates of $\lambda_2, \cdots, \lambda_7$ homogenized on λ_1. Though, for long-run estimates to be significant, we need to test for a cointegration relationship. Pesaran *et al.* (2001) proposed two tests: an F-test to find the joint significance of the lagged level variables and the t-test to find the significance of λ_1, which also needs also to be negative. Though, the two tests are non-standard, Pesaran *et al.* (2001) presented new critical values which account for the level of variables integration. The long- and short-term estimations will be conducted in the case of existence of a cointegration relationship.

In equation (2), it is assumed that the effects of the explanatory variables on oil price are symmetric. One drawback of symmetric ARDL modeling is that it is unable to generate positive and negative shocks from the independent variables so the nonlinear linkage between the variables cannot be examined. However, according to Kumar *et al.* (2021), most of the financial time series (Oil and gold prices, exchange rate,...) are known to exhibit an inherent nonlinearity. Also, the rise and fall of theses series may have different directional effects on oil price. Indeed, for example, if during the decline of the dollar exchange rate (depreciation of the US dollar), oil prices fall by 1%, during the rise of the dollar exchange rate (appreciation of the US dollar) the oil price does not decrease by 1% when it is considered that the appreciation is short lived. Due to change in expectations during appreciation as compared to depreciation, oil price could react asymmetrically to changes in the dollar exchange rate. Thus, the linear framework has become inappropriate to investigate this phenomenon. To distinguish an increase in the explanatory variable from a decrease, we used the nonlinear ARDL (NARDL) model developed by Shin *et al.* (2014). The NARDL model, like ARDL model, is flexible as this approach does not require that all the variables have the same order of integration, i.e., the variables can be I(1) or I(0). In sum, this approach allows us to assess the short-run and long-run asymmetric effects of the variables involved.

To test whether the effects are asymmetric, we follow Shin *et al.* (2014) in decomposing the explanatory variables into their positive and negative shocks. These new variables are constructed using the partial sum concept as follows:

$$gold_t^+ = \sum_{i=1}^{t} \Delta gold_t^+ = \sum_{i=1}^{t} max(\Delta gold_i, 0)\,; gold_t^- = \sum_{i=1}^{t} \Delta gold_t^- = \sum_{i=1}^{t} min(\Delta gold_i, 0)$$

$$OPEC_t^+ = \sum_{i=1}^{t} \Delta OPEC_t^+ = \sum_{i=1}^{t} max(\Delta OPEC_i, 0)\,; OPEC_t^- = \sum_{i=1}^{t} \Delta OPEC_t^- = \sum_{i=1}^{t} min(\Delta OPEC_i, 0)$$

$$Exusd_t^+ = \sum_{i=1}^{t} \Delta Exusd_t^+ = \sum_{i=1}^{t} max(\Delta Exusd_i, 0)\,; Exusd_t^- = \sum_{i=1}^{t} \Delta Exusd_t^- = \sum_{i=1}^{t} min(\Delta Exusd_i, 0)$$

$$futures_t^+ = \sum_{i=1}^{t} \Delta futures_t^+ = \sum_{i=1}^{t} max(\Delta futures_i, 0)\,; futures_t^- = \sum_{i=1}^{t} \Delta futures_t^- = \sum_{i=1}^{t} min(\Delta futures_i, 0)$$

$$EPU_t^+ = \sum_{i=1}^{t} \Delta EPU_t^+ = \sum_{i=1}^{t} max(\Delta EPU_i, 0)\,; EPU_t^- = \sum_{i=1}^{t} \Delta EPU_t^- = \sum_{i=1}^{t} min(\Delta EPU_i, 0)$$

$$COVID_t^+ = \sum_{i=1}^{t} \Delta COVID_t^+ = \sum_{i=1}^{t} max(\Delta COVID_i, 0)\,; COVID_t^- = \sum_{i=1}^{t} \Delta COVID_t^- = \sum_{i=1}^{t} min(\Delta COVID_i, 0)$$

We then replace each explanatory variable in equation (2) with their two partial sums to reach:

$$\begin{aligned}
\Delta OP_t = c &+ \sum_{i=1}^{n} \varphi_{1i} \Delta OP_{t-i} + \sum_{i=0}^{n} \varphi'_{2i} \Delta gold^+_{t-i} + \sum_{i=0}^{n} \varphi''_{2i} \Delta gold^-_{t-i} + \sum_{i=0}^{n} \varphi'_{3i} \Delta Exusd^+_{t-i} \\
&+ \sum_{i=0}^{n} \varphi''_{3i} \Delta Exusd^-_{t-i} + \sum_{i=0}^{n} \varphi'_{4i} \Delta futures^+_{t-i} + \sum_{i=0}^{n} \varphi''_{4i} \Delta futures^-_{t-i} \\
&+ \sum_{i=0}^{n} \varphi'_{5i} \Delta OPEC^+_{t-i} + \sum_{i=0}^{n} \varphi''_{5i} \Delta OPEC^-_{t-i} + \sum_{i=0}^{n} \varphi'_{6i} \Delta EPU^+_{t-i} \\
&+ \sum_{i=0}^{n} \varphi''_{6i} \Delta EPU^-_{t-i} + \sum_{i=0}^{n} \varphi'_{7i} \Delta COVID^+_{t-i} + \sum_{i=0}^{n} \varphi''_{7i} \Delta COVID^-_{t-i} + \lambda'_1 OP_{t-1} \\
&+ \lambda'_2\, gold^+_{t-1} + \lambda''_2\, gold^-_{t-1} + \lambda'_3\, Exusd^+_{t-1} + \lambda''_3\, Exusd^-_{t-1} \\
&+ \lambda'_4\, futures^+_{t-1} + \lambda''_4\, futures^-_{t-1} + \lambda'_5\, OPEC^+_{t-1} + \lambda''_5\, OPEC^-_{t-1} \\
&+ \lambda'_6\, EPU^+_{t-1} + \lambda''_6\, EPU^-_{t-1} + \lambda'_7\, COVID^+_{t-1} + \lambda''_7\, COVID^-_{t-1} + u_t \qquad (3)
\end{aligned}$$

