Determinants Of Crude Oil Price: An Econometric Analysis

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Abstract

Crude oil is currently the world's most important energy source, contributing to over one-third of global energy consumption. It is particularly essential in industries that rely heavily on fuel, such as manufacturing and aviation, and in financial markets where it serves as the underlying asset in many derivative contracts. Volatility in crude oil price impacts not only the consumers of the primary and secondary products of the commodity but also financial markets, such as equity market indices and foreign exchange markets. Given the disruptive impact that such volatility can have on oil-producing and consuming countries' economies, it becomes imperative to identify and critically analyze the factors that contribute to oil price movements. Our primary objective in carrying out this project is to identify and analyze the factors that have affected crude oil prices from 1987 to 2020 using Bayesian Model Averaging. Our findings indicate that the most crucial factors are GDP Growth in India and China, the Number of Oil Rigs, and Black Swan Events.

Keywords: *Crude oil, Brent, WTI, Bonny Light, Price Movement, Volatility, OPEC, China, India, United States, Shale Oil, Oil Rig*

I.   Introduction

From generations past, humanity has depended on energy for the proper functioning of society. The sources of energy exploited by man have evolved over the years: from the sun, the oldest source of energy to fire, wood, beeswax, steam, coal, hydropower, wind, crude oil, natural gas, and nuclear fusion. Wood has the added advantage that in addition to being used as an energy source, it also has other uses such as building homes, bridges, and carriages.

Natural gas has been around for millions of years but posed a mystery to man for a long time. One of the earliest indications of the presence of natural gas reported in the literature was around 1000 BC when a goat herdsman came across a flame burning from a crack in a rock on Mount Parnassus *(Lee, J, 2015)*. The Greeks, believing that it was supernatural, built a temple on it (the Temple of Delphi) from where a priestess made prophecies which she claimed to be inspired by the flame!

Crude oil is currently the world's most important energy source, accounting for 34% of global energy consumption in 2018, i.e., 4,662 million tons oil equivalent (Mtoe) out of a total global energy consumption of 13,864.9 Mtoe *(BP Statistical Review of World Energy, 2019)*. It is particularly essential in industries that rely heavily on fuel, such as manufacturing and aviation, and in financial markets where it serves as the underlying asset in many derivative contracts.

Therefore, crude oil price is one of the critical variables that significantly impacts economic development in countries around the world. Volatility in crude oil prices affects not only the consumers of the primary and secondary products of the commodity but also affects financial markets, such as equity market indices and foreign exchange markets. Indeed, fluctuations in global macroeconomic indicators often accompany fluctuations in crude oil prices and vice versa.

The global crude oil market witnessed significant increases in demand in the aftermath of the Global Financial Crisis, from 85.8 million barrels per day (mbd) in 2008 to 100.1mbd in 2019. Increased demand was accompanied by a matching increase in production, which rose from 86.7.8mbd in 2008 to 100.6mbd in 2019. Indeed, we computed the correlation between crude oil production and consumption as 0.99 for the period. The US increased the production of Shale Oil by 942% between 2008 and 2018, from 2,116 Billion Cubic Feet to 22,054 Billion Cubic Feet *(EIA data).* However, with the outbreak of the COVID-19 pandemic, global oil demand is expected to contract for the first time since 2009 *(IEA, 2020).*

II. Theoretical Framework

Introduction

Many theories exist about the origin of crude oil[1], but the most popular ones today ascribe the formation of crude oil to the transformation of fossilized remains of tiny marine plants and animals in a process that took several million years in underground rock formations, into the thick dark oil that is crude oil. Therefore, crude oil is called a "fossil fuel" (as are coal and natural gas which were formed through a similar process).

There are currently over 300 different crude oils that are typically named based on their geographical origin. However, the most popular ones that serve as benchmark crude oils are Brent, OPEC Reference Basket, WTI, and Bonny Light (the first two are crude oil blends). Crude oils are characterized by their density, viscosity, API gravity[2], and Sulphur content.

Crude oil is extracted from underground oil wells either by vertical drilling in conventional oil wells or by horizontal drilling accompanied by hydraulic fracturing ("fracking") for oil wells located under shale rock. The crude oil is then transported and stored in onshore and offshore tankers and subsequently sold in spot and futures markets to refiners. The importance of crude oil storage space and capacity came to the fore in April 2020 when the exhaustion of existing storage space forced producers to pay buyers to take up their oil.

The final parts of the process include the refining of the crude oil and the distribution and marketing of its products, including gasoline, kerosene, and diesel.

History of the Crude Oil Market

The ancient history of crude oil has been traced back to 600 BC when the Chinese reportedly extracted oil from the ground using bamboo sticks. They found that the flame could be used to boil seawater and separate the salt to get drinking water. By 347AD, they were transporting the crude oil in pipelines made from bamboo sticks. Other ancient civilizations also found use for crude oil and its derivatives. For instance, the ancient Egyptians used it as medicine. The ancient Iranians coated Baghdad's streets with tar (a derivative of crude oil), and ancient Babylonians used crude oil to seal walls and pave roads.

One cannot discuss the modern history of crude oil without the mention of Abraham Gesner, the Canadian physician, and geologist who invented kerosene oil in 1853 and patented it in 1854. He is considered a founder of the modern petroleum industry. Worthy of mention, also, is the Scottish chemist James Young who pioneered the distillation of paraffin from coal and oil shales in 1847.

The Industrial Revolution led to an ever-growing demand for crude oil as a cheap and convenient source of lubricants and illuminating oil. The invention of the internal combustion engine made crude oil even more important as a flexible source of energy to power the engines. This increase in demand led to higher investments in crude oil exploration and refining and accelerated the growth of the sector.

In 1859, Edwin Drake drilled what is considered the first modern oil well, a 69-foot-deep well in Pennsylvania. This oil well initially yielded 25 barrels of oil per day. The first commercial oil well in West Africa was the Oloibiri-1 oil well, which was drilled on August 3, 1955, in Nigeria and produced about 5,000 barrels of oil per day.

The global oil industry has since grown in leaps and bounds, with global oil production totaling 100.58 million barrels per day, while consumption was 100.1 million barrels per day in 2019. As of December 2018, the world had 1,730 billion barrels of oil reserves *(BP Statistical Review of World Energy, 2019)*. At an average global demand of 100 million barrels per day, the reserves should be sufficient for 17,300 days (approximately 47 years) of oil consumption.

