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Review

Oil Prices and the Hydrocarbon Markets: A Review

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Abstract: In this paper, we review the literature that investigates the impact of oil price shocks on the selected hydrocarbon prices. First, we present the empirical studies that presume, due to the global nature of the crude oil market, that the world oil price is an exogenous determining variable to the evolution of the local hydrocarbon markets such as natural gas or natural gas liquids (NGLs). Then, we present recent empirical studies that have improved our understanding of the source of oil price changes. They treat the real price of oil as an endogenous variable, identify the causes underlying oil price shocks, and then evaluate the impact of structural supply and demand shocks on the other hydrocarbon prices. The first strand of studies does not represent a consensus on the relationship between crude oil and other hydrocarbon prices—some demonstrate stable and asymmetric relationships, and some find no relationship or a very weak relationship. The second strand of studies shows that oil supply-side shocks have a transitory and temporary impact while oil demand-side shocks have a persistent and permanent impact on other hydrocarbon prices. In addition, it shows that the structural shocks in the global crude oil market explain approximately 50% of the variation in the other hydrocarbon markets in the long run.

Keywords: oil price shocks; hydrocarbon markets; transmission channels; asymmetries

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1. Introduction

Since the second oil shock of 1979–1981 and the consequent increased oil price volatility, energy market stakeholders and researchers have paid more attention to how energy commodity prices are linked to oil price fluctuations. In the last two decades, the expansion of unconventional oil from shale and tar sands has also challenged many underlying beliefs that oil prices are the main driver of other hydrocarbon prices. For example, the crude oil and natural gas prices in the United States were moving together, but they have started to decouple episodically since 2000—see Jadidzadeh and Serletis [1] for more detail. Since then, the improvements in both theoretical and empirical studies modeling the sources of oil price shocks have evolved our understanding of the interaction between integrated *global* oil markets and *local* hydrocarbon markets.

Understanding the behavior of price volatility in hydrocarbon markets is significant for several reasons. Persistent changes in volatility can affect the risk exposure of energy producers and investors and alter their incentives to invest in natural gas and oil sectors and facilities for production and transportation. Likewise, volatility is a key determinant of the value of commodity-based contingent claims, whether financial or real. In addition, based on the recent trends toward increasing global trade in petroleum products, Zavaleta et al. [2] discuss that mainly due to a significant increase in global refining capacity utilization the global petroleum refining industry is moving from a primarily local to a global market structure. Thus, reviewing the studies that investigate the determinants of volatilities in hydrocarbon markets is important for derivative valuation, hedging decisions, decisions to invest in physical capital concerning the production or consumption of

hydrocarbons, and undertaking plausible policy decisions on key energy commodities by policy makers [3].

Therefore, this article aims to present a selective review of the studies on the effect of oil price shocks on selected hydrocarbon prices, primarily natural gas and natural gas liquids (namely, ethane, propane, normal butane, iso-butane, and natural gasoline). As most literature on the effect of oil price shocks on hydrocarbon prices has employed U.S. data that provide long historical time-series data to test and run econometric models, we focus mainly on the U.S. hydrocarbon markets. We first discuss the channels through which crude oil price shocks impact hydrocarbon prices and then present the empirical econometric methods that explore the relationship between oil price shocks and the hydrocarbon prices based on the economic theories.

The economic theories that explain the relationship between oil and hydrocarbon prices consider either substitutability between oil and hydrocarbons (a demand-side linkage) or the way that hydrocarbons are extracted from oil and gas (a supply-side linkage). With regard to the relationship between oil and natural gas liquids (NGLs), it should be noted that crude oil is not consumed directly, but it is the main source of hydrocarbons, such as methane, ethane, propane, butane, pentane, and various other paraffinic, naphthenic, and aromatic hydrocarbons which are derived from refining crude oil. Similarly, the raw natural gas extracted from gas wells is refined to produce the end products including methane and natural gas liquids (NGLs). Methane, delivered by pipelines, is the main source of heating and burning in the residential, commercial, and industrial sectors, and NGLs, stored and shipped in a liquid state, are used as feedstocks in petrochemical plants, space heating, motor gasoline components, and other fuel use. Therefore, it is the demand for refinery and petrochemical end-products that drives the demand for crude oil and natural gas. Therefore, the shocks in oil and gas markets lead to changes in the production costs and, consequently, the price of NGLs. In addition, Oglend et al. [4] argue that the oil and natural gas markets are also related through the state of the NGLs markets. The liquids' prices are determined in a market that is indexed to oil prices with long-term contracts. Therefore, an increase in oil prices might raise NGL prices.This might make natural gas producers increase their production, as NGLs are a key source of income for them, consequently lowering natural gas prices.