Once the nonlinear ARDL model in equation (3) is estimated, several asymmetric hypotheses may be formally tested. First, in (3) if at a given lag order i estimate of φ'_{ji} is different from φ''_{ji} (for $j = 2, \dots, 7$) then short-run effects of the explanatory variable on oil price will be asymmetric. However, in the case where the Wald test rejects the null hypothesis of $\sum_{i=0}^{n} \varphi'_{ji} = \sum_{i=0}^{n} \varphi''_{ji}$ then short-run cumulative or impact asymmetry will be established. Secondly, these explanatory variables will have long-run asymmetric effects on oil price if the Wald test rejects the null of $\frac{\lambda'_j}{-\lambda'_1} = \frac{\lambda''_j}{-\lambda''_1}$.

4. Empirical results and discussion

The aim of this study is to investigate the main determinants of oil prices and to assess whether the effects of these variables are symmetric or asymmetric.

Figure 1 shows the movements of crude oil prices (WTI) from 2003 to 2021. These movements were characterized by significant fluctuations over time due to major events such as the Iraq War, the Financial Crisis, the Arab Spring uprisings against established authorities in the Maghreb and the Middle East, and finally the Covid-19 pandemic. For the global financial crisis of 2008, a dummy variable is included in the specification without COVID. Furthermore, since our sample period includes the second gulf war (in Iraq from 2003), we add a second dummy variable in the model without the COVID variable to account for this War.

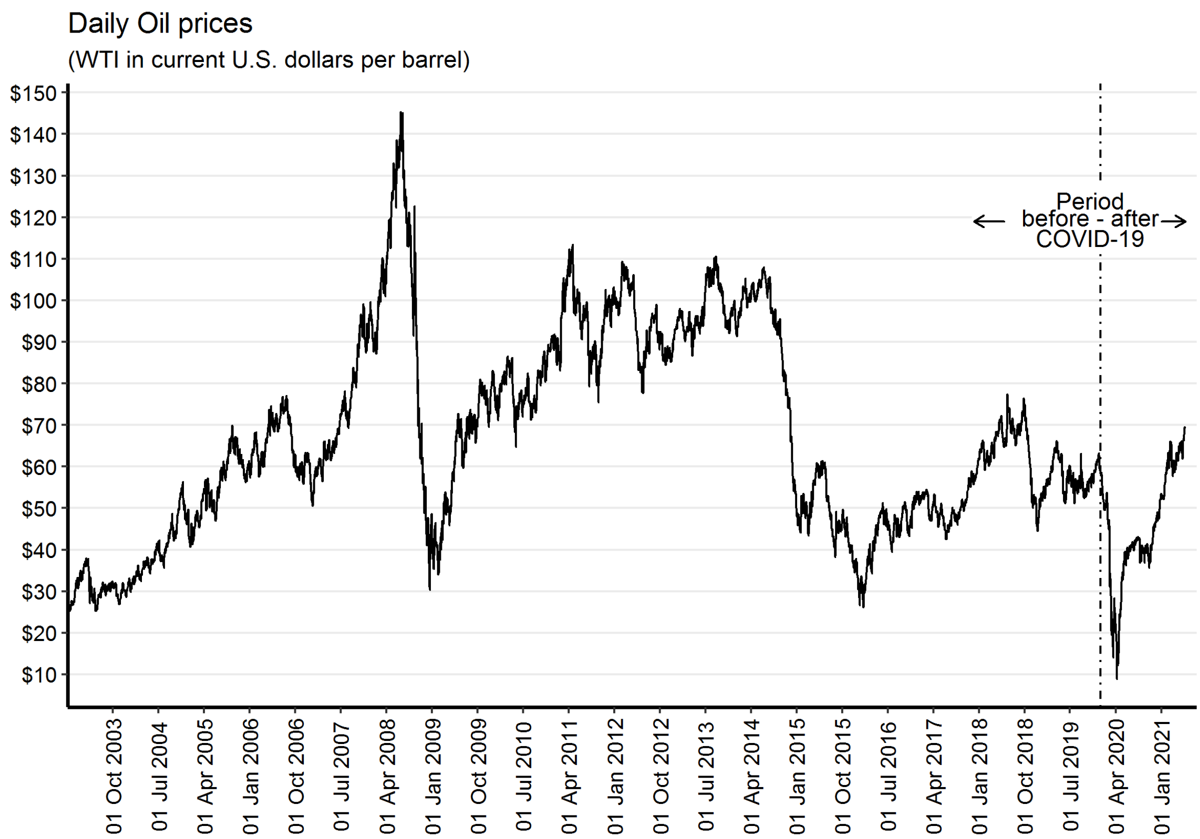

Fig. 1: Plot of crude oil price (OP)

