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A multi-resolution and multivariate analysis of the dynamic relationships between crude oil and petroleum-product prices

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HIGHLIGHTS

- A novel statistical approach named "wavelet local multiple correlation" (WLMC).
- Correlation between time series of crude oil and six distilled products.
- Correlation between time series is dependent on the time window analysed.
- The strong decay in wavelet correlation values approximately from 2013 to 2015.
- Heating oil, diesel and kerosene are the most dependent variables.

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ABSTRACT

This paper proposes the use of a novel multivariate, dynamic approach – wavelet local multiple correlation (WLMC) (Fernández-Macho, 2018) – to analyse the relationship between oil time series in the time-scale domain. This approach is suitable for use with energy data of any kind that change over time and involve heterogeneous agents who make decisions across different time horizons and operate on different time scales. The study of the links between multivariate oil time series is of great importance in energy research, e.g., it is extremely important for petroleum industry refiners and investors to know the relationships and margins between output prices and crude oil costs. The estimation of wavelet correlations in a multivariate framework between such prices is a suitable way to analyse crude oil and petroleum products as a system. To exemplify the use of WLMC, we analyse the relationships between the prices of seven commodities: West Texas Intermediate crude oil and six distilled products (conventional gasoline, regular gasoline, heating oil, diesel fuel, kerosene and propane) from 10/06/2006 to 17/01/2017. The results reveal that the wavelet correlations are strong throughout the period studied and there is a strong decay in correlation values from 2013 to 2015. The most plausible explanation for this decay is overproduction of tight oil in the U.S. and a slowdown in global demand for oil. Furthermore, our results also reveal that heating oil, diesel and kerosene maximise the multiple correlation with respect to the other oil variables on different scales, indicating that these products are the most dependent variables in the crude-product/price system. WLMC offers new opportunities for applications in energy research and other fields.

1. Introduction

Crude oil is an important, indeed indispensable commodity for the global economic system [1,2]. It is one of the most major energy sources for current civilization, accounting for around 40% of global energy consumption [3]. It is used in different economic activities and domains including industrial production, transportation, and agriculture, among others [4]. Crude oil is not a homogeneous commodity and is classified by its density and sulphur content. Taking into account these physical and chemical properties, there are over 160 different internationally traded crude oils [5]. Two of the most representative worldwide crudes are West Texas Intermediate (WTI) and Brent, which are the benchmarks for the US and Europe [2,5]. Crude oil can be refined into many petroleum products, e.g., regular gasoline, heating oil, diesel ful, jet fuel and others. These refinement process converts approximately 47% of crude oil barrels into gasoline, 24% into diesel fuel

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and heating oil, 13% into jet fuel oil (e.g., kerosene), 4% into heavy fuel oil (HFO), 4% into liquefied petroleum gas (LPG; e.g., propane) and 8% into other products (e.g., paraffins or asphalt) [6,7].

The prices of crude oil and the main petroleum products (gasoline, diesel and heating oil) are the ultimate embodiment of trading results in the global market [8]. Crude oil price fluctuations have significant impacts mainly on economic growth [9], financial markets [4,10] and national security [3]. Crude oil prices are driven by different market factors such as supply and demand; moreover they are strongly influenced by exogenous factors such as irregular events [11], global economic status [12], speculation [13], and political and social attitudes [14], the effects of which on the crude oil market are not always easy to quantify [8]. On the other hand, the petroleum-products prices are enormously influenced by crude oil prices [15,16] and by demand from consumers, the strategies of refineries and investors, stocks volumes, seasonality and meteorological conditions (e.g. heating oil) [16,17]. The prices of the main petroleum products can also influence crude oil prices [16,18]. This means that there is feedback between them. For this reason, strong correlations between the prices of crude oil and petroleum products are expected, as pointed out previously by several authors [5,18,19].

The study of the relationships between the prices of crude oil and refinery products is of great interest to refiners, investors, policymakers and scholars. One of the main reasons for that interest is that it is extremely important to know the differences or margins (or crack spread) between the output prices of distilled products for petroleum industry refiners and crude oil costs. It is therefore fundamental to investigate what dynamic interactions there are between crude and refined product prices. Since the seminal works of Girma and Paulson [20] and Gjolberg and Johnsen [21] published in 1999, a relatively moderate amount of research effort has been done during the last 20 years. For example, [20,21] analyse the co-movements between the prices of crude oil and major refined products and investigate the long-term pricing relationship. [20] finds that these commodities are co-integrated for the period 1983–1994, whereas [21] finds that the spread was stationary during 1992–1998. The next relevant paper was published in 2003: [15] apply a multivariate approach in the time domain to study the relationships between the prices of crude oil and several refined products for 1992–2000. They find that crude oil prices are weakly exogenous, that the spread is constant in some but not all relationships, and that the link between these prices implies market integration for these refined products. Shortly afterwards, in 2005 [5] carried out one of the most complete studies about this topic: they investigated ten prices series of crude oil and fourteen prices series of petroleum products from America and Europe from 1999 to 2002 through co-integration and error correction models. They find that the significance of product prices in the long-run relationship is specific to each geographical area, the relevant product mix also depends on the market area and on the characteristics of the crude, and the market price is the driving variable of the crude price also in the short-run, irrespective of the specific area and the quality of the crude.

