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How do supply or demand shocks affect the US oil market?

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Abstract

The study of the relationship between crude oil and its refined products prices may be perceived as an important tool for testing how are the dynamics and the type of integration of the petro-derivatives market in the United States. In this sense, we have applied a set of causality tests to study the possible presence of asymmetries in the relationship between WTI crude oil and each refined product price and to explore the type of market integration. Furthermore, the application of these causality tests lets us explore the validation of different hypotheses in the literature, such as the Rocket and Feathers hypothesis and the Verleger hypothesis. Our findings reveal that Reformulated Gasoline Blendstock for Oxygen Blending (RBOB), heating oil, diesel and kerosene are supply-driven integrated and conventional gasoline and kerosene are demand-driven integrated when linear effects are assessed. This behaviour changes deeply when the existence of asymmetries is tested, noticing that the Rocket and Feathers hypothesis is not fulfilled when a negative shock appears. Conversely, the Verleger hypothesis is supported when a negative shock appears for conventional gasoline and kerosene. These results provide important policy implications for investors, energy policymakers and refiners.

Keywords: Asymmetries, Causality, Crude oil, Refined products

JEL Classification: C22, Q31, Q41

Introduction

The study of the shocks in the relationship between crude oil prices and refined product prices bears significant information to refiners, investors, policymakers or practitioners, who would monitor the dynamics to establish different strategies or measures (Fousekis and Grigoriadis 2017). The abovementioned shocks are often produced by supply and demand forces, and the market participants would be on the lookout to obtain the maximum possible benefit and the reduction of the risk through portfolio diversification and hedging strategies (Hamilton and Wu 2014; Kyritsis and Serletis 2018) or taking into account sectoral financial innovations as elastic alternative investment options in order to improve the risk-adjusted returns for oil investors during a crisis (Salisu and Obiora 2021).

The COVID-19 outbreak triggered in Wuhan (China) and its rapid spread around the world caused a collapse in West Texas Intermediate (WTI, hereafter) prices in April

2020, for reasons such as the weakness of the demand and ongoing production versus storage limitations (Jefferson 2020). Another factor that could play an important role is the different lockdown measures implemented[1] by the countries to prevent and impede contagions. These lockdown measures have affected businesses, job securities and services and have brutally impacted all types of transport, either by road, rail, sea or/and air. As previously mentioned, the government's response faces the COVID-19 pandemic. People's behaviour has dramatically changed by the imposition of restrictions on mobility and economic activity, letting to work from home those who could and domestic and international travel severely restricted. People stopped driving, flying, or travelling on public transport (see Billio and Varotto 2020) so, the flows of people and goods have been reduced. This triggered a decline in demand for energy sources (transport fuels, for instance), leading to a drop in oil prices (Ozili and Arun 2020) or being a source of systematic risk, provoking a decline in global financial indices (see Ahundjanov et al. 2020; or Sharif et al. 2020). Given this, it is not unreasonable to think that, especially these factors have played an essential role in the shock influences the crude oil market so, as Bakas and Triantafyllou (2020) or Zhang et al. (2021) affirmed, in times of higher uncertainty (as the case of a pandemic like COVID-19), supply and demand drop dramatically and gradually over time because of the rise in the price elasticity.

Likewise, in 2021 the prices become to rise and recover their original path due to the reactivation of the economy and mobility. On the other hand, there is a combination of the deliberate production cuts agreed by OPEC and other non-OPEC producers, such as Russia; and a drop in production in the United States and elsewhere due to the low prices registered per barrel the previous year. This was translated into the explosiveness of crude oil and its derivatives prices that society is experimenting with nowadays. However, and more importantly, by the beginning of 2022 the 'Ukraine–Russian war' pushed the refined product prices up to high levels, around 5 dollars per gallon in the United States, provoking that inflation to reach high levels. In this sense, Li et al. (2020) suggest actual extreme political events will drive crude oil prices and provide that geopolitical factors affect crude oil prices.

In this sense, the study of energy prices linkages lets researchers evaluate the degree and type of integration, which market (or product) may be the price setter, the asymmetries that could incur in the information transmission, the co-movements between prices, or to value the price risk (see Girma and Paulson 1999; Grasso and Manera 2007; Douglas 2010; Bremmer and Kesselring 2016; or Caro et al. 2020; for instance). In this respect, as it is well-known, crude oil is the raw ingredient with which refined products are made so, it stands to reason that a change in the price of oil could affect the price of refined products, being this an example of supply-driven market integration (Asche et al. 2003). Conversely, according to Kilian (2010, 2014), when refined product prices condition crude oil prices due to crude oil is necessary to generate these products, i.e., gasoline, diesel or heating oil, that is consumed straightaway so, the flow demand for oil increases, being this an example of demand-driven market integration, i.e., the demand from crude oil is given from the demand for refined products (see Kilian 2010). Thus,

[1] According to Sovacool et al. (2020), by the end of April 2020, more than half of the entire world's population (54%) was under some form of COVID-19 lockdown.

accounting the nature of the shocks would provide us information regarding the type of market integration.

In this context, the study of the causality link regarding the crude oil and its refined products has not been discussed in great depth but has been more related to other commodities (see Villar and Joutz 2006; Brown and Yucel 2008; Zhang and Wei 2010; Wolfe and Rosenman 2014; Yu et al. 2015; or Rezitis 2015) or economic[2] and financial variables (see Kilian 2008; Kilian and Vigfusson 2011; Brahmasrene et al. 2014; Bal and Rath 2015; Ding et al. 2016).

Thus, the contribution of this work is a further step in this area of research so, as far as we know, this is the first time that this methodology (the methodology developed by Hatemi-J (2012), which is an expansion of the model developed by Toda and Yamamoto (1995)) has been used to capture how the different nature of the shocks (positive and negative) can affect the relationships between crude oil and its derivatives and the type of market integration. Based on Hatemi-J (2012) test, which is an extension of the Toda and Yamamoto (1995) test, is a causality approach that allows for asymmetry. This means that we can assess causality by considering the cumulative sum of positive and negative shocks separately. The impact of these shocks on causal relationships can differ since shocks can be either positive or negative, a characteristic not considered in other causality tests (Mishra et al. 2022). Following Hatemi-J (2012), this method has the advantage of causality can be tested among variables of a different order of integration and even in the absence of cointegration (Masih and Masih 1998).

In fact, the objective of the present study is to investigate whether crude oil and its refined products may represent a demand-driven or supply-driven market integration by analysing the asymmetric causal links between crude oil and its refined products, studying the behaviour when a negative or positive shock affects the variables. To this end, in this paper, we use the asymmetric causality analysis that allows us to explore the type of market integration. Afterwards, when we seek for the different type of market integration, i.e., demand-driven or supply-driven market integration, we could subsequently test the existence of the Rockets and Feathers hypothesis (if the market follows an asymmetric supply-driven market integration) or the Verleger hypothesis (if the market follows an asymmetric demand-driven market integration).

In this respect, our findings indicate the heterogeneity in the behaviour of the refined products attending to their causal relation to WTI, exposing the need to study the asymmetries regarding the causal relationships given. In this regard, the dependent role to crude oil of kerosene is represented in each type of integration when assessing the effects of linear relation or positive and negative shocks, which makes sense. This aspect would convey us to explore the treatment of this refined product, which is essential to the airlines and the travel industry. In this sense, the hedging strategies followed by airlines are well-known to protect themselves from volatility and explosiveness in fuel prices. Furthermore, our results indicate the importance of attending when negative shocks appear, where all refined products would be located under the supply-driven market integration. On the other hand, conventional gasoline joints to kerosene are also placed on the side

[2] See Hamilton (2011) for a survey of the nonlinear relationship between macroeconomic effects and oil prices.

of demand-driven market integration. In this respect, it catches the eye that, in contrast to linear effects where conventional gasoline is only situated under the demand-driven market integration when the negative effects make their appearance conventional gasoline prices become fully integrated.