Some of the major players in the crude oil market include:
- National Oil Companies such as Saudi Aramco, China National Petroleum Corporation, Petróleos Mexicanos (Pemex), and Kuwait Petroleum Corporation.
- International Oil Companies such as BP Plc, ExxonMobil, and Royal Dutch Shell.
- Oil cartels and organizations such as the Organisation of Petroleum Exporting Countries (OPEC, *see Section 2.4*), OPEC+, the International Energy Agency (IEA) and the Organisation of Arab Petroleum Exporting Countries (OAPEC)

The table below lists the top 10 producers, consumers, and proved reserve holdings of crude oil as of December 2018, as well as their share of global production, consumption, and proved reserves (based on BP data).

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[1] Another theory, "the Abiotic Theory," states that crude oil is formed from inorganic sources rather than from fossilized remains of organic matter.

[2] API gravity is an acronym for "American Petroleum Institute gravity," and it gives the ratio of the weight of crude oil to the weight of water.

Table 1: Crude Oil production, Consumption, and Reserve Holdings (2018 Data)

S/N	Top Producers	Top Consumers	Top Proved Reserve Holdings[3]
1.	United States – 16.2%	United States – 20.5%	Venezuela – 17.5%
2.	Saudi Arabia – 13.0%	China – 13.5%	Saudi Arabia – 17.2%
3.	Russia – 12.1%	India – 5.2%	Canada – 9.7%
4.	Canada – 5.5%	Japan – 3.9%	Iran – 9.0%
5.	Iran – 5.0%	Saudi Arabia – 3.7%	Iraq – 8.5%
6.	Iraq – 4.9%	Russia – 3.2%	Russia – 6.1%
7.	UAE – 4.2%	Brazil – 3.1%	Kuwait – 5.9%
8.	China – 4.0%	South Korea – 2.8%	UAE – 5.7%
9.	Kuwait – 3.2%	Canada – 2.5%	United States – 3.5%
10.	Brazil – 2.8%	Germany – 2.3%	Libya – 2.8%

Data Source: BP Statistical Review of World Energy, published June 2019

Volatility in Crude Oil Prices

Crude oil prices have historically exhibited a high degree of volatility, as the chart below clearly shows:
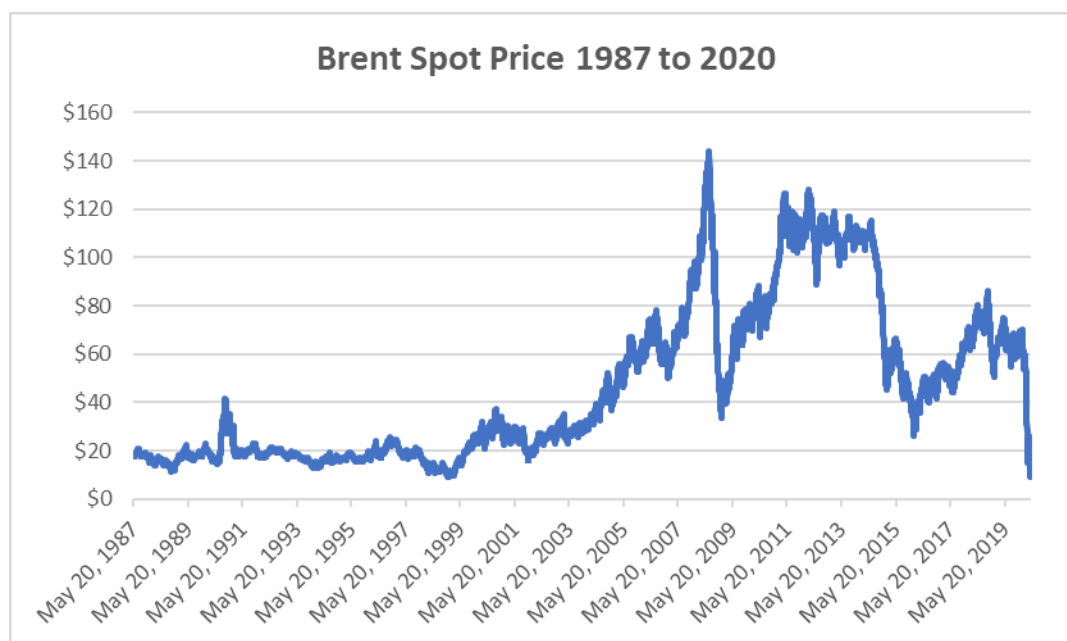
Figure 1: Brent Spot Price - 1987 to 2020
Data Source: EIA

According to the EIA, the relative short-run inelasticity of crude oil demand and supply are key factors causing the volatility of oil prices. Also, volatile swings in oil price result when the industry experiences shocks, which may be due to economic, political, extreme weather, or other unforeseen events. In the absence of these shocks, oil prices would typically show a seasonal swing due to seasonal changes in demand. However, the impact of the seasonality factor becomes insignificant in the face of economic or geopolitical shocks.

The table below tracks the highs and lows of crude oil prices since 1987[4], with events that might have led to these prices:[5]

Table 2 - Oil Price Volatility: 1987 to 2020

Year	Average	Low	High	Major Oil Events
1987	$19.20	$15.12	$22.44	Disputes within OPEC leads to oil glut; Black Monday
1988	$15.97	$12.58	$18.54	End of the Iran-Iraq war; OPEC agreement on production quota
1989	$19.64	$16.99	$24.62	Exxon oil spill; OPEC relaxes production quota
1990	$24.53	$15.43	$41.07	Iraq invades Kuwait triggering the Gulf war;