About the relationship between the crude oil market and the natural gas market, on the demand side, oil and gas compete indirectly with their derivatives. Methane (a natural gas derivative) and heating oil (a crude oil derivative) compete in the heating markets of residential and commercial sectors. Methane is also a substitute for the residual and distillate fuels in electricity generation and industrial plants. For example, Hartley et al. [5] argue that the installation of advanced combined cycle gas turbine (CCGT) power plants has increased the demand for natural gas relative to residual fuel oil in the United States. On the supply side, associated natural gas is a coproduct of crude oil as it occurs in oil reservoirs, whereas the non-associated natural gas is not in contact with crude oil and is found in natural gas reservoirs. Although associated natural gas accounts for a small fraction of natural gas production in the United States, it is also utilized to extract NGLs in oil refineries. In addition, recent technological innovations in horizontal drilling and hydraulic fracturing have increased the production of both shale oil and shale gas.

There are a large number of empirical studies that sought to investigate whether the price of crude oil was an important determinant of the natural gas price. However, less attention has been paid in the literature to the relationship between other hydrocarbon products and the oil market. Most of this literature employs time series models and can be categorized into two strands. The first strand of studies investigates the existence of correlation and long-run cointegrating relationships between oil and hydrocarbon prices using different types of time series models such as Vector Error Correction Models or Vector AutoRegressive (VAR) models. These studies mostly treat the price of oil as exogenous and investigate the response of other hydrocarbon prices to exogenous changes in the oil price. Basically, this literature shows that the relationship between the oil price and the

natural gas or NGL prices is asymmetric in a way that the oil price predominantly drives the other hydrocarbon prices, but not the other way around. The second strand of studies treats the price of crude oil as endogenous and disentangles the causes underlying oil price shocks. This recent empirical literature, which is built on Kilian [6] employs a structural VAR model to identify the source of oil price fluctuations as a result of supply disruptions and demand changes in the integrated global oil market. They augment Kilian's structural VAR model to include the real price of another hydrocarbon and investigate the response of other hydrocarbon prices to the structural shocks in the oil market.

The paper is organized as follows. Section 2 discusses the channels through which oil price technically impacts other hydrocarbon prices. Section 3 reviews the literature that investigates the relationship between crude oil and other hydrocarbon markets, and the final section concludes the paper.

2. Transmission Channels between Oil and Hydrocarbon Prices

As illustrated in Figure 1, raw natural gas is extracted either from gas reservoirs or oil reservoirs. The former is called non-associated natural gas or wet gas, and the latter is called associated-dissolved natural gas. The associated natural gas is delivered to oil refineries to extract hydrocarbon gas liquids (HGLs). The HGLs from oil refineries are usually converted to olefins such as ethylene, propylene, normal butylene, and isobutylene to make resins, plastics, and adhesives in petrochemical plants. However, the non-associated gas is delivered to a gas processing plant and then to other facilities, namely, fractionators, to separate the majority of the hydrocarbon gas liquids (HGL) from the gas stream and to apply additional separation to meet certain commercial specifications. The end-products are natural gas liquids (NGLs), including ethane propane, normal butane, isobutane, and natural gasoline, which are abbreviated as C2, C3, NC4, IC4, and C5, respectively. The liquidation of NGLs makes possible their storage and delivery from remote producing areas, with oil-indexed prices and long-term contracts, to large consuming areas—see Jadidzadeh and Serletis [7], Wamsley [8], and the HGLs page by the U.S. Energy Information Administration [9] for more detail.