Despite the importance of the study of the links between the prices of crude oil and its products, the number of papers published from 2005 to the beginning of 2010 is small, especially as regards papers in which several products are analysed, in comparison, for example, to the number of studies published about the link between crude oil spot prices and futures markets [22]. Some exceptions are [23], who studied retail gasoline and crude oil price movements in the US and find that gasoline prices in the long-run are influenced more by the technological changes on the demand side than by crude oil price movements on the supply side. It is worth noting that this finding is in disagreement to the literature that attributes asymmetric price movements to market power refiners. However, we would like to highlight that [23] only analyse the prices of one petroleum product and the paper does not consider crude oil and petroleum products as a system. Other exceptions are [7,18] or [22], and although some products are analysed in these papers they focus more on crack spreads than on the empirical relationships between the prices of crude oil and petroleum products.

During the last few years, however, there has been a relative increase in the number of publications that threat the prices of crude oil and the main products as a system, and in particular in paper that use a variety of advanced statistical techniques originally developed to analyse complex systems. For instance, Ref. [16] uses a copula approach to capture potential nonlinear relations between crude oil and some refined products and finds that lower and upper tail dependences are both positive, indicating that crude oil and refined product markets tend to move together; the same paper also finds asymmetry in tail dependence between crude oil and heating oil/jet fuel returns. Ref. [17] uses detrended cross-correlation analysis to investigate the cross-correlations between crude oil and refined product prices for 1991–2013, and finds that cross-correlations are significant and strong, that there is strong multifractality in them, and that long-term cross-correlations are stronger in recent ten years than in previous decades. Ref. [24] also investigates the same problem and finds that nonlinear correlations are stronger in the long-term than in the short-term, crude oil and product prices are co-integrated and financial crisis in 2007–2008 caused a structural break in the co-integrating relationship so that refined product prices dominated crude oil prices during the financial crisis. Ref. [25] analyses a dynamic conditional correlation between crude oil and fuels prices in a non-linear framework and finds a need for a different model for each pair analysed and the presence of at least one structural break in the conditional volatility and in the correlation between WTI and each product.

Such statistical techniques are suitable way of obtaining knowledge in energy research due the fact that oil/petroleum products prices make up a complex system [9,10]. This means that there are a large number of variables and factors interacting with one another and belonging to a range of areas that are interconnected, e.g. energy industry, economics, finance, engineering, technology, environment, etc. [26–28]. On the other hand, these techniques are specifically designed to tackle many of the characteristics contained in oil market data, such as the following: (1) oil time series change over time, i.e., they are not stationary (in other words their main statistical properties, e.g. their mean or variance, can change over time); (2) these series are not necessarily normally distributed [24,29]; (3) they can display nonlinear structures [24,30]; and (4) and they can involve heterogeneous agents who make decisions with different time horizons and operate on different time scales (frequencies) [30,31]. The wavelet transform (WT) is a suitable statistical technique for handling many of these features contained in oil time series [32,33].

The wavelet transform is a statistical tool that can handle non-stationary time series and that works in the combined time-and-scale domain (multi-scale analysis). There are essentially two approaches to estimating the WT: the first uses the continuous wavelet transform (CWT) and the second the discrete wavelet transform (DWT) [32,33]. The CWT enables the spectral features of the time series under analysis and their co-movements to be visualized as a function of both time and scale (frequency) and is adequate for extracting low signal/noise ratio and periodical components. However, it is highly redundant in both time and scale, which is not a desirable feature for correlation decomposition over timescales [35,33]. By contrast, the DWT is a compact representation of the data, that is, selects a minimal subsample of time-frequency values from the CWT without losing any information contained in the original data, and is particularly useful for noise reduction and data compression [35,33]. However, in many applications time redundancy is desirable to some extent as long as it allows for data features to be properly aligned and compared across all scales/frequencies. In this sense, the maximal overlap discrete wavelet transform (MODWT) is the most popular wavelet transform as it is redundant in the time dimension but non-redundant in the scale/frequency dimension [35,32]. Here, we seek to study the relationship between non-stationary oil time series by means of the MODWT, so we are interested