Year	Average	Low	High	Major Oil Events
1991	$21.54	$17.43	$32.25	Iraq fires missiles into Israel; US releases its *Strategic Petroleum Reserves* (SPR) to commercial buyers; OPEC announces production cuts
1992	$20.58	$17.89	$23.03	OPEC production hits 10-year high, NAFTA agreement signed, Hurricane Andrew strikes the US,
1993	$18.43	$13.98	$21.05	Oil glut caused by overproduction by OPEC and the North Sea Oil
1994	$17.20	$13.89	$20.72	Nigerian oil production disrupted by "June 12" riots
1995	$18.43	$16.86	$20.53	US places sanctions on Iran
1996	$22.12	$17.33	$26.55	Yet again, US releases oil from its SPR; Gabon withdraws from OPEC; US deploys cruise missiles against Iraqi military facilities
1997	$20.61	$17.60	$26.55	Caspian Pipeline Consortium created (pipeline would transport oil to Russia's Black Sea coast); OPEC increases production quotas; Asian financial crisis
1998	$14.42	$10.82	$17.93	OPEC members agree on voluntary production cuts
1999	$19.35	$11.38	$28.03	BP and Amoco Oil merger finalized; OPEC and Non-OPEC reach an agreement to cut output; Second Caspian Sea oil pipeline completed; Exxon and Mobil merge
2000	$30.38	$23.91	$37.22	The Dot-Com Crash, OPEC cancels plans to increase production; US crude oil stock falls to lowest level since 1976,
2001	$25.98	$17.50	$32.21	OPEC production cuts; largest oil field discovered in the Caspian Sea, US slips into recession due to Y2K scare, terrorist attack on 9/11
2002	$26.19	$18.02	$32.68	Angola signs ceasefire with rebels, Russia increases crude oil exports, oil tanker sinks with 24 million gallons of oil.
2003	$31.08	$25.25	$37.96	US invades Iraq; Hurricane Claudette shuts down 21% of oil production in the Gulf of Mexico, SARS outbreak
2004	$41.51	$32.49	$56.37	OPEC members agree to lower output; Hurricane Ivan shuts down production in the Gulf of Mexico; Militants disrupt oil production in Nigeria's Niger Delta
2005	$56.64	$42.16	$69.91	Hurricane Katrina wreaks havoc leading to record-high oil price
2006	$66.05	$55.90	$77.05	North Korea launches missile, Israel-Hezbollah war
2007	$72.34	$50.51	$99.16	The US subprime mortgage crisis, oil spill in South Korea
2008	$99.67	$30.28	$145.31	Oil pipeline attacked by militants in Nigeria, the Global Financial crisis sets in, Israeli cabinet officer's comment leads to a spike in oil price.
2009	$61.95	$34.03	$81.03	Tensions in Gaza strip, Swine Flu pandemic,
2010	$79.48	$64.78	$91.48	The Deepwater Horizon oil spill, European sovereign debt crisis
2011	$94.88	$75.40	$113.39	The "Arab Spring" conflicts; Iran threatens to close the Straits of Hormuz, Fukushima nuclear disaster
2012	$94.05	$77.72	$109.39	Tropical Storm Ernesto, the Syrian crisis, EU sanctions Iran
2013	$97.98	$86.65	$110.62	Tropical Storm Ernesto, the Syrian crisis
2014	$93.17	$53.45	$107.95	Russia-Ukraine war, US increases shale oil production,
2015	$48.66	$34.55	$61.36	Shale oil production continues to grow with new fracking technology, Chinese Black Monday
2016	$43.29	$26.19	$54.01	OPEC implements production cuts, Brexit
2017	$50.80	$42.48	$60.46	US Oil inventories reach record high, Gulf Crisis between Qatar and its neighboring countries
2018	$65.23	$44.48	$77.41	Several countries sanction Venezuela, the country's oil production declines significantly
2019	$56.99	$46.31	$66.24	US-China and Euro-China trade wars, Civil unrest, and riots in Venezuela,
2020 *(as of May 29, 2020)*	$37.28	$11.26	$63.27	COVID-19 pandemic, Saudi-Russia Oil Price War.

OPEC's Impact on the Crude Oil Market

The Organization of Petroleum Exporting Countries (OPEC) is a cartel made up of some of the biggest oil-producing countries in the world. As of May 2020, its members were Algeria, Angola, Congo, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, the United Arab Emirates, and Venezuela.

Saudi Arabia and four other oil-exporting nations (Iran, Iraq, Kuwait, and Venezuela) formed OPEC as founding members in 1960 in a bid to get more control over oil prices. Qatar joined the group in 1961, and since then, the membership of the body has seen many changes with some members exiting and later re-joining (Qatar, for instance, exited the cartel in January 2019 while Ecuador exited in January 2020). The "OPEC Statue" governs relations between the members of the body. The Statue is a resolution that was initially signed by members in 1961 and last updated in 2012.

Some of the world's major oil producers who are not members of OPEC include the United States, Russia, and Canada. In July 2019, OPEC signed a "Charter of Cooperation" with some non-member oil-producing countries, including Russia, Mexico, and Kazakhstan, for an alliance known as OPEC+.

OPEC's member countries currently account for 79.4% of the world's proven oil reserves[6] and 44% of global oil production, thus giving the cartel significant influence over the worldwide price of oil. OPEC has exercised this influence by increasing or reducing its oil production and implementing oil embargos, depending on its objectives at any point in time.

Figure 2: OPEC's Share of Crude Oil Reserves (2018 Data)
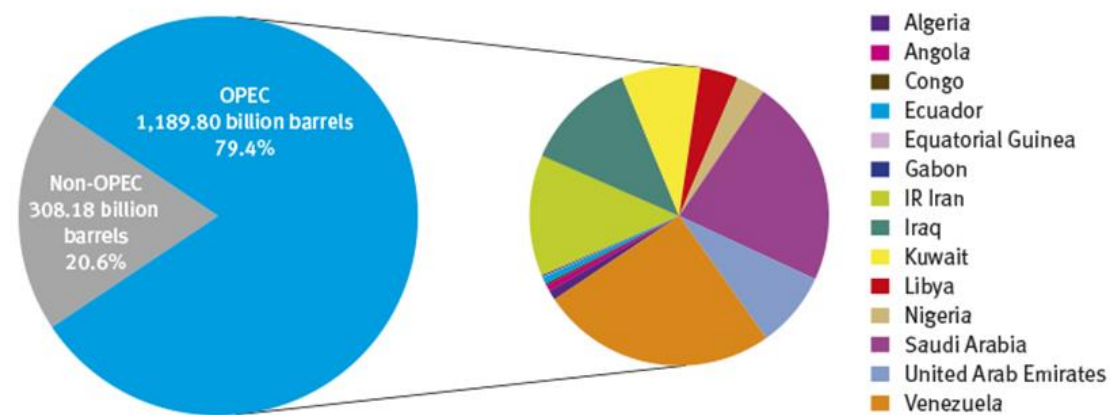
OPEC proven crude oil reserves, at end 2018 (billion barrels, OPEC share)

| Venezuela	302.81	25.5%	Kuwait	101.50	8.5%	Algeria	12.20	1.0%	Gabon	2.00	0.2%
Saudi Arabia	267.03	22.4%	UAE	97.80	8.2%	Ecuador	8.27	0.7%	Equatorial Guinea	1.10	0.1%
IR Iran	155.60	13.1%	Libya	48.36	4.1%	Angola	8.16	0.7%			
Iraq	145.02	12.2%	Nigeria	36.97	3.1%	Congo	2.98	0.3%			

Source: OPEC Annual Statistical Bulletin 2019.