The rest of the paper is organized as follows. The following "Literature review" section reviews the existing literature on this topic. "Data and methodology" section describes the methodology applied to this topic. "Results" section details and displays the results, and "Conclusions" section identifies the conclusions and policy implications.

Literature review

Nowadays, due to globalization process and the free market economy, the prices of refined products are projected to adjust with the change in the crude oil price. Nonetheless, some studies evidence that prices of refined products may react faster and on a greater scale to the increase of crude oil price, while the price of the former plunges at a slower rate and slighter size in reaction to drop in crude oil prices. Therefore, the relationship and the integration between crude oil price and energy (or its refined products) price is essential to disentangle the comportment of the price formation.[3]

Indeed, following Ederington et al. (2019), the literature has dealt with this topic in two ways. The first strand argues that the causal relation flows from crude oil prices to refined product prices (see Frey and Manera 2007) for a survey). Furthermore, Bacon (1991) explain an influential paper where the Rockets and Feathers Hypothesis is demonstrated. He showed that when prices of crude oil rise, this causes an increment of gasoline prices (or other refined products) in a faster way. Conversely, as previously mentioned, the drop in crude oil prices does not provoke a faster response to gasoline prices. Indeed, the influential paper of Borenstein et al. (1997) shows that when crude oil prices fluctuate, i.e., increase or decrease, the response of the gasoline prices is asymmetric. Gjolberg and Johnsen (1999) used the Error Correction Model (ECM hereafter) to examine the relationship between crude oil monthly prices and refined product prices. They confirmed that any crude oil price deviation from equilibrium could give information on how the refined products behaviour could be in the short-run. Adrangi et al. (2001) employ VAR methodology and a bivariate GARCH model to prove that movements in crude oil prices cause shifts in the price of the refined product used, i.e., the Los Angeles diesel. This can also happen in the opposite direction due to demand inferences and Venditti (2013) evidence proofs on the rockets and feathers issue by using weekly data on gasoline and gasoil prices for the U.S., the euro area, by using nonlinear impulse response functions and forecast accuracy tests and displaying evidence of asymmetries in the U.S.

Another influential paper, as Bachmeier and Griffin (2003) apply the basic and asymmetric ECM, could not evidence a pass-through response from crude oil prices to gasoline prices. Hammoudeh et al. (2003) apply a cointegration, an error-correction representation, and GARCH models to crude oil and gasoline daily prices, suggesting a bidirectional causal relationship between daily crude oil and gasoline prices. They also

[3] See Table 8 for a selected review of empirical studies.

evidence a unidirectional causality from crude oil price to heating oil. Additionally, Yang and Ye (2008) developed a simple search model to explain the performance of refined products prices when a positive (or negative) shock affects crude oil price. Honarvar (2009) explains the behaviour of gasoline and crude oil prices for the USA by using a Crouching ECM, which describes the hidden cointegration. He demonstrates that the behaviour of the forms depends on the fluctuations of the crude oil price, being conditioned by the origin of the shocks, i.e., if there is a shock in the crude oil price, it could be due to market conditions. In contrast, if the shock occurs in the refined product price, the origin may be induced by "efficiency or consumers' incentives", i.e., the demand side. Later, Kaufmann and Laskowski (2005) use monthly data and ECM to study the possible existence of asymmetries between the crude oil and refined petroleum products prices in the United States, evidencing that the asymmetric relation between crude oil and motor gasoline is explained by refinery utilization rates and inventory behavior. Additionally, the asymmetric relation between crude oil and heating oil maybe is produced by contractual arrangements between retailers and consumers. Indeed, these results would suggest that price asymmetries might be caused by efficient markets.

For its part, Karali and Ramirez (2014) examine the volatility and spillover effects in some energy markets such as crude oil, heating oil, and natural gas, by using daily prices in a GARCH model and incorporating changes in important macroeconomic variables and major political and weather-related events. They obtain the presence of asymmetric effects in crude oil following major political, financial, and natural events. Furthermore, seasonality and day-of-the-week effects in the crude oil and heating oil markets are encountered. Atil et al. (2014) assessed the pass-through from crude oil prices into gasoline and natural gas prices when the non-linear autoregressive distributed lags (NARDL) model is applied. So, if a shock in the crude oil price transfers in a non-linear manner to gasoline and natural gas prices and shows that energy products prices dynamics possess a complex relationship. For its part, Han et al. (2015) uses a battery of techniques such as VAR and ECM, Granger causality and impulse-response functions, finding bidirectional causality between crude oil and gasoline prices when facing a supply shock. They show that the interaction between crude oil price and gasoline price possess long-live. Kpodar and Abdallah (2017) also apply the VAR model and impulse-response function to study the price pass-through between retail gasoline prices and crude oil prices for a large dataset that encompasses 162 countries. Their results point out that positive shocks on crude oil prices possess a larger impact than negative shocks on gasoline prices response, and Martinez et al. (2018) apply a novel approach, the wavelet local multiple correlation (WLMC), to evaluate the relationship between oil time series in the time-scale domain. In fact, they use the prices of seven commodities: crude oil (WTI) and six refined products (conventional gasoline, RBOB regular gasoline, heating oil, Ultra-Low-Sulphur diesel fuel, kerosene and propane). They find that the wavelet correlations are strong throughout the period studied and show a strong decline in correlation values from 2013 to 2015 (due to the overproduction of tight oil in the U.S. and a slowdown in global demand for oil).

More recently, Martin-Moreno et al. (2019a, b) applied a Markov-switching model and used it to contrast the robustness of the results obtained with the TAR-ECM methodology to Spanish and German, French, Italian and UK data, respectively, getting significative evidence of asymmetric adjustments of gasoline and diesel prices to variations in crude oil price. Indeed, if changes in retail prices are translated by increases or decreases in input prices thus, the standard economic theory states that the market is perfectly competitive (Martin-Moreno et al. 2019a). Furthermore, Kyritsis and Andersson (2019) explored the causal relationship between crude oil and its refined products. They compared different causality tests and indicated a unidirectional causality relation from crude oil price returns to refined products price returns. Remarkably, they show a bidirectional causal relationship between heating and crude oil price returns and between natural gas and crude oil price returns, respectively. It is worth noting that they interpret causality as a predictability way instead of studying structural economic relations. Finally, Gosinska et al. (2020) examined the European wholesale market, analyzing the relationship between Brent crude oil and unleaded 95 petrol and diesel using a threshold cointegration, concluding that the pass-through of crude oil price to the retail prices is asymmetric. Olayungbo and Ojeyinka (2021) show that an increase in crude oil prices turns out a stronger effect on refined product prices than the effect of a decrease in crude oil prices. This could be indicator of asymmetries in Nigerian crude oil market and further convincing evidence in favour of the Rocket and Feather hypothesis in the pass-through between crude oil and refined product prices. More recently, Bakhat et al. (2022) provide new evidence on asymmetric price transmissions, by using a NARDL model. They pay attention to the asymmetric response of both diesel and gasoline weekly prices to oil price shocks, particularly not just to the magnitude but also to the duration of the effect, offering an understanding of how diesel and gasoline markets operate and how these markets are efficient.