Crude oil is traded in a global marketplace where many international buyers and sellers are absent in a geographically proximate situation. However, markets for natural gas and refined petroleum products are typically considered national or even regional. Specifically, there are three major regional markets, including the North American, European, and East Asian trading hubs, where the prices of NGLs are determined. Three channels link NGL prices to oil prices. First, NGLs are either the direct product of crude oil or are used as blendstocks in petroleum products. For example, although a considerable share of NGLs is extracted from natural gas at the fractionators, a large amount originates from the crude oil at the refineries. Since 2000, the amount of U.S. HGLs production from petroleum refineries has remained almost unchanged at about 0.55 million barrels per day, while the production from natural gas processing plants has increased from 2.16 to 5.72 million barrels per day in 2020. Gasoline, which is the main product of crude oil, needs to be mixed with natural gasoline and normal butane to enhance combustion. So, the channel that the crude oil prices impact natural gasoline and normal butane through is the interplay of gasoline supply and demand. Second, the market structure of NGLs links the NGL contracts to oil prices. There are many trading gas hubs all over the world where NGL prices are determined by oil-indexation mechanisms that tie NGL prices to oil prices, compared to the gas-on-gas completion mechanism, where NGL prices are determined based on their supply and demand interactions [10]. Third, crude oil products such as heating oil compete with methane, propane, and butane through their utilization for fuel and heating. Furthermore, the development of the Liquefied Petroleum Gas (LPG) markets has strengthened the connection between the oil and gas markets. So, any change in oil or gas prices is expected to change the NGL prices either directly or indirectly.

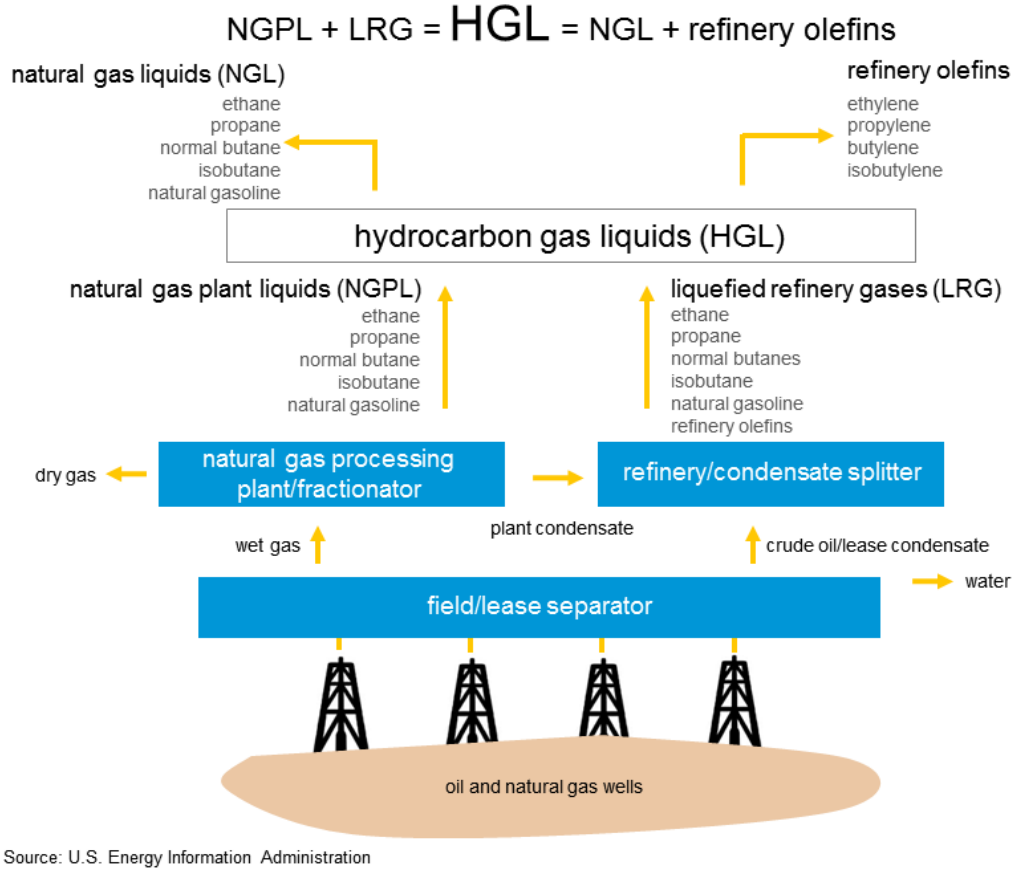

Figure 1. Sources of hydrocarbon gas liquids (HGL) and Natural gas liquids (NGL).

3. Empirical Models

In this section, we first review the studies that presume that the real price of oil is exogenous with respect to economic fundamentals, and supply disruptions, such as political events in the Middle East, only drive the oil price shocks. The key insight in them is that the relationship between oil price and other hydrocarbons is evaluated on a *ceteris paribus* basis—i.e., the oil price varies while all other variables are held constant. Then, we present recent empirical studies that are mostly built on Kilian [6] and treat the real price of oil as an endogenous variable. They believe that oil price fluctuations do not occur *ceteris paribus*. As a result, the volatility in the integrated global oil market is driven by both supply and demand shocks. They disentangle the source of price changes and then evaluate the impact of supply and demand shocks on the other hydrocarbon prices.