Oil embargos and production cuts, however, did not begin till 1973 when the Arab members of OPEC, acting with Egypt and Syria, stopped selling oil to the US to protest against the U. S's provision of military aid to Israel which assisted the latter's conflict with Egypt and Syria. The aftermath of this action saw oil prices spike from $25.97 per barrel in 1973 to $46.35 per barrel in 1974. Since then, OPEC has embarked on many other embargos, production cuts, and price wars, with the latest price war happening in March 2020 between Saudi Arabia and Russia as a result of Russia's refusal to support OPEC's proposal to implement deeper oil production cuts. The combined effect of the price war and the COVID-19 pandemic saw WTI price dropping below $0 for the first time in history on April 20, 2020, to as low as minus $37. The price war has since ended, and WTI price has rallied to $32.8 as of May 27, 2020.

Impact of COVID-19 on Crude Oil Prices
COVID-19 started as a health crisis but quickly dove-tailed into a deep economic crisis with significant socio-economic implications. The pandemic affected the crude oil market by practically wiping out the demand for crude oil, with leading oil consumers like the US, China, and India having to shut down factories, and the Aviation industry, another source of high oil demand, grinding to a standstill. These events were exacerbated by the Saudi-Russia oil price war *(discussed in Section 2.4).*

[6]. *See* https://www.opec.org/opec_web/en/data_graphs/330.htm

Figure 3: WTI Price Chart, January to May 2020
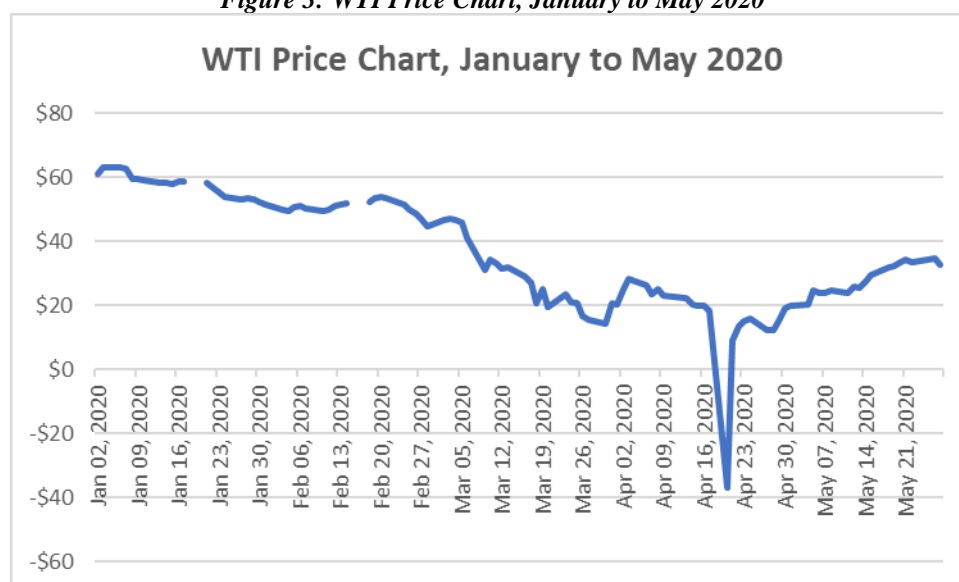
Data Source: EIA

Risks in the Oil Industry

Many of the oil industry risks also represent the factors that cause oil price movements. In determining these factors, we also identify the risks in the sector. We have highlighted these factors in section 3.1. We will, therefore, approach this section from a risk type perspective.

Thus, we will look at the following types of risks that impact on the sector: operational risks, regulatory risks, legal risks, financial risks, and reputational risks.

Operational Risks

Operational risk is, in our opinion, the most significant type of risk affecting the sector. Operational risk refers to those risks arising from an organization's processes, people, systems, and external events. An example of operational risk is equipment failure or obsolescence. In the oil industry, external events have historically caused the most significant negative impacts in the sector. External events include extreme weather events like Hurricane Katrina. Most Black Swan events (discussed in section 3.1.6) also fall under this risk class. Geopolitical conflicts are also examples of external events that can result in an adverse impact on the industry.

Regulatory Risks

Regulatory risk (the risk that the laws, rules, regulations, and policies implemented by governments, whether domestic or international, result in an adverse impact on an organization) is another significant risk that affects the oil industry. For instance, many countries have recently issued regulations that encourage the growth of alternative energy sources while limiting the manufacture and utilization of vehicles operating with fossil fuels. Implementing such policies would directly impact demand and thus repress crude oil prices in the medium to long term.

Legal Risks

The operations of oil companies sometimes lead to adverse effects on the environments in which the companies operate. Oil spills, for instance, can result in costly litigation and considerable payouts in damages. Examples are the Exxon Valdez oil spill of 1989 and the BP Deepwater Horizon oil spill of 2010.

Financial Risks

Financial risks include credit risks (due to exposure to third party default), liquidity risks (due to mismatches in short term assets and liabilities), and market risks (caused by adverse movements in prices, interest rates, and exchange rates). For the oil industry, market risk constitutes a large portion of financial risks as the industry continually faces price volatility as well as exchange rate volatility.

Reputational Risks

Reputational risk is the risk that an organization will suffer from negative perception by its stakeholders and that this perception will negatively impact on the organization's business. The oil industry has suffered from

a poor reputation for some time now, no thanks to highly publicized oil spills and other environmental impacts. However, due to the inelastic nature of oil demand, negative perceptions have not made any significant impact on the operations of oil companies, except, perhaps, in the area of increased regulations. However, these negative perceptions are contributing to global advocacy to end the dominance of fossil fuels in global energy consumption.