The second strand explores the relationship between refined product prices to crude oil prices. It is worth noting that this link has received limited attention but increasing lately. In this respect, it is worth noting Verleger (1982), who states that refined product prices are the primary determinant of crude oil prices, i.e., this is known as the Verleger hypothesis. Indeed, Verleger (2011) exposes that refiners could reduce their production if they do not find a price for crude oil which matches with refined product prices, triggering a decline in the crude oil demand, reducing the price of crude oil and the subsequent fall in the supply of refined products, which would increase their prices, that is, shifts in demand for a determined refined product could have predictive power for the crude oil price (Baumeister et al. 2018). For its part, Kaufmann et al. (2009) apply an ECM to show that shifts in prices of refined products do not affect crude oil prices. Hence, changes in the demand for a given refined product have effects on the product mix of refined products and thus, for the demand for crude oil, arising a situation in which excess demand may result in rising prices (Alquist et al. 2013). Furthermore, Bilgin and Ellwander (2019) evidenced that changes in global demand for fuel explained most of the fluctuations in crude oil prices when a structural VAR model is applied. Finally, Vides et al. (2021) employ the fractionally cointegrated VAR model, showing that the Verleger hypothesis is rejected for all refined products and Ederington et al. (2021) finds that spot crude oil prices Granger-cause spot gasoline and actual spot heating oil prices.

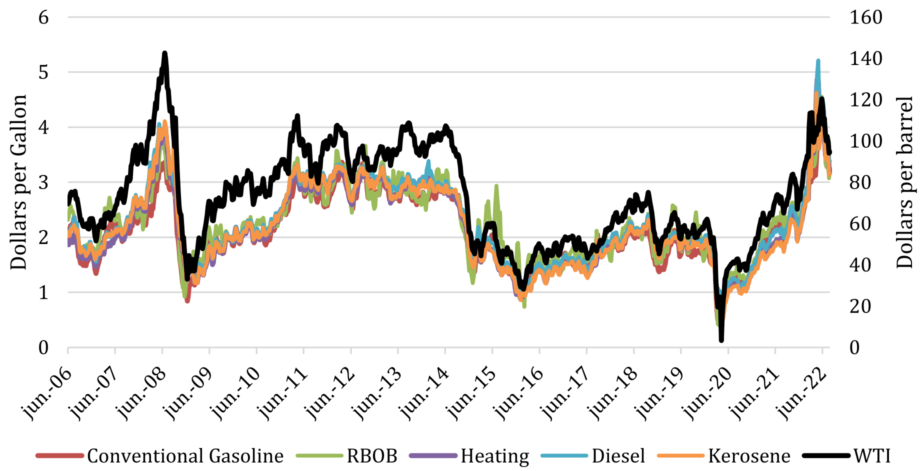

Fig. 1 Crude oil and its refined products' price dynamics. *Notes* Left-axis refers to dollars per Gallon for refined products and the right-axis refers to dollars per barrel for WTI crude oil

Data and methodology

Our econometric strategy implicates obtaining and analysing the model estimation at a weekly frequency, assessing the long-run relationship. Hence, we perform statistical tests for causality and the possibility of asymmetries in those possible causal relations based on the fundamental equation for the bivariate relationship between crude oil price and each of its refined products in an econometric context.

Data

In this article, we focus on the US oil market, considering the relationship between the spot price of West Texas Intermediate (WTI) crude oil and its refined products,[4] named conventional gasoline NY, Reformulated Gasoline Blendstock for Oxygen Blending (RBOB[5] hereafter), Ultra-Low-Sulphur Diesel NY (diesel hereafter) and kerosene. According to the US Energy Information Administration (EIA), the refinement process converts approximately 49% of crude oil barrels into gasoline, 25% into distillate fuel oil, i.e., diesel and heating oil, 9% in kerosene and the rest into other products. These proportions may be used as a preliminary notion of affecting the refining process to the price formation. All data were obtained from the US Energy Information Administration (EIA),[6] and each series covers a period spanning from June 16th 2006 to August 12th 2022, collecting 844 observations weekly.[7] Regarding the dynamics of the data, Fig. 1 plots the behaviour of the prices over time. It is apparent that crude oil and its refined products prices display a similar pattern, explained by these products directly extracted from crude oil. As we can see, those prices (both crude oil prices and refined products) follow a similar trend, which could suggest the existence of a long-run relationship. As previously mentioned in the literature review section, this view has been generally

[4] Crude Oil are valued in Dollars per barrel and the refined products in Dollars per gallon, which are converted to dollars per barrel by using 1 barrel = 42 US gallons, considering the US production.

[5] RBOB is heavily dependent on crude oil, as it is a refined product of the commodity.

[6] http://www.eia.gov/dnav/pet/pet_pri_spt_s1_w.htm.

[7] A table with descriptive statistics is included in Table 6 in the "Appendix".

treated. It exposes that a variation in refined products prices may be driven by a change in the crude oil price (Ederington et al. 2019).

Methodology

Traditionally, this topic has been studied by using the linear Granger causality (Granger 1969). The purpose of this work is to check the possible existence (or not) of Granger causality relationships between the WTI crude oil and its refined products by using a set of econometric procedures to achieve more robust and comparable results, from asymmetric point of view. Firstly, we apply the methodology suggested by Hatemi-J (2012), which expands the model developed by Toda and Yamamoto (1995) to capture the behaviour of the whole US fuel market. The Toda and Yamamoto (1995) method and the Hatemi-J (2012) method focus on performing an asymmetric analysis that lets us examine the origin of the price formation, i.e., if the price is given by the demand or, otherwise, the supply. Those latter techniques are an extension of Toda and Yamamoto (1995).

Granger causality, by product: Toda–Yamamoto test

In the literature, one of the most common methods for testing the causality effects between different variables is the Granger causality method based on the estimation of VAR models. The method developed by Toda and Yamamoto (1995) measures causality by solving problems derived from cointegrating relationships and non-stationary series. Delving into the relationship suggested, we follow the Toda–Yamamoto causality approach as an enlarged form of the Granger causality test based on augmented-VAR models in levels and extra lags, providing more efficient and robust results than the standard VAR model because it may provide biased results with finite samples (see Johansen and Juselius 1990; Zapata and Rambaldi 1997; Maddala and Kim 1998; Pesaran et al. 2001; Clarke and Mirza 2006). The core advantage of this test is the possibility of being applied regardless of whether the series are or are not cointegrated. In the case of cointegration, the order of integration is not crucial. In this exercise, a bivariate model including the West Texas Intermediate crude oil and each refined product price are examined. Thus, we can describe the benchmark model for this test:

$$WTI_t = \alpha_1 + \sum_{i=1}^{l+d_{max}} \beta_{1i} WTI_{t-i} + \sum_{j=1}^{l+d_{max}} \gamma_{1j} refined\ product_{t-j} + \varepsilon_{1t} \quad (1)$$

$$refined\ products_t = \alpha_2 + \sum_{i=1}^{l+d_{max}} \beta_{2i}\ refined\ product_{t-i} + \sum_{j=1}^{l+d_{max}} \gamma_{2j} WTI_{t-j} + \varepsilon_{2t} \quad (2)$$

where l is the optimal lag structure for the VAR model according to the Schwarz Information Criterion (SIC); d_{max}, extra lagged explanatory variables, corresponds to the maximum order of integration for the variables considered in the model; and the error terms ε_{1t} and ε_{2t} follow a Gaussian Distribution and are white noise processes. Therefore, this test estimates a $VAR(l + d_{max})$ model employing a Modified Wald test (MWALD), which is statistically asymptotically distributed as a χ^2 with p degrees of freedom. Furthermore, α_i is the intercept and β_{ji} and γ_{ij} are the parameters of the model which denote the relationship among the different variables.