3.1. Oil Price as an Exogenous Variable

This line of study relies on the global nature of the crude oil market and presumes that large variations in the price of oil are historically driven by supply disruption as a result of political events and OPEC decisions. It assumes that oil prices are exogenous to macroeconomics variables and discards the source of oil price shocks in their analyses. Among those, some studies, such as Wang et al. [11], Brown and Yücel [12], Panagiotidis and Rutledge [13], Pindyck [3], Serletis and Rangel-Ruiz [14], and Serletis and Herbert [15], show that there is a stable and asymmetric relationship between the crude oil price and natural gas price in a way that the oil price dominantly derives the natural gas price, but not the other way around. On the contrary, other studies such as Bachmeier and Griffin [16], Drachal [17], and Zhang and Ji [18] show that, in the long run, there is no relationship or a very weak relationship between the prices of crude oil and natural gas. Serletis and Rangel-Ruiz [14] show that there are no shared stochastic trends between West Texas Intermediate (WTI) crude oil prices and Henry Hub natural gas. They attribute this to the deregulations

of the natural gas market in the United States. Hailemariam and Smyth [19] argue that since the shale gas revolution in 2008 the price of natural gas has been determined based on its supply and demand in the natural gas market. In the short run, studies such as Hartley et al. [5] and Brown and Yücel [12] show that seasonal factors, such as weather and natural disasters, and oil inventories have a significant impact on natural gas prices, which makes them deviate from oil prices.

Yücel and Guo [20] is one of the first studies that investigated a cointegrating relationship between oil, natural gas, and coal prices from 1947 to 1990 in the U.S. They show that oil and natural gas are not cointegrated when using the full sample because the natural gas market was heavily regulated before 1974. However, their results verify that the cointegration exists episodically in sub-samples. For example, one can find a long-run relationship between oil and natural gas prices for the 1974–1990 time span in a way that the oil price drives natural gas prices—see also Hou and Nguyen [21], Hailemariam and Smyth [19], and Aruga [22], who verify Yücel and Guo's results over the 1974–1990 period. Similarly, Bachmeier and Griffin [16]'s study does not support the idea of a primary energy market as they show that oil, natural gas, and coal are very weakly integrated in the U.S. They argue that the end products of oil and natural gas are used in different sectors, while in the short-run, little possibilities of interfuel substitution exist. For example, oil and natural gas products, mostly heating oil and methane, can compete in residential and commercial heating or in power plants, while gasoline, which is mostly produced from oil, does not have a considerable successor to natural gas in the transportation sector. In contrast, Barcella [23] argues that fuel oil and natural gas are significant substitutes in the electric power sector and that is why crude oil and natural gas prices are highly correlated in the liberalized U.S. gas market. Therefore, the state of the transmission channels, discussed in the previous sections, is used to explain how the hydrocarbon prices are integrated with the crude oil prices. They attribute either changes in the state of market structure and regulations (i.e., oil-indexed versus gas-on-gas contracts), supply-side interruptions and developments, or demand-side changes in oil and gas derivatives to co-movements in the prices.

The liberalization of natural gas markets refers to the deregulation and structural reforms that lead to the gas-on-gas competition in liquid spot and futures markets rather than long-term contracts with prices determined in advance and frequently linked to the crude oil or heavy fuel price (a system known as oil-indexation). Some studies such as Barton and Vermeire [24] and Heren [25] believe that the liberalization of gas markets in the U.K. has weakened the linkage between crude oil and gas prices since the spot and futures markets were first established in 1995–1996. Asche et al. [26] employ cointegration models and show that the U.K. natural gas market and Brent oil are integrated in an interim period (1995–1998) when the U.K. gas market was liberalized in 1995 but not yet linked to the Continental gas markets through the U.K.–Mainland Europe Interconnector gas pipeline at the end of 1998. They do not find any evidence of cointegration for the period after opening the Interconnector between 1998 and 2002. In contrast to Asche et al. [26], Panagiotidis and Rutledge [13] and Drachal [17] show that a long-run equilibrium relationship between U.K. gas and oil prices exists over the period 1996–2003. Panagiotidis and Rutledge [13] believe that the differences in results with Asche et al. [26] could stem from the inclusion of the electricity price in their study. These studies do not represent a general consensus on the relationship between crude oil and natural gas prices. This lack of consensus across studies is mainly due to either methodological or some other factors such as data, time period, and location of the study.