Review of Related Literature

Research into the determinants of price movements in the oil industry has been carried out by several authors, with interesting results. We highlight the outcomes of some of these studies below.

Bretenfellner, Guaresma, and Keppel (2014) analyzed the impact of 30 potential determinants of crude oil prices grouped into four classes: the fundamental factors affecting supply and demand, factors related to the structure of the oil market (OPEC) and factors associated with the behaviour of market participants (speculation), from 1983 to 2008. Their findings indicated that no single factor had a dominant impact throughout the assessment period and that each factor's significance varied over time. However, the fundamental factors affecting supply and demand tended to trigger and dominate price trends. They concluded that oil price was determined by complex processes occurring within the global economy.

Similarly, Gyagri, Amarfio, and Marfo (2017), in their paper on a theoretical review of the determinants of crude oil price, observed that crude oil price was impacted by many factors, which, either individually or collectively could lead to oil price volatility. They, however, concluded that the changes in crude oil prices over time could not be attributed to one single market factor but rather to a highly complicated market system that depends on several variables.

In 2012, Kathleen King, Ai Deng, and David Metz carried out an econometric analysis of oil price movements with particular emphasis on the effect of political events, economic news, financial trading, and market fundamentals. Their findings suggested that political events, economic news, OPEC production decisions, and unexpected news about oil inventory levels all had a significant effect on oil prices. They could not find sufficient evidence to suggest that commercial trading by speculators had any significant impact on oil prices.

However, Sarwat et al. (2019) assessed the impact of speculative activities on oil prices by applying Granger Causality Test and Vector Error Correction model on WTI futures and spot prices. Their results indicated that causality ran from the futures prices to the spot prices, which they interpreted as evidence that speculative trading had a more substantial impact on oil prices than market fundamentals.

Yoshina and Alekhina (2019) concluded from their studies on global oil price determinants that the balance of influence over oil prices had shifted from the supply side to the demand side. They found that major consumers like China and the OECD countries had more impact on oil prices than major producers.

Tian (2016) concluded that increases and decreases in crude oil prices are affected by different sets of factors, thus making short-term oil price movements challenging to predict.

III.   Methodology

Selection of Factors

The disparity in the findings of the research papers that we reviewed in carrying out this project led us to hypothesize that crude oil prices are determined by many variables which, through their interactions with each other and with other variables within the economy, produce a very complicated effect on prices.

We hypothesized that the following six groups of factors (as well as their sub-factors) are the critical determinants of movements in crude oil prices, based on our observation of global trends.

Demand

Market demand is one of the two fundamental drivers of crude oil prices. Industry (especially manufacturing) and transportation (aviation, in particular) and are the most significant contributors to crude oil demand, accounting for about 85% of global demand. Electric power generation and heating account for a sizeable part of the remaining 15%.

Demand is affected by many factors. An example of these factors is seasonal changes in energy requirements at different times of the year (more heating in winter and more petrol in summer). These patterns lead to seasonal changes in crude oil demand and, consequently, crude oil prices. Demand also increases in response to economic growth because growth is usually accompanied by an increase in industrial and other commercial activities, requiring more gasoline, diesel, aviation fuel, and natural gas. According to the fundamental law of demand, there is an inverse relationship between demand and prices (as prices increase, demand reduces).

Supply

Supply is the other fundamental driver of crude oil prices. In section 2.4 above, we highlighted the OPEC and non-OPEC producers of crude oil. Some of the non-OPEC major oil producers like the United States and

Canada are members of the International Energy Agency (IEA). Countries like China (8th-largest producer and 2nd-largest consumer) and India (third-largest consumer) are neither members of OPEC nor the IEA. Russia (3rd largest producer), however, is in an alliance with OPEC (*OPEC+*), but the fate of that alliance remains to be seen.

Like demand, many factors also affect supply. Extreme weather conditions, for instance, can affect oil rigs, refineries, and other crude oil production and processing facilities. Hurricane Katrina and the flooding of the Mississippi, for example, led to significant oil price fluctuations.

The location and amount of oil in the reserves, the physical properties of the oil (as discussed in section 2.2), and the time and investment required to discover new oil wells are crucial determinants of supply. There is a direct relationship between supply and prices (as prices increase, supply increases).

Decisions of Oil Producers

The decisions of OPEC and the other major oil producers can significantly impact crude oil prices. A good example is the ongoing oil price war between Saudi Arabia and Russia, which (coupled with the demand disruption caused by COVID-19), has had the unprecedented effect of crashing oil futures price below $0.

Availability of Alternative Sources of Energy

Advancements in the development of alternative energy sources diminish the importance of crude oil and thus affect its price. Examples of these alternative sources are solar energy, wind energy, and nuclear energy.

Many countries have committed significant resources to the research on the manufacture of electric vehicles, for instance. The chart below shows that several of the world's largest automakers are incentivizing people to switch to electric vehicles:

Figure 4: Current Upfront Incentives for Electric Vehicles in Major Auto Markets
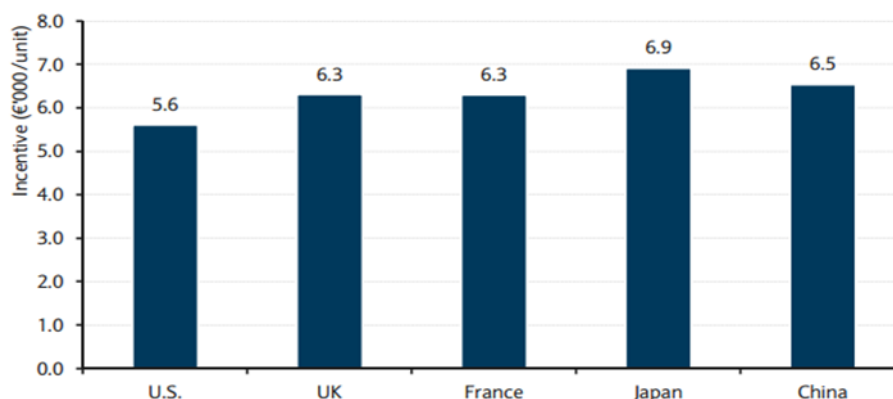
Source: ACEA, Barclays Research. Note: Includes upfront national level incentives only. Additional regional incentives, as well as may also be applicable.