Apart from the extreme variations that followed major crises, and since the early 2000s, the price of oil has been rising steadily. The recurring downward fluctuations did not prevent the price from reaching the record level of USD 145.31 on June 26, 2008. At an average of almost USD 95 between December 2010 and November 2014, this level is significantly higher than the average price recorded during the second half of the decade, at just over USD 50 between January 2015 and December 2019. However, what characterize these two periods are mostly the large fluctuations in prices. Based on these data, and over the same periods cited above, the standard deviations of prices were USD 8 and USD 9.45 respectively for the two periods cited. It is not surprising therefore that the price of oil raises questions about the determinants of its fluctuations. With the advent of the Coronavirus crisis, the price of oil suddenly fell before resuming an upward trend but with extreme volatility. The level of USD 69.21 reached at the end of the period is almost identical to that recorded in 2006, or even lower if inflation is considered.

Therefore, we estimate the linear model specified in (2) and the asymmetric nonlinear model in equation (3). The two models are estimated for the period before the onset of the COVID-19 pandemic (January 2003 through December 2019) and after the onset of the pandemic (January 2020 to May 2021). For the first period, as the models do not incorporate the COVID variable, we impose $\lambda_7 = \varphi_{7i} = 0$ and $\lambda_7' = \lambda_7'' = \varphi_7' = \varphi_7'' = 0$ for all i in (2) and (3) respectively, and we incorporate two dummy variables denoted d_1 and d_2. The first dummy reflects the Iraq war period of 2003 while the second represents the financial crisis of 2008. We apply a maximum of four lags to each first-differenced variable in each model, and we select the optimum lag order using Akaike's Information Criterion (AIC).

Results from the linear ARDL model are presented in Tables 4-5.

TABLE 4-5 go about here

Table 4 presents the estimates of the short-run coefficients (model without and with COVID). It can be noticed that the variables OPEC, futures and the two dummy variables are significant in the model without COVID. However, in the model with COVID, only EPU and COVID are significant. The sign of these 2 variables is expected confirming the findings of Atri *et al.* (2021). Increasing economic policy uncertainty is a result of the COVID-19 pandemic spread. Oil prices are sensitive and vulnerable to bad and negative news. The spread of many cases of covid in the world, aggravates doubts, which in turn negatively affects the price of oil. Also, our result confirms Aloui *et al.* (2016) findings. They found a rise in economic policy uncertainty impact negatively the economy. As a result, the demand and price of oil will decrease. This result is in accordance too with Liang *et al.* (2020) and Yang (2019) who found that economic policy uncertainty can anticipate and predict the movements of the crude oil market.

The estimated coefficients of the long-run relationship on the ARDL model presented in Table 5 show that, for the model without COVID pandemic, only the variables dollar exchange rate (Exusd) and futures oil prices (futures) are significant. The sign of futures is expected; this variable affects the price of oil positively. This result is in accordance with Quan (1992), who showed that there is an information flow between these two markets and that spot prices contain information about futures prices. The sign of dollar exchange rate is expected confirming Coudert *et al.* (2008), Frankel (2003) and Akram (2009) findings. Indeed, oil price and dollar exchange rate tend to rise and fall inversely: the demand side, when the U.S. dollar depreciates, countries will increase their oil imports since oil is then considered cheaper. This increases the demand for oil, which increases oil prices. On the supply side, the dollar's depreciation reduces the purchasing power of exporting nations, which in turn leads them to reduce supply and thus increase oil prices as a compensatory measure.

For the linear ARDL model including the effect of the COVID crisis, no variable is significant in the long-run proving that the linear framework (ARDL) has become inappropriate and insufficient. This result is in accordance with Kisswani (2021).

In Table 5, in addition to long-run coefficients, we have also reported some diagnostic statistics such as F-Statistic, t-test and Lagrange Multiplier (LM). If the coefficient of the t-test is negatively significant, variables are cointegrated and they converge to equilibrium over longer time periods. Since the t-test is applied to determine this estimate's significance, and similarly to the F-test, Pesaran *et al.* (2001, p. 303) include an upper and a lower bound for crucial values since still variables are a mixture of I(0) and I(1). The outcomes of these two statistics (t-test and F-Statistic) prove that we can reject the null hypothesis of no level relationship between variables in the ARDL model. The Lagrange Multiplier test (LM) is used to check for serial correlation. It appears that this statistic, in most cases, seems insignificant confirming autocorrelation-free residuals.

Tables 6-7 present estimates from the nonlinear models.

TABLE 6-7 go about here

From Table 6, we notice that among the two compositions of each explanatory variable (positive and negative), dollar exchange rate and oil futures have short-run effects on the price of crude oil, at least one having a significant considerable lag coefficient, for the model without COVID pandemic. The increase in the number of significant variables in the short run – from 4 in Table 4 (linear model without COVID) to 5 in Table 6 (nonlinear models without COVID) can be clearly attributed to the nonlinear adjustment of the explanatory variable. The two dummy variables are significant in the short run. Indeed, d_1 coefficient is negative, showing that the Iraq crisis of 2003 amplified the decline in oil prices. However, d_2 coefficient is positive, showing that the financial crisis of 2008 amplified the rise in oil prices.