In recent years, some studies employ new empirical techniques to address the spillover effects between natural gas and crude oil markets in different time frequencies—see Batten et al. [27], Ji et al. [28], Perifanis and Dagoumas [29], Zhu et al. [30], Wang et al. [11], Li et al. [31], and Lovcha and Perez-Laborda [32]. To investigate the information or volatility spillover effect of the markets, they use more explanatory variables (e.g., historical events or disasters) with high-frequency data (e.g., daily data) from the financial sector. Similar to the studies that employ cointegration techniques, there is no consensus on the results of

these studies. Many of them [27,29,30,32] argue that since the shale gas revolution in 2008, the spillover effect from the oil market to the gas market has disappeared or accounts for very small changes in the U.S., while before the shale gas revolution, the spillover effect was present episodically in some periods from the oil market to the natural gas market, or in some cases the effect was reversed. Wang et al. [11] show that the negative shock of the oil market did spill over sharply into the gas market. In addition, they argue that the effects of the shale gas revolution are not apparent in Europe.

Unlike the studies that focus on the relationship between oil and natural gas markets, there are limited studies that investigate the relationship between crude oil and other hydrocarbon markets. Oglend et al. [4] is the only study we are aware of in this strand. They investigate how the shale gas revolution has impacted the relationship between LPGs (namely, propane and butane), natural gas, and oil prices using a generalized cointegrated VAR model. They find that the expansion of shale gas has weakened the strong relationship between LPG and natural gas prices with crude oil prices in the United States. They argue that the state of the LGPs market affects the relationship between oil and gas prices. For instance, when high prices in the oil market increase the prices for liquids in LPG markets, then natural gas producers might increase the production of natural gas, aiming to gain more profits from the liquids, which, consequently, a higher supply of natural gas lowers its prices. However, there are other studies such as Westgaard et al. [33] and Myklebust et al. [34], who investigate the price dynamics of propane, butane, and naphtha traded in the north European market. They employ state-space models with unobservable components in a multivariate context to address the joint dynamics of these gas component prices. They do not incorporate natural gas or oil prices in their analysis to see how the prices might vary as the price of oil or gas fluctuates.

3.2. Oil Price as an Endogenous Variable

There has been considerable improvement in econometrics methods to identify the causes underlying oil price shocks in the last two decades. These studies are mostly built on Kilian [6]'s article, in which he shows how the price of oil is disengaged. Kilian [6] initiates an index to capture the changes in the real global economic activity and employs the structural Vector AutoRegressive (VAR) model to decompose the evolution of the real oil prices into three different sources: shocks to the global supply of crude oil, shocks to the global demand for all industrial commodities (including crude oil) that are driven by the global business cycle, and oil-market-specific demand shocks (also referred to as precautionary demand shocks). Since Kilian [6], the literature has departed from the earlier studies that mostly treat the price of oil as exogenous and incorporates supply and demand shocks to the real price of oil. Kilian's approach has resulted in the formation of new extensive literature to study the effects of the oil shocks. Some studies have examined the effect of oil price shocks on macroeconomic and financial variables. For more detail, see the review papers of Kilian [35] and Herrera et al. [36]. In this section, we review the studies that augment Kilian [6]'s structural VAR model to include the real price of hydrocarbons and investigate the response of the real price of hydrocarbons to the structural shocks in the crude oil market.

Jadidzadeh and Serletis [1] and Zamani [37] both augment Kilian [6]'s model and incorporate the real price of natural gas as the fourth variable to investigate the impact of those structural shocks in the oil market on natural gas prices. The former uses the monthly U.S. natural gas wellhead price from 1976:1 to 2012:12, and the latter uses the monthly U.S. natural gas imported price from 1989:1 to 2014:12. Both of these studies show that supply shocks in the oil market do not have a statistically significant impact on the real price of natural gas, but it increases the real price of natural gas after 12 months. The response of gas prices to the oil supply shocks measured by the impulse response functions are only statistically significant based on one-standard error bands. The demand shocks that are explained by an unexpected increase in the global demand for all industrial commodities have an immediate and sustained increase in the real price of natural gas.