Political Events and Conflicts

Decisions of governments, often implemented through laws, rules, and regulations, have a significant impact on the availability, supply, and utilization of crude oil. Such decisions and actions include decisions on the investments in exploration and production, subsidies on petroleum products, energy policy, and taxes.

Crude oil price is also affected by war, terrorism, and guerrilla activities resulting from political instability or conflict, leading to significant effects on crude oil price. For instance, when an Israeli cabinet minister (in June 2008) stated that Israel might attack Iran, his comment resulted in a $10.75 increase in oil price, the most massive increase in oil price up to this point.

Black Swan Events

Black swan events are rare and unexpected events with severe consequences. Such events have historically had a significant impact on the price of crude oil. We will consider the impact of the following Black Swan events:
i.   Black Monday (1987);
ii. First Gulf War (1990);
iii. The Asian Financial Crisis (1997);
iv. The Dot-Com Crash (2000);
v.   9/11 attacks (2001);
vi. SARS outbreak (2003);

vii. Global Financial Crisis (2008);
viii. European Sovereign Debt Crisis- (peaked between 2010 and 2012)
ix. Fukushima Nuclear Disaster (2011);
x. Chinese Black Monday (2015);
xi. Brexit (2016);
xii. COVID-19 Pandemic (2020);

The chart below shows the reaction of oil prices to some of these Black Swan events.

Figure 5: Oil Disruption, Spare Capacity, and Crude Prices
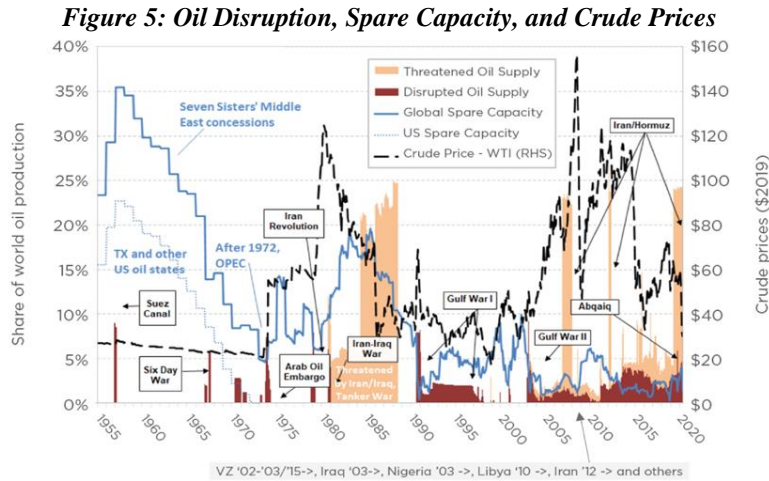
Source: Rapidan Energy Group, EIA, BP, St. Louis Fed, US Senate

Model Selection

We analyzed the effects of our selected factors on oil price using Bayesian Model Averaging (BMA) in 'R,' complemented with simple correlation analysis and Google Trends analysis.

In selecting BMA, we refer to the work done by Bretenfellner et al. *(2014)*, who analyzed five groups of determinants of crude oil price using this technique. BMA was their preferred technique because it allows the analysis of a large number of explanatory variables under model uncertainty, and helps with the selection of the variables to be used in a regression model.

A typical linear regression model suffers from model uncertainty when there are many variables that could potentially be included. Therefore, a researcher would have two significant issues to contend with: the selection of the best explanatory variables to use and the selection of the model that best explains the dependent variable, given the set of explanatory variables chosen.

Steel, F. *(2019)*[7] explains various approaches that have been used by researchers in dealing with the model uncertainty problem, including stepwise regression, shrinkage, information criteria, cross-validation, Extreme Bounds Analysis, *s*-values, BMA, as well as five other models.

Hinne, M. et al. *(2019)*[8] summarized the benefits of BMA as follows:
▪ Reducing overconfidence by accounting for model uncertainty;
▪ Producing optimal estimates;
▪ Avoiding threshold-based all-or-nothing decisions, and
▪ Preventing model-misspecification.

BMA incorporates model uncertainty into the conclusions about the factors by estimating models for all possible combinations of the independent variables which seek to explain the changes in the dependent variable. It estimates a weighted average over all the combinations, using weights that are based on the posterior probabilities of each model.

The class of models under consideration are parametrized using the following equation:

$$p_t = \alpha + \sum_{j=1}^{k} \beta_j x_{j,t-1} + \varepsilon_t$$

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[7] Model Averaging and its Use in Economics (Steel, F., 2019), https://arxiv.org/pdf/1709.08221.pdf
[8] A Conceptual Introduction to Bayesian Model Averaging (Hinne, M. et al, 2019), https://psyarxiv.com/wgb64/

where $p_t =$ oil price;
α = the intercept
$x_{j, t-1}$ = the explanatory variables (which are investigated as determinants of the oil price),
for $j = 1, \ldots, k$, and
$\mathcal{E}_t$ = the error term.

The 'R' BMA package is useful in carrying out this analysis and has been known to improve predictive performance of under conditions of model uncertainty.

Data Collection and Analysis
Quantitative information was collected for the following variables from 1987 to Q1 2020:
1. OPEC Crude Oil Production
2. World Crude Oil Production
3. World Crude Oil Consumption
4. % of Renewable Energy to Total Energy Consumption
5. GDP Growth (Global)
6. GDP Growth (US)
7. GDP Growth (China)
8. GDP Growth (India)
9. Global Total Number of Oil Rigs

We downloaded the required data from various sources (see the list of data sources in Appendix 2) and compiled them into CSV files. The data was further split into two series, taking into consideration the economic shocks from the 2008 Global Financial Crisis, as follows:
- Complete data set: From 1987 to 2020
- Subset 1: From 1987 to 2007
- Subset 2: From 2008 to 2020

We analyzed the data in Python, R and Excel.

Table 3: Tools and libraries used

Python	R	Excel
- Pandas - Matplotlib - Seaborn - Pytrends	BMA	Data Analysis Toolpak

We sourced qualitative information required for the project (such as information on Black Swan events) from mainstream media and other online media sources.
A list of the Black Swan events analyzed for this project is provided in section 3.1.6. These events were introduced into the data as dummy variables, with the value "1" assigned to years in which there was a Black Swan event and "0" for years in which there was no event that we regarded as a Black Swan.
Pytrends was used to assess the "Interest Over Time" of some keywords (OPEC, China, India, United States, and crude oil price) from Google Trends.