Regarding the NARDL model estimated during COVID-19 pandemic in the short run (Table 6), oil futures, economic uncertainly policy and COVID variations are significant. A high (low) spot price increases (decreases) speculation in the futures markets, which in turn increases (decreases) futures prices. The spot price then follows the futures price and will rise (fall) accordingly. These results are in accordance with those of Kaufmann and Ullman (2009) and Polanco-Martínez and Abadie (2016).

Based on the long-term estimates in Tables 7, we observe that either the Δ^{+} or Δ^{-} variable[c] carries a significant and meaningful coefficient for the dollar exchange rate and futures price in the case of the NARDL model without COVID and for all explanatory variables, except OPEC and economic uncertainly polity (EPU), in the case of the same model with COVID. Our result confirms the findings of Kumar (2017), and Kumar *et al.* (2021) who revealed the superiority of the non-linear ARDL model by demonstrating the existence of an asymmetric bidirectional relationship between oil and gold prices in India.

The Wald test reported as short-run asymmetry, for the model without covid, is significant, rejecting the equality of the two sums, for the futures price and dollar exchange rate. In table 7, $Exusd_t^{+}$ coefficient is significant. The sign is negative: an appreciation of the US dollar ($Exusdt$+) may decrease crude oil price. This negative relationship between oil price and the dollar exchange rate confirms theoretical literature (see Zhang *et al.*, 2008; Coudert *et al.*, 2008; Krugman, 1980). However, the EPU_t^{+} and EPU_t^{-} coefficients in both models are not significant. This result is in accordance with Degiannakis *et al.* (2018) who suggested that financial and economic policy uncertainties in the US did not always affect oil price, but that it was dependent on time. For the Wald test reported as long-run asymmetry in Tables 7 confirms an asymmetric impact of gold, dollar exchange rate and covid on crude oil prices. This result is in accordance with Shehzad *et al.* (2021) and Kisswani *et al.* (2019).

Whereas the worldwide economy has been significantly impacted by the global lockdown caused on by the new coronavirus (COVID-19), it has had a particularly negative effect on crude oil prices. Indeed, the COVID-19 pandemic has been deleterious for crude oil price. When the global number of new infections per day increases ($LCOVID_t^{+}$), crude oil price

[c] Δ^{+} is the partial sum of positive changes in the explanatory variable. Δ^{-} is the partial sum of negative changes in the explanatory variable.

decreases. Our result confirms those of Albulescu (2020), Narayan (2020) and Mzoughi *et al.* (2020). The Wald test reported as long-run asymmetry in Table 7 confirms an asymmetric impact of COVID on crude oil prices confirming Arezki and Nguyen (2020) and Algamdi *et al.* (2021) findings. The reduction in economic activity due to the restrictions imposed in different countries of the world lead to fall in current and potential future demand for oil and a decrease in oil prices.

For the OPEC basket, the two variations ($LOPEC_t^+$) and ($LOPEC_t^-$) are not significant for the two models. These findings confirm the results found by Alhajji and Huettner (2000), showing that the OPEC cartel does not present the most dominant factor in the world oil market.

The diagnostic statistics reported in Tables 7 indicate that we can reject the null hypothesis of no level relationship between variables in the Non-Linear ARDL model. The Lagrange Multiplier (LM) is used to inspect for serial correlation. In most cases, we notice that this statistic appears to be insignificant, confirming autocorrelation free residuals.

Clearly, the results obtained from the non-linear model with the NARDL approach are better than those of the linear model with the ARDL approach. Indeed, in the short run, the number of significant variables increased from 4 in the linear model to 5 in the non-linear model. Furthermore, in the long run, we notice an increase of the number of significant variables from 2 in the symmetric model to 5 in the asymmetric model (table 7).

5. Policy implications

These findings have important policy implications. First, policymakers should establish a solid dynamic monitoring process for various oil shock components, paying close attention to variations in each. Adaptive measures are proposed in response to the changes to ensure the integrity and stability of each factor influence on oil prices in both short and long-term. Second, considering our results, policymakers should give more importance to the main items affecting oil prices. We found that the price of oil is negatively tied to the US dollar. Additionally, investors can diversify their assets: they can use oil to hedge risks and avoid losses if the US dollar depreciates. On the other hand, when this rate rises, investors should decrease their oil stocks and raise their dollar investments to guarantee their profits. Also, to avoid excessive speculative demand, policymakers should closely supervise the operation of the oil trading system in financial markets.

For instance, governments should be aware of any type of oil shocks, crisis, or pandemic, and should adjust their plans as soon as an abnormal change happens. As an example, derived from our results, oil-importing countries can use these findings to forecast oil prices in order to decrease their import costs. On the other hand, oil-exporting countries can also manage their oil exports to optimize their production volumes, maximize their revenues, and minimize the risks. In the other hand, to assist in making appropriate decisions, uncertainty indices developed by researchers should be well monitored and supervised, and policymakers must pay more attention to the sources of uncertainty in the oil market.