To test the Granger causality between the two selected variables, attending to the first equation, if $\sum_{j=1}^{l}\gamma_{1j} \neq 0$, suggests a given $refinedproduct_t$ Granger causes WTI_t. Similarly, in the second equation, if $\sum_{j=1}^{l}\gamma_{2j} \neq 0$, WTI_t Granger causes a given $refined\ product_t$. Subsequently, if both hypotheses are rejected, this implies that there may exist a bi-directional causality in the examined relationship.

Looking for asymmetric causality relationships

Following the empirical literature, causality is often rejected due non-linear relationships are not contemplated. For this, we apply a non-linear test developed by Hatemi-J (2012) based on the indications of Granger and Yoon (2002), enabling us to determine if cumulative positive and negative shocks can have different impacts on the causal relationship between WTI and the refined products. Ensuing, we begin denoting our two variables through a random walk model:

$$WTI_t = WTI_{t-1} + \varepsilon_{1t} = WTI_0 + \sum_{i=1}^{t}\varepsilon_{1i} \tag{3}$$

and

$$refined\ product_t = refined\ product_{t-1} + \varepsilon_{2t} = refined\ product_0 + \sum_{i=1}^{t}\varepsilon_{2i} \tag{4}$$

where $t = 1, 2, \ldots T$, the constants WTI_0 and each $refined\ product_0$ are the primary constant values, and the variables ε_{1i} and ε_{2i} are white noise error terms. The maximum and minimum initial constant values of both the positive and negative shocks are identified as:

$\varepsilon_{1i}^{+} = \max(\varepsilon_{1i}, 0)\text{and}\varepsilon_{2i}^{+} = \max(\varepsilon_{2i}, 0)\text{and}\varepsilon_{1i}^{-} = \min(\varepsilon_{1i}, 0)\text{and}\varepsilon_{2i}^{-} = \min(\varepsilon_{2i}, 0)$, respectively. Clustering these terms as follow, $\varepsilon_{1i} = \varepsilon_{1i}^{+} + \varepsilon_{1i}^{-}$ and $\varepsilon_{2i} = \varepsilon_{2i}^{+} + \varepsilon_{2i}^{-}$, we reach:

$$WTI_t = WTI_{t-1} + \varepsilon_{1t} = WTI_0 + \sum_{i=1}^{t}\varepsilon_{1i}^{+} + \sum_{i=1}^{t}\varepsilon_{1i}^{-} \tag{5}$$

$$refined\ product_t = refined\ product_{t-1} + \varepsilon_{2t} = refined\ product_0 + \sum_{i=1}^{t}\varepsilon_{2i}^{+} + \sum_{i=1}^{t}\varepsilon_{2i}^{-}. \tag{6}$$

Therefore, positive and negative shocks can be written as follows:

$$WTI_t^{+} = \sum_{i=1}^{t}\varepsilon_{1i}^{+};\ WTI_t^{-} = \sum_{i=1}^{t}\varepsilon_{1i}^{-};\ refined\ product_t^{+} = \sum_{i=1}^{t}\varepsilon_{2i}^{+};\ refined\ product_t^{-} = \sum_{i=1}^{t}\varepsilon_{2i}^{-}. \tag{7}$$

Assuming that:

$y_t^{+} = \left(WTI_t^{+}, refined\ product_t^{+}\right)$, $y_t^{-} = \left(WTI_t^{-}, refined\ product_t^{-}\right)$, $y_t^{\pm} = \left(WTI_t^{+}, refined\ product_{1t}^{-}\right)$, and

$$y_t^{\mp} = \left(WTI_t^-, refinedproduct_1^+\right),$$

the causal relationship between the variables could be examined using a VAR model of order p, for lag order $r = (1, \ldots, p)$. To perform a Wald test, the VAR (p) model can be expressed in a compressed form (for the first combination, y_t^+, for instance),

$$\begin{aligned}
&Y = DZ + \delta, \text{ where} \\
&Y := \left(y_1^+, \ldots, y_T^+\right)(n\ x\ T)matrix, \\
&D := \left(\upsilon, A_1 \ldots, A_p\right)(n\ x\ (1 + np))matrix, \\
&Z_t := \begin{pmatrix} 1 \\ y_t^+ \\ y^+ t - 1 \\ \vdots \\ y_{t-p+1}^+ \end{pmatrix}((1 + np)\ x\ 1)matrix, \text{ for } t = 1, \ldots, T, \\
&Z := (Z_0, \ldots, Z_{T-1})((1 + np)\ x\ T)matrix, \text{ and} \\
&\delta := \left(u_1^+, \ldots, u_T^+\right)(n\ x\ T)\ matrix.
\end{aligned} \tag{8}$$

The Wald statistic is $(C\beta)'\left[C\left(\left(Z'Z\right)^{-1} \otimes S_U\right)C'\right]^{-1}(C\beta)$, where $\beta = vec(D)$, being $vec(\cdot)$ the column-stacking operator; $\otimes$ is the Kronecker product; C is a $pxn(1 + np)$ indicator matrix with elements for restricted parameters and zeros for the rest of the parameters; and $S_U = \frac{\hat{\delta}_U' \hat{\delta}_U}{T-q}$, q is the number of parameters in each equation of the VAR model. Under the assumption of normality, the Wald statistic follows an asymptotic χ^2 distribution with equal degrees of freedom of the number of constraints to be tested (in this case, equal to p). The null hypothesis of non-Granger causality, $H_0 : C\beta = 0$, is rejected at the α level of significance (1%, 5% or 10%) according to the bootstrap critical values generated by GAUSS software.

Results

According to the econometric strategy above-described, in this section, we show the results to investigate the Granger causality relationships not only product-by-product but also by allowing asymmetries between the variables WTI and the different refined products and the inverse. In this sense, we apply the method of Hatemi-J, which is an extension of Toda and Yamamoto's work, for a product versus product study that also permits the study of asymmetries. Depending on the hypotheses to be tested, the results of these methods are described and differentiated by the direction of the causality. In this sense, Table 1 shows the empirical hypotheses coined for our goal and additionally, the estimated results are presented in Tables 2, 3 and 4, while Table 5 shows a summary of the main results. Prior to conducting our analysis, we perform four different tests: The augmented Dickey–Fuller (ADF) test offered by Dickey and Fuller (1979), the Phillips–Perron (PP) test offered by Phillips and Perron (1988), the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test offered by Kwiatkowski et al. (1992) and the Ng-Perron test developed by Ng and Perron (2001). We test for the stationarity of the series by means of the conventional ADF, PP, KPSS and Ng-Perron unit root tests. The unit root test results are presented in Table 7.