IV.   Results

Correlation Analysis Results
A preliminary correlation analysis of each of the selected quantitative variables with Brent Crude price yielded the following results:

Table 4: Correlation of the determinants with Brent Crude price

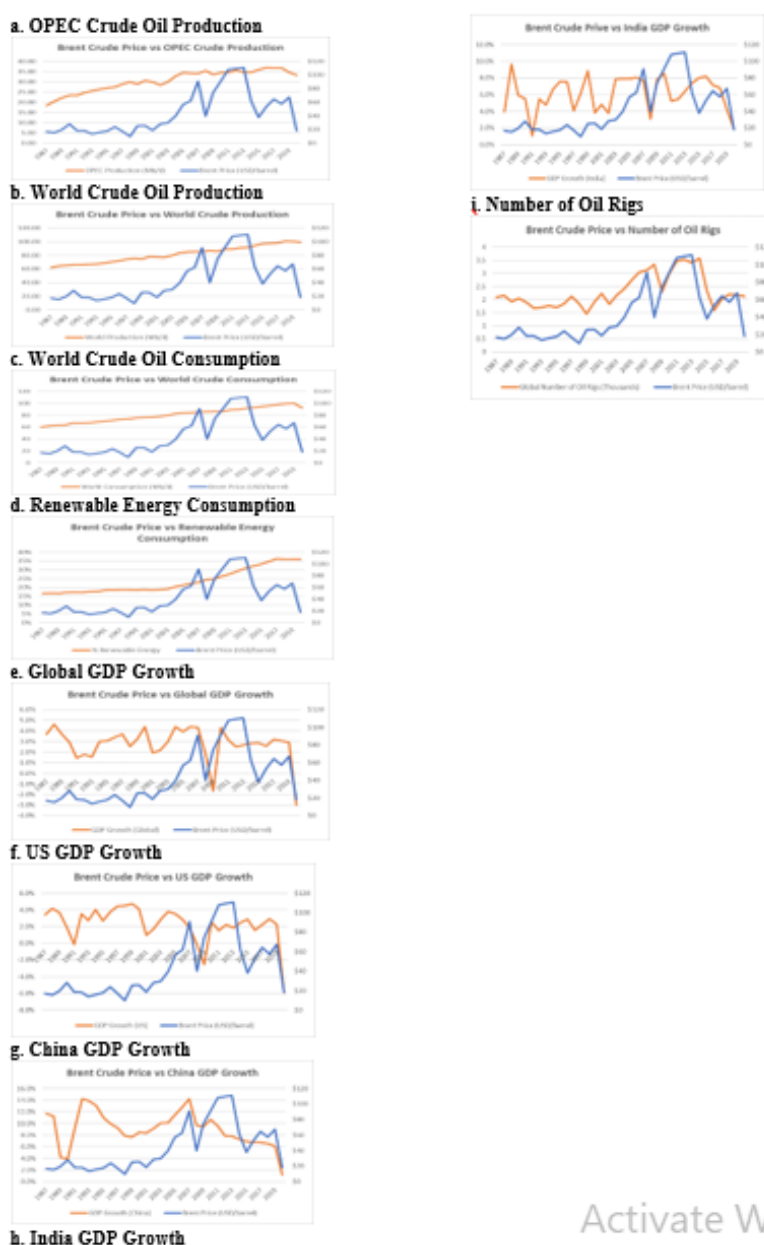| S/N	FACTOR	CORRELATION WITH BRENT CRUDE PRICE		
		1987 to 2020	1987 to 2007	2008 to 2020
1.	OPEC Crude Oil Production	0.69	0.66	-0.07
2.	World Crude Oil Production	0.64	0.73	-0.48
3.	World Crude Oil Consumption	0.68	0.72	-0.29
4.	% of Renewable Energy to Total Energy Consumption	0.58	0.86	-0.40
5.	GDP Growth (Global)	0.10	0.49	0.44
6.	GDP Growth (US)	-0.17	-0.19	0.44
7.	GDP Growth (China)	-0.01	0.31	0.59
8.	GDP Growth (India)	0.24	0.36	0.28
9.	Global Number of Oil Rigs	0.77	0.85	0.57

When analyzed from 1987 to 2020, economic growth (proxied by the GDP growth rates) shows very little (and in some cases, slightly negative) correlation with crude oil price. However, the picture is slightly different for the data subset, as seen with the economic growth factors showing moderate positive correlation with oil price.

Additional correlation analysis against *% change in Brent crude price* showed that GDP growths of China and India showed the highest positive correlation (0.47 and 0.55 respectively) while world production, number of oil rigs, and renewable energy consumption showed the highest negative correlation (-0.28, -0.25 and -0.22 respectively) for the 2008 to 2020 data series.

This finding is counterintuitive as, based on the conventional economics of price elasticity of demand, one would expect that oil consumers like China and India would show a negative correlation between economic growth and crude oil price. We make three deductions from this:

▪ It is a clear indication of the inelastic nature of crude oil demand and supply.
▪ It is consistent with the findings of Yoshina and Alekhina (2019) that demand factors currently have a more substantial influence over crude oil prices than supply factors.
▪ It also shows that the factors affecting crude oil prices interact to bring about an impact different from the effect that each variable would have if considered independently.