6. Conclusion

Understanding the variables that determine crude oil price fluctuations is crucial to evaluate their effects. Having this in mind, this study aims at identifying the main determinants influencing oil price. The most frequently used variables in the literature were tested; that is: gold, dollar exchange rate, futures prices, OPEC basket, number of new COVID-19 cases per day and economic policy uncertainty index. We also tested the effect of two events on the price of oil, namely, the 2003 Iraq war, and the 2008 financial crisis.

Previous studies have assumed the symmetric or linear effect of these factors on crude oil prices. The use of an asymmetric error correction model with asymmetric cointegration provided new insights into the investigation of the factors that influence oil prices. In this paper, besides the symmetric (linear) ARDL approach proposed by Pesaran *et al.* (2001), we have also applied the asymmetric (nonlinear) ARDL approach of Shin *et al.* (2014) to daily time-series data over the period January 2, 2003, to December 24, 2021 (January 22, 2020, to May 26, 2021). Two models were estimated for each approach: a model before COVID and one with COVID.

The results might be best summarized by affirming that when the linear model was estimated, we found short-run effects of futures price, OPEC, Iraq war and financial crisis on oil price. Therefore, when we computed the NARDL model, we discovered the short-run effects of either positive or negative change of variable (Δ^{+} or Δ^{-}) for 5 out of 10 variations. The rise in the number of variables is related to the introduction of nonlinear adjustment of determinants of oil price. Although almost all variables exhibited asymmetrical short-run effects, the short-run cumulative or impact asymmetric effects are supported only for futures price and dollar exchange rate. As for the long term, we notice an increase of the number of significant variables from 2 in the linear model (oil futures and dollar exchange rate) to 5 in the nonlinear model (positive or negative change). We found that, in the model with COVID, an increase in gold price can cause crude oil price to rise. However, an increase in the dollar exchange rate (dollar appreciation) and in the number of new COVID cases per day may lower oil price. Also, a decrease in the futures price can reduce crude oil price. The estimates used in this research suggest that the COVID-19 pandemic has influenced the trend in crude oil prices from early 2020 to the present.

References

Akram, Q. F. (2009). Commodity prices, interest rates and the dollar. *Energy economics*, *31*(6), 838-851.

Albulescu, C. (2020). Coronavirus and oil price crash. Available at SSRN 3553452.

Algamdi, A., Brika, S. K. M., Musa, A., & Chergui, K. (2021). COVID-19 Deaths Cases Impact on Oil Prices: Probable Scenarios on Saudi Arabia Economy. *Frontiers in Public Health*, *9*, 6.

Alhajji, A. F. (2004). The impact of dollar devaluation on the world oil industry: do exchange rates matter. *Middle east economic survey XlVii*, *33*.

Alhajji, A.F. & D. Huettner (2000), "OPEC and World Crude Oil Markets from 1973 to 1994: Cartel, Oligopoly, or Competitive?", *The Energy Journal, 21(3): 31-59.*

Aloui, R., Gupta, R., & Miller, S. M. (2016). Uncertainty and crude oil returns. *Energy Economics, 55, 92-100.*

An, H., Gao, X., Fang, W., Ding, Y., & Zhong, W. (2014). Research on patterns in the fluctuation of the co-movement between crude oil futures and spot prices: A complex network approach. *Applied Energy*, *136*, 1067-1075.

Antonakakis, N., Chatziantoniou, I., & Filis, G. (2014). Dynamic spillovers of oil price shocks and economic policy uncertainty. *Energy Economics*, 44, 433-447.

Antoshin S., & Samiei H. 2006, Has Speculation Contributed to Higher Commodity Prices? *IMF, World Economic Outlook*, Washington D. C., pp. 153–168.

Apergis, N., & Cooray, A. (2015). Asymmetric interest rate pass-through in the US, the UK and Australia: New evidence from selected individual banks. *Journal of Macroeconomics, 45, 155-172.*

Arezki, R., & Nguyen, H. (2020). Novel coronavirus hurts the Middle East and North Africa through many channels. *Economics in the Time of COVID-19*, 53.

Atri, H., Kouki, S., & imen Gallali, M. (2021). The impact of COVID-19 news, panic and media coverage on the oil and gold prices: An ARDL approach. *Resources Policy, 72, 102061.*

Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring economic policy uncertainty. *The quarterly journal of economics,* 131(4), 1593-1636.

Baldwin, R., & Di Mauro, B. W. (2020). Economics in the time of COVID-19: A new eBook. *VOX CEPR Policy Portal*, 2-3.

Bentzen, J. (2007). Does OPEC influence crude oil prices? Testing for co-movements and causality between regional crude oil prices. *Applied Economics*, *39*(11), 1375-1385.

Brémond, V., Hache, E., & Mignon, V. (2012). Does OPEC still exist as a cartel? An empirical investigation. *Energy Economics*, *34*(1), 125-131.

Cardona-Arenas, C. D., & Serna-Gómez, H. M. (2020). COVID-19 and oil prices: Effects on the colombian peso exchange rate. *Available at SSRN 3567942*.

Chkili, W., Hammoudeh, S., & Nguyen, D. K. (2014). Volatility forecasting and risk management for commodity markets in the presence of asymmetry and long memory. *Energy Economics*, *41*, 1-18.

Coudert, V., Couharde, C., & Mignon, V. (2008). *Do Terms of Trade Drive Real Exchange Rates? Comparing Oil and Commodity Currencies*. CEPII.