Table 1 Empirical hypotheses

Hypothesis	Explanation	Causality link
Supply-driven market integration	Supply forces influence the prices of refined products	*WTI* ⇒ *Deriv* *WTI*+ ⇒ *Deriv*+ *WTI*− ⇒ *Deriv*−
Rockets and feathers hypothesis	Refined products prices rise more quickly when crude oil prices increase than they plunge when crude oil prices drop	*WTI*+ ⇒ *Deriv*+ *WTI*− ⇏ *Deriv*−
Demand-driven market integration (Verleger hypothesis)	Refined products are the main determinants of crude oil price	*Deriv* ⇒ *WTI* *Deriv*+ ⇒ *WTI*+ *Deriv*− ⇒ *WTI*−
Feedback mechanism	Both of demand-driven and supply-driven market integration affect any product	*WTI* ⇔ *Deriv* *WTI*+ ⇔ *Deriv*+ *WTI*− ⇔ *Deriv*−

Own elaboration based on literature. WTI refers to West Texas Intermediate crude oil and Deriv refers to derivatives products, respectively. The signs + and − denotes the nature of the shocks, being + positive and − negative

Table 2 Linear effects

Refined product	*WTI⇒Deriv*				*Deriv⇒WTI*			
	Supply-driven				Demand-driven			
	Test statistic	Bootstrap critical values			Test statistic	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Conv. Gasol. NY	2.241	9.760	6.637	4.810	24.078***	9.123	6.075	4.522
RBOB	20.374***	9.576	6.443	4.929	8.839***	8.839	5.710	4.291
Heating Oil	7.157**	9.033	6.008	4.702	0.473	9.137	5.990	4.644
Diesel NY	10.037***	8.762	5.798	4.590	0.110	9.163	6.051	4.727
Kerosene	22.338***	10.050	6.168	4.622	5.021*	9.275	6.209	4.675

Lag orders are selected by minimizing the Schwarz Information Criteria

***, **, * denotes significance at 1%, 5% and 10% respectively

Table 3 Positive shocks on market integration

Refined product	*WTI+ ⇒Deriv+*				*Deriv+ ⇒WTI+*			
	Positive supply-driven				Positive demand-driven			
	Test statistic	Bootstrap critical values			Test statistic	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Conv. Gasol. NY	2.908	10.413	6.054	4.541	1.281	9.861	6.171	4.654
RBOB	3.414	10.800	6.627	4.815	7.668**	9.250	5.925	4.661
Heating Oil	0.198	12.730	5.987	4.489	0.364	11.620	6.214	4.551
Diesel NY	0.489	13.257	5.803	4.468	0.632	11.925	6.118	4.519
Kerosene	8.852**	10.800	5.800	4.506	1.892	11.198	6.496	4.581

Lag orders are selected by minimizing the Schwarz Information Criteria

***, **, * denotes significance at 1%, 5% and 10% respectively

Table 7 shows mixed results on whether the petro-derivatives prices follow a stationary process or not. Evidence shows that at a 1% significance level, the null hypothesis of a unit root cannot be rejected at levels in almost all the variables, while it is soundly rejected at first-differences.

Table 4 Negative shocks on market integration

Refined product	*WTI−* ⇒*Deriv−*				*Deriv−* ⇒*WTI−*			
	Negative supply-driven				Negative demand-driven			
	Test statistic	Bootstrap critical values			Test statistic	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Conv. Gasol. NY	5.984*	10.617	6.446	5.073	16.197***	9.230	6.075	4.506
RBOB	29.893***	9.832	5.997	4.446	0.119	9.123	5.877	4.653
Heating Oil	12.212***	9.892	6.394	4.955	1.306	10.343	5.941	4.582
Diesel NY	9.663**	10.387	6.334	4.887	0.752	11.563	6.249	4.467
Kerosene	13.372***	9.898	6.052	4.702	12.807***	8.292	5.698	4.526

Lag orders are selected by minimizing the Schwarz Information Criteria

***, **, * denotes significance at 1%, 5% and 10% respectively

Table 5 Summary of results

	Market integration		
	Supply-driven	Demand-driven	Supply–demand-driven
Asymmetries			
Linear effects	Heating oil diesel	Conventional gasoline	RBOB kerosene
Positive shocks	Kerosene	RBOB	
Negative shocks	RBOB Heating oil Diesel		Conventional gasoline Kerosene

Our first approach is shown in Table 2, which reveals that causality runs from WTI crude oil prices to all refined products prices except for conventional gasoline. In contrast, the inverse relationship shows causality from conventional gasoline, RBOB and kerosene to WTI. In general, as an upstream commodity, the price of crude oil is a major driving force for refined product prices. Thus, a significant movement in the price of crude oil is usually accompanied by a substantial movement in the prices of refined products. Conversely, extreme increases in refined product prices due to a demand shock can ultimately push crude oil prices higher (Tong et al. 2013). These results evidence the divergence between supply-driven and demand-driven market integration (Asche et al. 2003). In our case, our results suggest that all refined products except conventional gasoline could follow a supply-driven market integration, and for its part, conventional gasoline would follow a demand-driven market integration. Furthermore, we note that, at first sight, RBOB and kerosene would be included in both types of market integration, being interpreted as a feedback mechanism or a full integration, i.e., both prices would be influenced by supply and demand. These results are in line with those obtained by Martinez et al. (2018).

However, the nature of the previous results shown in Table 2 may shed more light when assessing the existence of asymmetries between crude oil and each refined product prices. In other words, we will analyze how positive or negative shocks could influence the causal relationship between our variables, being this idea the main contribution of this paper. In this sense, when the analysis is executed by contemplating the asymmetries, these results vary. In Table 3, the results of the positive effects show that a positive WTI shock causes positive shocks in kerosene. In this regard, these cases show that the price formation of that refined products is affected or caused by changes in crude oil prices. This corresponds to the so-called supply-driven market integration. At the same time, a positive shock on RBOB causes a positive shock on crude oil, denoting a demand-driven market integration. When the shock is positive, the significance of conventional gasoline, diesel or kerosene has disappeared, suggesting the importance of the study of the asymmetries existence. These results imply that external aspects such as the role of the valued chain in the price formation process or the information content of futures markets for these products.

Conversely, Table 4 shows the negative effects of these relationships. These results argue that a dropping price of WTI would cause a fall in price to each refined product. This result, in contrast to those obtained in Table 3, evidence a fall in WTI crude oil prices may cause the prices of refined products to drop, being strongly integrated when a negative shock appears. Thus, a negative shock on conventional gasoline and kerosene prices would cause a drop in WTI crude oil prices, being evidence for the fulfilment of Verleger hypothesis when a negative shock is given. Following Baumeister et al. (2018), this negative shock on conventional gasoline and kerosene prices will negatively affect the price of crude oil, suggesting that the difference between, in this case, both refined product prices and the purchase price of crude oil should have predictive power for the price of crude oil. The case of conventional gasoline must be highlighted. As we could see in Table 2, conventional gasoline appeared on the demand-driven side, but when asymmetries are considered, the conventional gasoline behaviour has changed, becoming a fully integrated refined product when the shock is negative.

The following Table 5 summarizes the results previously shown,[8].[9] First, the causalities of the overall effects are also found when asymmetries are allowed. In addition, these results show that the causalities differ depending on the nature of the shock in which the relationship is observed, demonstrating that an analysis that only contemplates the overall effects could be biased.

In this regard, we can see a mix of results, following a heterogeneous pattern and revealing the need to study the asymmetries regarding the causal relationships given. In this sense, our results suggest the dependent role of crude oil, represented in each type of integration, i.e., supply-driven and demand-driven market integration, when assessing the effects of linear relation or positive and negative shocks. Furthermore, our results indicate that all refined products would be under supply-driven market integration when negative shocks occur. On the other, conventional gasoline joints to kerosene are also placed on the side of demand-driven market integration. In this respect, it catches the eye that, in contrast to linear effects where conventional gasoline is only situated under the demand-driven market integration when the negative effects make their appearance, conventional gasoline prices become fully integrated.

Finally, concerning the existence of asymmetries, our results align with those of Karali and Ramirez (2014). Thereby, the crude oil effect on refined products is more significant and more persistent during bearish markets than bullish ones. These findings

[8] The same analysis has been carried out for the sample before COVID-19, and the results are robust with those obtained in the present analysis.