Finally, expectations in the oil market captured by the precautionary demand for oil has an immediate and sustained increase in natural gas prices.

Jadidzadeh and Serletis [1] employ the forecast-error-variance decomposition to quantify the share of the oil market structural shocks on the variation of natural gas prices over different time horizons. They find that in the short-run the oil market shocks do not demonstrate a considerable effect on the variations in the real natural gas prices. For example, all three structural shocks account for less than one percent fluctuations in the real price of natural gas in the first month, while the contribution of the structural shocks increases as the forecast horizon increases. However, in the long run, 45% of the variation in the real price of natural gas originates from the three structural shocks in the crude oil market. The largest contributor to the variation in the real natural gas prices is the aggregate demand shocks (which explain more than 16% of the variation), followed by the contribution of precautionary demand shocks and oil supply shocks (accounting for about 16% and 13% of the variation, respectively) to the long-run variation in the real price of natural gas. The remaining variation (about 55%) in the real price of natural gas is from the shocks that are specific to the natural gas markets or generally other shocks.

A recent study by Jadidzadeh and Serletis [7] investigates the impact of structural shocks in the crude oil market on the price of ethane, propane, normal butane, isobutane, and natural gasoline over the period from January 1985 to April 2020. The results are very similar to what was presented in Jadidzadeh and Serletis [1] and Zamani [37] for natural gas prices. Although the supply-side shocks in the crude oil market do not demonstrate statistically significant impulse responses, a negative (one standard deviation) shock in the supply of crude oil would tend to increase each NGL's price after six months temporarily. A positive (one standard deviation) demand shock, either in the aggregate demand shock or the precautionary demand shock, represents an immediate and persistent increase in NGL prices. The forecast-error-variance decompositions show that in the short-run (first three months horizon), the oil market's structural shocks explain 23%, 34%, 44%, 50%, and 67% of the variation in ethane, propane, normal butane, isobutane, and natural gasoline prices, respectively. In the long run, the share of structural shocks accounts for approximately 55% of fluctuations in the prices of NGLs.

Unlike the studies that treat oil prices as exogenous and employ cointegration models, this stream of studies distinguishes the transmission channels that the price of oil impacts the other hydrocarbon prices. They presume that the system of equations in the SVAR model is composed of two blocks. The first block consists of the three structural shocks that are specific to the oil market, including oil supply shocks, aggregate demand shocks, and precautionary demand shocks. The second block captures the volatilities in the natural gas or NGLs markets that are not driven by the shocks in the oil market. Then, the model investigates how the structural shocks that are specific to the oil market impact the natural gas or NGLs prices.

4. Conclusions

We have provided a survey of studies that investigated the effect of crude oil price shocks on the main hydrocarbon prices. First, we discussed the channels through which oil price technically impacts natural gas and hydrocarbon gas liquids. We then reviewed two strands of studies. The first strand relies on the global nature of the crude oil market and presumes that large variations in the price of oil are historically driven by supply disruption as a result of political events and OPEC decisions. It assumes that oil prices are exogenous to macroeconomics variables and discards the source of oil price shocks in their analyses. It investigates the existence of correlation and the long-run cointegrating relationship between oil and hydrocarbon prices using different types of time series models such as Vector Error Correction Models. Initially, this literature shows that the relationship between the oil price and the natural gas or NGLs prices is asymmetric in a way that the oil price predominantly drives the other hydrocarbon prices, but not the other way around.

The second strand of studies treats the price of crude oil as endogenous and disentangles the causes underlying oil price shocks. This recent empirical literature, which is built on Kilian [6], employs a structural Vector AutoRegressive (VAR) model to identify the source of oil price fluctuations as a result of supply disruptions and demand changes in the integrated global oil market. Other studies augment Kilian [6]'s structural VAR model to include the real price of another hydrocarbon and investigate the response of other hydrocarbon prices to the structural shocks in the oil market. They show that oil supply-side shocks have a transitory and temporary impact while oil demand-side shocks have a persistent and permanent impact on other hydrocarbon prices. In addition, they show that about 50% of the variation in the other hydrocarbon markets is explained by the structural shocks in the global crude oil market in the long-run.

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Abbreviations

The following abbreviations are used in this manuscript:

HGL	Hydrocarbon Gas Liquids
LPG	Liquefied Petroleum Gases
NGL	Natural Gas Liquids
VAR	Vector AutoRegressive

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