Dees, S., Karadeloglou, P., Kaufmann, R. K., & Sanchez, M. (2007). Modelling the world oil market: Assessment of a quarterly econometric model. *Energy policy*, *35*(1), 178-191.

Degiannakis, S., Filis, G., & Arora, V. (2018). Oil prices and stock markets: a review of the theory and empirical evidence. *Energy J, 39(5)*

Fernandes, N. (2020). Economic effects of coronavirus outbreak (COVID-19) on the world economy. *Available at SSRN 3557504*.

Frankel, J. A. (2003). Experience of and lessons from exchange rate regime in emerging economies. *National Bureau of Economic Research,Inc,NBER Working Papers. 10.2139/ssrn.413162.*

Gulen, S. G. (1997). Regionalization in the world crude oil market. *The Energy Journal*, *18*(2).

Hailemariam, A., Smyth, R., & Zhang, X. (2019). Oil prices and economic policy uncertainty: Evidence from a nonparametric panel data model. *Energy economics*, 83, 40-51.

Hamilton, J. D. (2011). Nonlinearities and the macroeconomic effects of oil prices. *Macroeconomic dynamics*, *15*(S3), 364-378.

Haughton, J. (1989). Should OPEC use dollars in pricing oil? *The Journal of Energy and Development*, 193-211.

Joy, M. (2011). Gold and the US dollar: Hedge or haven? *Finance Research Letters*, *8*(3), 120-131.

Kaufmann, R. K., Bradford, A., Belanger, L. H., Mclaughlin, J. P., & Miki, Y. (2008). Determinants of OPEC production: Implications for OPEC behavior. *Energy Economics*, *30*(2), 333-351.

Kaufmann, R. K., Dees, S., Karadeloglou, P., & Sanchez, M. (2004). Does OPEC matter? An econometric analysis of oil prices. *The Energy Journal*, *25*(4).

Kaufmann, R. K., & Ullman, B. (2009). Oil prices, speculation, and fundamentals: Interpreting causal relations among spot and futures prices. *Energy Economics*, *31*(4), 550-558.
Kanjilal, K., & Ghosh, S. (2017). Dynamics of crude oil and gold price post 2008 global financial crisis–New evidence from threshold vector error-correction model. *Resources Policy*, *52*, 358-365.
Kisswani, K. M. (2021). (A) symmetric time-varying effects of uncertainty fluctuations on oil price volatility: A nonlinear ARDL investigation. *Resources Policy, 73, 102210.*
Kisswani, K. M., Harraf, A., & Kisswani, A. M. (2019). Revisiting the effects of oil prices on exchange rate: asymmetric evidence from the ASEAN-5 countries. *Economic Change and Restructuring, 52(3), 279-300.*
Krichene, N. (2005). A simultaneous equations model for world crude oil and natural gas markets. *Washington, D.C., International Monetary Fund.*
Krugman, P. R. (1980). Oil and the dollar. *NBER working paper*, (w0554).
Kumar, S., Choudhary, S., Singh, G., & Singhal, S. (2021). Crude oil, gold, natural gas, exchange rate and Indian stock market: Evidence from the asymmetric nonlinear ARDL model. *Resources Policy, 73, 102194.*
Kumar, S. (2017). On the nonlinear relation between crude oil and gold. Resources Policy, 51, 219-224.
Liang, C., Wei, Y., Li, X., Zhang, X., & Zhang, Y. (2020). Uncertainty and crude oil market volatility: new evidence. *Applied Economics, 52(27), 2945-2959.*
Lin, B., & Bai, R. (2021). Oil prices and economic policy uncertainty: evidence from global, oil importers, and exporters' perspective. *Research in International Business and Finance, 56, 101357.*
Liu, Y. S., Chen, L., & Su, C. W. (2011). The price correlation between crude oil spot and futures–evidence from rank test. *Energy Procedia*, *5*, 998-1002.
Loutia, A., Mellios, C., & Andriosopoulos, K. (2016). Do OPEC announcements influence oil prices? *Energy Policy*, *90*, 262-272.
Mzoughi, H., Urom, C., Uddin, G. S., & Guesmi, K. (2020). The Effects of COVID-19 Pandemic on Oil Prices, CO 2 Emissions, and the Stock Market: Evidence from a VAR Model.
Narayan, P. K. (2020). Oil price news and COVID-19—Is there any connection? *Energy Research Letters*, *1*(1), 13176
Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, *16*(3), 289-326.

Polanco-Martínez, J. M., & Abadie, L. M. (2016). Analyzing crude oil spot price dynamics versus long term future prices: A wavelet analysis approach. *Energies*, *9*(12), 1089.

Quan, J. (1992). Two-step testing procedure for price discovery role of futures prices. *The Journal of Futures Markets (1986-1998)*, *43*(1), 139.

Reboredo, J. C. (2013). Is gold a safe haven or a hedge for the US dollar? Implications for risk management. *Journal of Banking & Finance*, *37*(8), 2665-2676.

Reboredo JC, Ugolini A (2016) Quantile dependence of oil price movements and stock returns. *Energy Econ 54:33–49*

Shehzad, K., Zaman, U., Liu, X., Górecki, J., & Pugnetti, C. (2021). Examining the asymmetric impact of COVID-19 pandemic and global financial crisis on Dow Jones and oil price shock. *Sustainability, 13(9), 4688.*

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in honor of Peter Schmidt* (pp. 281-314). Springer, New York, NY.