[9] We also have included the positive and negative cumulative sums (Figs. 2, 3) in the “Appendix” section.

provide some interesting information for policymakers and practitioners, being important to consider policies in favour of consuming or producing one product over another, depending on the market conditions at a given moment. Additionally, we know that effective competition in the market relies heavily on the information available to concerned parties. Consequently, government policies designed for informing about the different prices in real time may be a good measure to influence price asymmetries.

Conclusions

The paper addressed to analyze the causality relationship is a set of alternative tests that reveals Granger causality considering asymmetries in the relationships, following the approaches by Toda and Yamamoto (1995) and Hatemi-J (2012). This paper provides evidence to previous empirical studies by analyzing the asymmetric behaviour of the relationship between crude oil price and the price of its refined products, which play a pivotal role in the global economy and remains at the core of energy markets (Fazelabdolabadi 2019). Furthermore, as previously mentioned in the literature review section, the shocks in different economic sectors caused by 'Ukraine–Russian war' and, significantly, the COVID-19 pandemic and the measures applied by governments have impacted crude oil prices differently and refined products. Thus, we have to highlight that the period analyzed covers several financially risky economic events, such as the global financial crisis and rises in tight oil production, and the abovementioned recent geopolitical events.

As Karagiannis et al. (2015) stated, symmetry in crude oil and refined products prices might be viewed because of an effective regulatory policy of the energy sector in an economy. Indeed, the remarkable nature of our results let us identify heterogeneity in the pattern of refined products concerning the causality versus WTI, revealing the opportuneness of studying the asymmetries regarding the causal relationships given. In line with Tiwari et al. (2021), the presence of asymmetries could be explained by the different arrangements between every link in the chain in the energy markets, provoking an extra payment of costs. On this point, the dependent role to crude oil of kerosene is represented in each type of market integration, i.e., it appears as a result in the supply-driven and the demand-driven market integration, when measuring the effects of linear relation or positive and negative shocks, which makes sense. This aspect would convey us to explore the treatment of this refined product, which is essential to the airlines and the travel industry. In this sense, the hedging strategies followed by airlines are well-known to protect themselves from volatility and explosiveness in fuel prices. Contrary to the efficient market hypothesis, investors could protect themselves and their portfolios by forecasting the prices due to the asymmetries, providing a convenient way to reduce portfolio risk (see Tang and Xiong 2012).

Furthermore, how changes in the crude oil price affect refined product prices is known as the pass-through. People's main sense is that the pass-through is not symmetric: The speed at which the price of any refined product changes is different depending on if the price of each refined product is relatively high or relatively low compared to the price of oil (Owyang and Vermann 2014). Thus, our results suggest the importance of attending when negative shocks appear, where all refined products would be located under the supply-driven market integration (this is evidence of rejection of the Rockets and

Feathers hypothesis). On the other, conventional gasoline joints to kerosene are also placed on demand-driven market integration, implying that these products would be the driving factor in the petro-derivatives price-generating process and could be key for refiners, which may use this information for designing refining strategies and controlling product stocks. Additionally, in contrast to linear effects where conventional gasoline is only situated under the demand-driven market integration when the negative effects appear, conventional gasoline prices become fully integrated.

Thus, given the results obtained, it is well-known that there exist two price transmission mechanisms between crude oil and its refined product prices in the economic sense. An increase in crude oil price fosters refining costs, raising the refined product prices. Therefore, if the refined products prices rise, refiners would be able to offer a more considerable volume of products. Subsequently, the demand for crude oil would grow, triggering a higher price. Due to the presence of asymmetries and the impact of different shocks on crude oil price and the prices of the refined products, there is a high degree of uncertainty in prices. In this regard, the US regulatory authorities and policymakers should implement and carry out a national energy outlook in oil markets, by using effective monitoring tools to avoid adverse effects of energy price shocks on consumers and, consequently, for the overall welfare of the economy. Also, the use of those tools provide to policymakers the possibility of minimizing oil price risk in different oil-dependent sectors, such as transportation, heating, or agriculture, by diversification and elaboration energy mixes with a view to a clean energy system. Furthermore, it would be advisable the implementation of fiscal and monetary stimulus packages to alleviate the aftermath of COVID-19 on commodity markets (Polat 2020). Additionally, in these times of high levels of inflation, it seems necessary to monitor the sign of the shock that may be a valuable tool for economic authorities to prevent the inflationist tensions that might occur and affect the transmission channels to the rest of the economy, affecting the rest of the products and altering the whole economy (Barros et al. 2011).

Lastly, we have revealed that the existence of asymmetries could be translated into a more predictability and, subsequently, a weaker form of market efficiency. This provides valued information to market participants regarding the behaviour of the WTI and refined products prices. Moreover, the consideration of asymmetries would response how the oil market reacts when a movement of its inputs occurs, i.e., whether a given refined product price moves symmetrically o asymmetrically when crude oil moves (Perdiguero-García 2013).

Likewise, our research findings have practical applications for developing a more effective approach focused on time series, especially when dealing with market participants who have varying temporal horizons, such as investors, speculators, hedge funds, and refineries. The energy sector, economists, policymakers, and investors require a deeper understanding of the relationship between crude oil and its refined products, particularly in light of the global economic crisis and the surge in tight oil production. Therefore, our results contribute to improving the comprehension of energy market behavior. This latter idea can be complemented by the fact that the energy market is changing over time, requiring that the different actors establish new positions because governments and public opinion demand heavier regulations and greater environmental commitment (Kirikkaleli and Güngör 2021). Thus, from an environmental point of view, the energy markets (the petro-derivatives market in particular) have a growing impact on the carbon emission problem due to the use of fossil fuels in transport vehicles. In this sense, Kou et al. (2022) argue that one plausible solution to mitigate and fight this problem is the use of electric vehicles, especially in road transport, being these electric vehicles would be solar-energy-type. Furthermore, Anser et al. (2021) identified this issue, i.e., carbon emissions, as one of the main problems that must be reduced so that economies can improve in the long term.

Finally, future research could be oriented to the study of the relationship between WTI crude oil and the refined products, by using other methodologies which also could capture the nature of the relations in a different way (thresholds, spatial analysis, among others), or by using the Brent crude oil as a benchmark. Additionally, large-scale GDM and fuzzy cluster analysis (Li et al. 2021) or an MCDM-based approach (Kou et al. 2014) might be suitable when assessing refiner's or investors' preferences, attending to spot and future prices or the financial risk associated.

Appendix

See Tables 6, 7, 8 and Figs. 2, 3.

Table 6 Descriptive statistics

	WTI	Conv. Gasol	RBOB	Heating oil	Diesel NY	Kerosene
Mean	71.994	2.106	2.249	2.160	2.248	2.160
S.D	23.278	0.641	0.657	0.721	0.732	0.736
Max	142.520	4.336	4.551	4.874	5.211	4.626
Min	3.332	0.499	0.369	0.654	0.692	0.461

Table 7 Unit root tests

	ADF	PP	KPSS	Ng-Perron			
				$\overline{MZ}_{\alpha}^{GLS}$	$\overline{MZ}_{t}^{GLS}$	$\overline{MSB}^{GLS}$	$\overline{MPT}^{GLS}$
Level							
WTI	− 2.153	− 2.166	0.243***	− 9.509	− 2.127	0.223	9.819
Conv. Gasoline	− 2.260	− 2.268	0.276***	− 11.597	− 2.319	0.200	8.334
RBOB	− 3.529*	− 3.559*	0.251***	− 25.982***	− 3.545***	0.136***	3.864***
Heating Oil	− 3.352*	− 3.521*	0.245***	− 8.655	− 2.009	0.232	10.795
Diesel NY	− 2.009	− 2.013	0.242***	− 9.338	− 2.072	0.222	10.137
Kerosene	− 2.016	− 2.011	0.236***	− 9.199	− 2.062	0.224	10.253
First differences							
WTI	− 24.849***	− 24.874***	0.056	− 409.220***	− 14.304***	0.035***	0.059***
Conv. Gasoline	− 22.862***	− 22.916***	0.064	− 393.127***	14.017***	0.036***	0.065***
RBOB	− 23.159***	− 23.303***	0.042	− 386.337***	− 13.896***	0.036***	0.066***
Heating Oil	− 24.294***	− 41.001***	0.082	− 26.118***	− 3.610***	0.138***	0.952***
Diesel NY	− 24.361***	− 33.136***	0.088	− 49.624***	− 4.980***	0.100***	0.496***
WTI	− 24.326***	− 43.328***	0.077	− 16.821***	− 2.875***	0.171***	1.552***

ADF Augmented Dickey–Fuller, *PP* Philips–Perron, *KPSS* Kwiatkowski–Philips–Schmidt–Shin, *SIC* Schwartz information criterion, *MSIC* Modified Schwartz information criterion lag length used in ADF and PP based in SIC, MSIC in Ng-Perron, and Newey–West bandwidth used for KPSS

***, **, * indicate rejection of the null hypotheses (of unit root for ADF, PP, and NG-Perron, and of stationarity for KPSS) at 1%, 5%, and 10% levels

Table 8 Summary of the literature review

Author	Country	Data span	Methodology	Results
Bacon (1991)	UK	15 June 1982–19 January 1990	The modelling of asymmetric partial adjustment	When prices of crude oil rise, this causes an increment of gasoline prices (or other refined products) in a faster way. Conversely, the drop in crude oil prices does not provoke a faster response to gasoline prices
Borenstein et al. (1997)	USA	March 1986–December 1992	Cointegration	When crude oil prices fluctuate, i.e., increase or decrease, the response of the gasoline prices is asymmetric
Girma and Paulson (1999)	USA	April 1984–December 1994	Cointegration	Cointegration between WTI and unleaded gasoline and heating oil prices
Gjolberg and Johnsen (1999)	USA	January 1992–August 1998	ECM	All refined products, possibly excluding heavy fuel oil, prices are co-integrated with the crude price. Having estimated two simple error correction models, we find that the current product–crude margin deviations from a long-run equilibrium may contain significant information about the future changes in product prices and margins
Adrangi et al. (2001)	USA		VAR model and a bivariate GARCH model	Movements in crude oil prices cause shifts in the price of the refined product used, i.e., the Los Angeles diesel. This can also happen in the opposite direction due to demand inferences
Bachmeier and Griffin (2003)	USA	February 1985–November 1998	Asymmetric ECM	No evidence a pass-through response from crude oil prices to gasoline prices
Hammoudeh et al. (2003)	USA		Cointegration, Vector ECM, ARCH/GARCH	They suggest a bidirectional causal relationship between daily crude oil and gasoline prices. He also evidences a unidirectional causality from crude oil price to heating oil
Grasso and Manera (2007)	France, Germany, Italy, Spain and the UK	1985–2003	Symmetric ECM, threshold ECM, and ECM with threshold cointegration	The type of stages and the number of countries which are characterized by asymmetric oil–gasoline price relations vary across models

Table 8 (continued)

Author	Country	Data span	Methodology	Results
Asche et al. (2003)	USA	January 1992–November 2000	Cointegration	In the long-run, changes in crude oil prices feed through to these refined product prices, while the reverse is not true. Given that the crude oil price seems to determine these prices, this also provides an example of supply driven market integration
Kaufmann and Laskowski (2005)	USA	January 1986–December 2002	ECM	An asymmetric relation between crude oil and motor gasoline is explained by refinery utilization rates and inventory behavior. Additionally, the asymmetric relation between crude oil and heating oil maybe is produced by contractual arrangements between retailers and consumers. Indeed, these results would suggest that price asymmetries might be caused by efficient markets
Honarvar (2009)	USA	September 1981–December 2007	Crouching ECM	The behaviour of the forms depends on the fluctuations of the crude oil price, being conditioned by the origin of the shocks, i.e., if there is a shock in the crude oil price, it could be due to market conditions. In contrast, if the shock occurs in the refined product price, the origin may be induced by "efficiency or consumers' incentives", i.e., the demand side
Kaufmann et al. (2009)	USA	25 February 1994–15 September 2006	VECM	They show that shifts in prices of refined products do not affect crude oil prices. Hence, changes in the demand for a given refined product have effects on the product mix of refined products and thus, for the demand for crude oil, arising a situation in which excess demand may result in rising prices

Table 8 (continued)

Author	Country	Data span	Methodology	Results
Kilian (2010)	USA	October 1973–October 2008	Structural VAR model and VAR model	The VAR model also ignores the possibility of asymmetries in the transmission of oil price increases to retail gasoline prices
Douglas (2010)	USA	August 1990–May 2008	Threshold autoregressive model for the error-correction term	He evidences that retail gasoline prices exhibit asymmetric price adjustment
Venditti (2013)	Germany, France, Italy and Spain and the USA	January 1999–September 2009	Cointegration and Impulse-Response Functions asymmetry tests	Evidences on the rockets and feathers issue by using weekly data on gasoline and gasoil prices for the U.S., the euro area, by using nonlinear impulse response functions and forecast accuracy tests and displaying evidence of asymmetries in the U.S
Karali and Ramirez (2014)	USA	January 14, 1994–February 4, 2011	GARCH model	They obtain the presence of asymmetric effects in crude oil following major political, financial, and natural events. Furthermore, seasonality and day-of-the-week effects in the crude oil and heating oil markets are encountered
Atil et al. (2014)	USA	January 1997–September 2012	NARDL model	They evidence that a shock in the crude oil price transfers in a non-linear manner to gasoline and natural gas prices and shows that energy products prices dynamics possess a complex relationship
Han et al. (2015)	USA	3 October 2005–30 June 2014	VAR and ECM, Granger causality, Markov model and Impulse-Response Functions	They find bidirectional causality between crude oil and gasoline prices when facing a supply shock. They show that the interaction between crude oil price and gasoline price possess long-live

Table 8 (continued)

Author	Country	Data span	Methodology	Results
Bremmer and Kesselring (2016)	USA	1/1/2008–12/31/2009	ECM Granger causality test	When the data set is partitioned into three subsets, regression results and their impulse response functions provide evidence in favor of "rockets and feathers" asymmetric pricing behavior during periods of generally rising crude oil prices. However, there is also evidence that during periods of generally falling oil prices "balloons and rocks" asymmetric pricing behavior prevails
Kpodar and Abdallah (2017)	162 countries	January 2000–December 2014	VAR model and Impulse-Response Functions	Their results point out that positive shocks on crude oil prices possess a larger impact than negative shocks on gasoline prices response
Baumeister et al. (2018)	USA	January 1992–September 2012	Verleger's decomposition and mean-squared prediction error (MSPE)	They explored the predictive content of product spreads for the WTI spot price of crude oil, showing that many approaches favored by practitioners do not work well in practice, and they derived alternative forecasting models that do. Although their analysis focused on forecasting the real price of oil, they note that our approach can be easily adapted to forecasting the nominal price of oil. These findings support the conclusion that there is valuable predictive information in product spot price spreads

Table 8 (continued)