Šimáková, J. (2011). Analysis of the relationship between oil and gold prices. *Journal of finance*, *51*(1), 651-662.

Vivian, A., & Wohar, M. E. (2012). Commodity volatility breaks. *Journal of International Financial Markets, Institutions and Money*, *22*(2), 395-422.

Wang, Y. S., & Chueh, Y. L. (2013). Dynamic transmission effects between the interest rate, the US dollar, and gold and crude oil prices. *Economic Modelling*, *30*, 792-798.

Yang, L. (2019). Connectedness of economic policy uncertainty and oil price shocks in a time domain perspective. *Energy Economics,* 80, 219-233.

Zhang, Y. J., Fan, Y., Tsai, H. T., & Wei, Y. M. (2008). Spillover effect of US dollar exchange rate on oil prices. *Journal of Policy modeling*, *30*(6), 973-991.

Zhang, Y. J., & Wei, Y. M. (2010). The crude oil market and the gold market: Evidence for cointegration, causality and price discovery. *Resources Policy*, *35*(3), 168-177.

Appendix

Table 1: Data Presentation				
Variables	**Description**	**Definition**	**Source**	**Expected sign**
OP	crude oil price (spot)	West Texas Intermediate oil per barrel in Dollars ($)	EIA	——
OPEC	OPEC Reference Basket price	The weighted average of eleven oils prices sold by the members of the Organization of the Petroleum Exporting Countries (OPEC)	opec.org	negative
Futures	Futures oil price	A financial contract that allows to sell in advance the oil that will be delivered on the expiry date of the contract (in a fixed date in the future)	EIA	positive
Exusd	dollar index	The value of the dollar (USD) against different currencies of trading partners of the United States (the Canadian dollar, the Euro, the Swedish krona, the Japanese Yen, the Swiss franc, and the British pound)	Bloomberg	negative
Gold	Gold price	Gold price per Ounce in US Dollars ($)	Bloomberg	positive
COVID	Covid-19 pandemic	The number of new daily Covid-19 infections in the world	WHO	negative
EPU	economic policy uncertainty index	A measure of the degree of uncertainty in an economy	policyuncertainty.com	negative

Table 2: Descriptive statistics for variables					
	observation	**Mean**	**Std.Dev**	**Min**	**Max**
Oil price	4669	65.87	23.98	8.91	145.31
Gold	4669	1114.58	446.76	315.2	2103.2
Exusd	4669	87.44	7.97	71.33	103.26
Futures	4669	66.17	23.78	10.01	145.29
OPEC	4669	67.4	27.08	12.22	140.73
EPU	4669	109.47	83.23	3.32	807.66

Table 3: Correlation Matrix						
	Oil Price	Gold	Exusd	Futures	OPEC	EPU
Oil price	1					
Gold	0.32	1				
Exusd	-0.76	0.045	1			
Futures	0.89	0.28	-0.67	1		
OPEC	0.91	0.43	-0.7	0.65	1	
EPU	-0.05	0.32	0.05	-0.04	0.037	1

Table 4: Short-Run Coefficients (Linear ARDL Model without and with COVID)										
	Model without COVID					**Model with COVID**				
Code	**# Lags**									
	0	***1***	***2***	***3***	***4***	***0***	***1***	***2***	***3***	***4***
$Lgold$	0.014	-0.018	-0.039	-0.025	-0.091	0.325				
$LExusd$	-0.042					0.799	1.432			
$Lfutures$	-0.028*	-0.026*				-0.047				
$LOPEC$	-0.017	-0.017	-0.004	-0.034	-0.04**	0.026	-0.040	0.024	-0.02	-0.062
LEPU	0.0003	-0.0003	-0.0004	-0.0007	-0.0014	0.017	-0.03*			
LCOVID	-	-	-	-	-	-0.0003	-0.021	-0.06**		
D1	-0.018	0.002	-0.041**			-	-	-	-	-
D2	0.028	-0.016	0.033	0.024	-0.043*	-	-	-	-	-
Note: * and ** indicate significance at 10% and 5% levels. respectively.										

Table 5: Long-Run Coefficient Estimates of Linear ARDL (without and with COVID)				
	Model without COVID		**Model with COVID**	
	Coefficient	**T-statistic**	**Coefficient**	**T-statistic**
c	0.11**	2.5	-1.68	-0.76
$Lgold$	0.076	0.99	5.37	1.12
$LExusd$	-1.24**	-2.48	3.87	0.35
$Lfutures$	0.7**	4.7	-0.71	-0.9
$LOPEC$	-0.09	-0.66	-0.01	-0.02
LEPU	0.02	0.62	0.44	0.59
$LCOVID$	-	-	-0.035	-0.2
D1	-0.09	-0.82	-	-

D2	-0.003	-0.04	-	-
Diagnostic Statistics Associated with Linear ARDL model (3) and (4)				
ECM_{t-1}	-0.018**	-5.77	-0.03**	-1.15
F Stat	6.39 **		1.87	
LM test	0.54 (0.46)		2.35 (0.12)	

Notes:
* and ** show level of significance at 10% and 5% respectively.
The upper bound critical value of the F test is 3.61(3.23) at the 5% (10%) significance level when there are three exogenous variables (k=6). See Pesaran *et al.* (2001. Table CI-Case III. page 300). The value of ECM_{t-1} is upper bound critical value at the 5% (10%) significance level is **-4.38 (-4.04)** when k=7 and -4.19 (-3.86) when k=6. See Pesaran *et al.* (2001. Table CII-Case III. page 303). LM is Lagrange Multiplier test of residual serial correlation, and it is distributed as $\chi^2(1)$ (p-value in parentheses).