Author	Country	Data span	Methodology	Results
Martinez et al. (2018)	USA	14 June 2006–16 February 2017	Wavelet local multiple correlation	They find that the wavelet correlations are strong throughout the period studied and show a strong decline in correlation values from 2013 to 2015 (due to the overproduction of tight oil in the U.S. and a slowdown in global demand for oil) when seven commodities (crude oil -WTI- and six refined products -conventional gasoline, RBOB regular gasoline, heating oil, Ultra-Low-Sulphur diesel fuel, kerosene and propane-) are analyzed
Bilgin and Ellwander (2019)	OECD countries	988Q1–2017Q3	Structural VAR	They show that despite the parsimony of the identifying assumptions, the information on global fuel consumption helps to provide comparatively sharp insights on elasticities and other quantitative features of the global oil market
Martin-Moreno et al. (2019a)	Germany, France, Italy and the UK	January 2005–November 2013	Markov-switching model and TAR-ECM	In general, the results show evidence of an asymmetric response of gasoline and diesel prices to changes in the price of crude oil, both in the short-run and with respect to the adjustment towards long-run equilibrium. These price asymmetries fall in line with the "rockets and feathers" hypothesis
Martin-Moreno et al. (2019b)	Spain	January 2009–December 2017	Markov-switching model and TAR-ECM	For small changes in international oil prices there is neither price asymmetry nor rockets and feathers behavior in the retail markets. However, price asymmetries in line with rockets and feathers behavior in retail gasoline and gasoil markets are present when these changes exceed a certain threshold

Table 8 (continued)

Author	Country	Data span	Methodology	Results
Kyritsis and Andersson (2019)	USA	2 January 1997–29 December 2017	Granger and Quantile causality	They show a bidirectional causal relationship between heating and crude oil price returns and between natural gas and crude oil price returns, respectively. It is worth noting that they interpret causality as a predictability way instead of studying structural economic relations
Gosinska et al. (2020)	European countries	January 2000–July 2016	Threshold CVAR	It is shown that between the European and domestic wholesale markets fuel prices adjust symmetrically and asymmetrically between the domestic wholesale market and the retail market. This finding confirms that the most probable cause of asymmetric price adjustments (especially in new EU member states) is the behaviour of petrol stations and not of oil companies
Olayungbo and Ojeyinka (2021)	Nigeria	1973Q1–2020Q2	Hidden cointegration and ECM	They find that positive and negative components of both the crude oil and petroleum prices move together in the long run. The result suggests evidence of long-run asymmetry in Nigeria. The empirical findings from both the long-run and short-run results show that petroleum prices in Nigeria respond asymmetrically to changes in crude oil prices. Specifically, the outcomes from the study reveal that positive changes (increase) in crude oil prices produce a larger and stronger effect on petroleum prices than the effect of negative changes (decrease) in crude oil prices indicating evidence of an asymmetric relationship between the two prices in Nigeria. Thus, the findings confirm the existence of the rocket and feather hypothesis in the retail energy market in Nigeria

Table 8 (continued)

Author	Country	Data span	Methodology	Results
Bakhat et al. (2022)	Bulgaria (BG), Cyprus (CY), Germany (DE), France (FR), Greece (GR), Italy (IT), Poland (PL), Romania (RO), Spain (SP), the United Kingdom (UK) and the United States of America (US)	2009–2020	NARDL model	The results show that both asymmetries, in terms of speed and magnitude, exist for many of the analyzed markets, demonstrating the importance of not only accounting for the impact but also for the mean lag of the response
Ederington et al. (2021)	USA	24 June 1988–26 April 2019	Granger causality	They cannot evidence Granger causality from product prices to oil prices is found for the full sample period nor the period up to the end of 2005, but evidence that gasoline prices Granger-caused oil prices is found for post-2005. Similar results are found for an extended model that also includes potentially endogenous real market variables related to supply and demand in the oil, heating oil and gasoline markets
Vides et al. (2021)	USA	16 June 2006–29 January 2021	FCVAR model	They evidence that the order of integration of the crack spread displays a long memory process. Finally, by attending to the coefficient adjustments, supply-driven market integration is given. Additionally, the Verleger hypothesis is rejected for all refined products, corroborated by the component share

Own elaboration

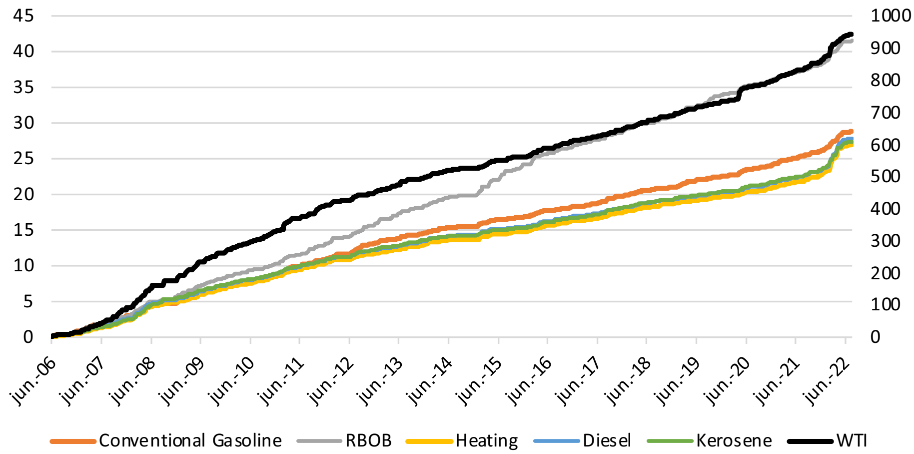

Fig. 2 Positive cumulative sums of the variables. *Notes* Own elaboration

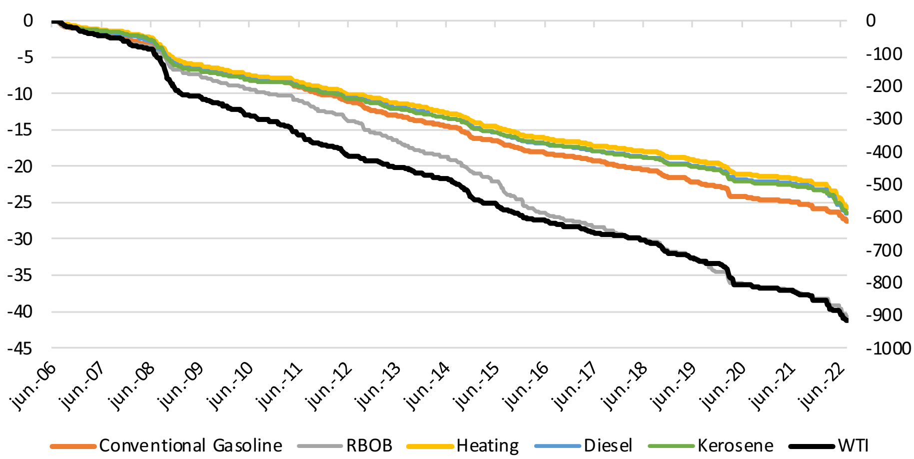

Fig. 3 Negative cumulative sums of the variables. *Notes* Own elaboration

Abbreviations

COVID-19	Coronavirus disease 2019
Deriv	Derivatives products
ECM	Error Correction Model
NY	New York
OPEC	Organization of the Petroleum Exporting Countries
RBOB	Reformulated Gasoline Blendstock for Oxygen Blending
U.S.	United States of America
VAR	Vector autoregression
WTI	West Texas Intermediate

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Author contributions
JV: Conceptualization, methodology, software, writing—original draft. AG: Investigation, data curation, software, validation, writing—review. JF: Data curation, methodology, writing—review and editing. JM: Conceptualization, visualization, methodology, investigation. All authors read and approved the final manuscript.

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