Table 6: Short-Run Coefficient Estimates Δ^+ and Δ^- in the Non-Linear ARDL (p=3)

	***Model* without COVID**			***Model* with COVID**		
	0	***1***	***2***	***0***	***1***	***2***
$Lgold_t^+$	0.07	-0.017	0.023	1.031	.495	-.0078
$Lgold_t^-$	-0.059	0.023	-0.063	-.732	-.4763	-.066
$LExusd_t^+$	0.241*			.989	-.565	-.1516
$LExusd_t^-$	0.173	0.176	.0475	2.181	2.372	-.094
$Lfutures_t^+$	0.084**			.221	.105	-.152
$Lfutures_t^-$	-0.09**			-.1513*	.067	.229
$LOPEC_t^+$	-0.053	-0.052	-0.004	.0715	-.0369	.111
$LOPEC_t^-$	0.0164	-0.004	-0.022	-.0224	-.064	-.060
$LEPU_t^+$	0.0006	0.0005	0.001	.049**		
$LEPU_t^-$	0.0002	0.001	-.0008	.0091	.0275	-.019
$LCOVID_t^+$	-	-	-	-.042	.011	-.142**
$LCOVID_t^-$	-	-	-	-.0397	-.106**	
D1	-0.018	0.037	-0.06**	-	-	-
D2	0.038*			-	-	-

Table 7: Long-Run Coefficient Estimates and Diagnostics of the Non-Linear ARDL Model (without and with COVID model (5) and (6)).

Long-Run Coefficients									
Long-run effect (+)					**Long-run effect (-)**				
	Without COVID		**With COVID**			**Without COVID**		**With COVID**	
	coef	**t-stat**	**coef**	**t-stat**		**coef**	**t-stat**	**coef**	**t-stat**
$Lgold_t^+$	-0.250	-0.834	3.43**	4.921	$Lgold_t^-$	-0.142	-0.402	-2.10**	-2.607
$LExusd_t^+$	-1.070*	-2.721	-2.995	-0.78	$LExusd_t^-$	-1.209**	-2.68	5.94*	2.852
$Lfutures_t^+$	0.92 **	17.88	-0.144	-0.36	$Lfutures$	-0.81**	-20.5	-0.3*	-2.739
$LOPEC_t^+$	-0.078	-0.200	-0.070	-0.13	$LOPEC_t^-$	-0.075	-0.15	0.240	0.94
$LEPU_t^+$	-0.044	-0.66	0.122	1.068	$LEPU_t^-$	-0.040	-0.57	0.082	0.74
$LCOVID_t^+$	-	-	-0.2**	-14.34	$LCOVID_t^-$	-	-	0.044	0.94
D1	-0.085	-0.404	-	-	-	-	-	-	-
D2	0.186**	2.068	-	-	-	-	-	-	-

Asymmetry statistics									
	Long-run asymmetry					**Short- run asymmerty**			
	Without COVID		**With COVID**			**Without COVID**		**With COVID**	
	F-Stat	**Prob**	**F-Stat**	**Prob**		**F-Stat**	**Prob**	**F-Stat**	**Prob**
$Lgold$	0.50	0.477	6.88**	0.009	$Lgold$	2.196	0.138	2.613	0.107
$LExusd$	0.20	0.654	3.013*	0.084	$LExusd$	3.239*	0.072	.4619	0.497
$Lfutures$	1.044	0.307	1.995	0.159	$Lfutures$	4.617**	0.032	.0065	0.935
$LOPEC$	.0008	0.976	.9991	0.319	$LOPEC$	1.176	0.278	.304	0.582
LEPU	3.205*	0.073	.6253	0.430	LEPU	.4395	0.507	.1301	0.719
Lcovid	-	-	34.8**	0.000	Lcovid	-	-	.1643	0.686

Diagnostic Statistics Associated with Nonlinear ARDL model (5) and (6)		
	Without COVID	**With COVID**
ECM$_{t-1}$	-.0208** **Prob.** =0.00	-5.36 **Prob.** =0.00
F Stat	5.264*** **Prob.** =0.00	3.082 **Prob.** =0.004
LM test	1.52 **Prob.** =0.22	0.37 **Prob**=0.39

Notes:
* and ** show level of significance at 10% and 5% respectively.
The upper bound critical value of the F test is 3.24 (2.94) at the 5% (10%) significance level when there are three exogenous variables (k=10). See Pesaran *et al.* (2001. Table CI-Case III. page 300).
The value of ECM$_{t-1}$ is upper bound critical value at the 5% (10%) significance level is **-5.03 (-4.69)** when k=10 and **5.03 (-4.69)** when k=12. See Pesaran *et al.* (2001. Table CII-Case III. page 303).
LM is Lagrange Multiplier test of residual serial correlation, and it is distributed as $\chi^2(1)$.