The rest of this section shows the plots of the different factors against crude oil, while Section 4.2 gives the results of the BMA analysis.

a. OPEC Crude Oil Production

b. World Crude Oil Production

c. World Crude Oil Consumption

d. Renewable Energy Consumption

e. Global GDP Growth

f. US GDP Growth

g. China GDP Growth

h. India GDP Growth

i. Number of Oil Rigs

Analysis of Google Trends

We analyzed Google Trends search data to see if public interest in the selected key words had any relationship with changes in crude oil price. Findings showed very little correlation between the level of public interest in the key words and the level or direction of movements in crude oil price. The findings are summarized in the table and charts below:
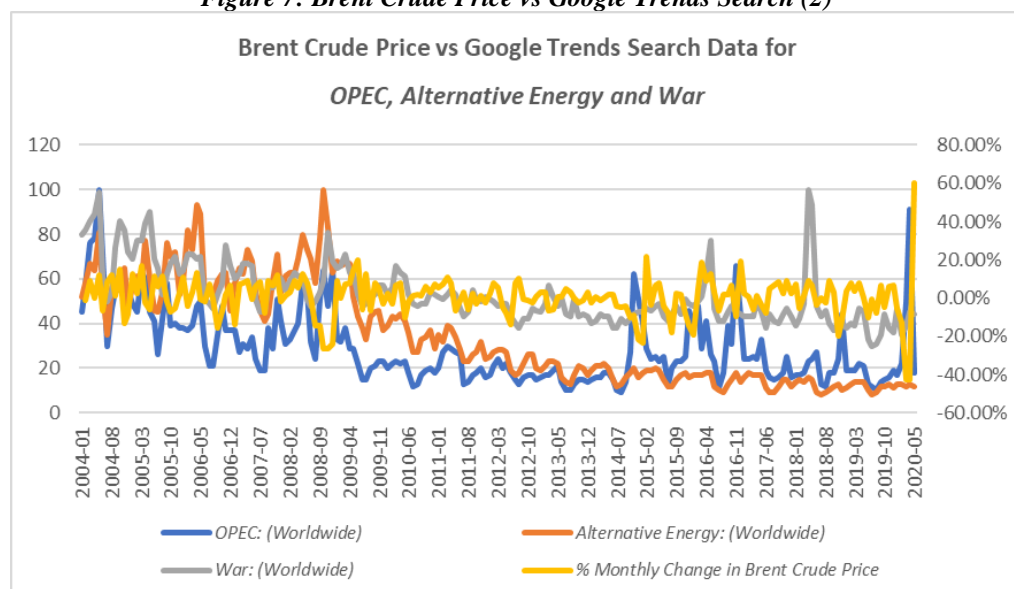
Table 5: Correlation of Keyword-Search with Changes in Brent Crude Price

S/N	Keyword	Correlation with Changes in Brent Crude Price
1.	OPEC	-0.17
2.	China	-0.13
3.	India	-0.14
4.	United States	0.05
5.	Alternative Energy	0.05
6.	War	0.13

Figure 6: Brent Crude Price vs Google Trends Search (1)
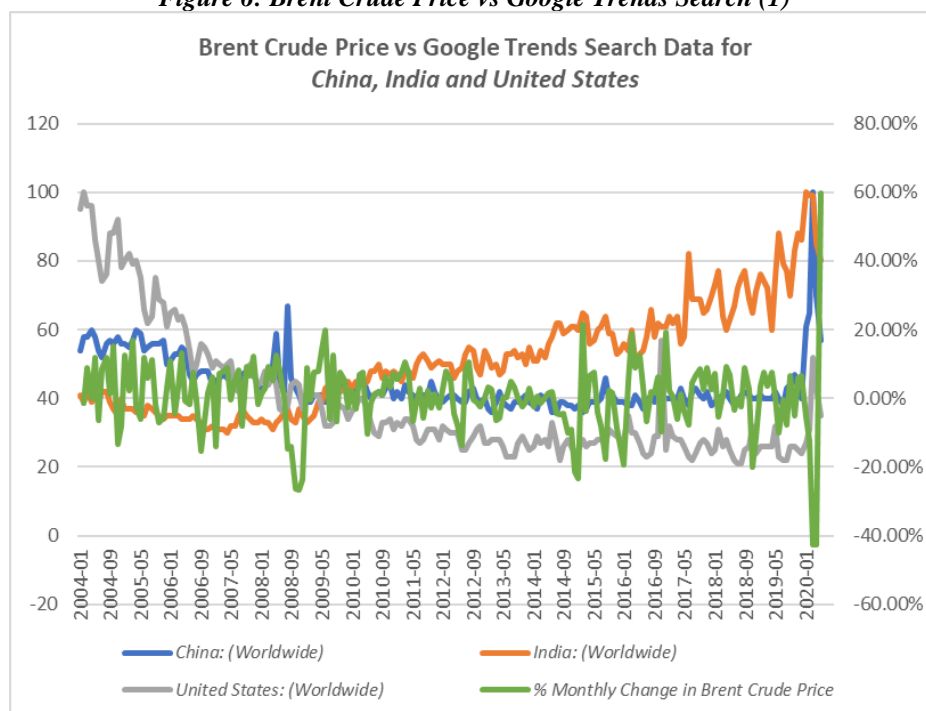
Figure 7: Brent Crude Price vs Google Trends Search (2)

BMA Results

For the BMA analysis, we ran the following code in R:

This code was executed on the three sets of data series and the results compared:

```
library(BMA)
# Then, import crude oil data to R:
CrudeOil <- as.matrix(read.csv("/Users/akinbolaji18982/Documents/WQU/Data/Crude Oil Data for
 BMA Analysis.csv", sep=",", header=TRUE))
# view data
summary(CrudeOil)
# outcome y is in column 2 (date is in column 1)
y<-CrudeOil[,2]
# covariates start in column 3
x<-CrudeOil[,3:12]
# Run BMA
CrudeOilBMA <- bicreg(x,y)
summary(CrudeOilBMA)
plot(CrudeOil)
plot(CrudeOilBMA)
```

The results are summarized in Table 5 below *(see details in Appendix 3)*.

Table 6: BMA Results

S/N	DATA SERIES	VARIABLES SELECTED
1	1987 to 2007	• India GDP growth • Number of oil rigs • Black Swan events
2	2008 to 2020	• China GDP growth • India GDP growth • Number of oil rigs • Black Swan events
3	Complete data series (1987 to 2020)	• India GDP growth • Number of oil rigs • Black Swan events

The results suggest that the critical determinants of crude oil prices during the period covered in this project were the number of oil rigs, the GDP growth rates of China and India, and the Black Swan events that occurred during the period.

This finding is not surprising, however, given the fact that China and India are currently the second-largest and third-largest consumers of crude oil globally. Economic growth in these countries is sure to result in increased economic activity with more factories working and goods transported. The increase in activity would have a significant impact on crude oil demand and, therefore, price.

The inclusion of Black Swan events in the factors selected is also of significance. Historically, crude oil prices have tended to be more volatile when events that increase uncertainty occur. Ultimately, the market thrives on the sentiments of its participants, and when unforeseen events occur, they tend to move market sentiments either positively or negatively.

An interesting part of the result is that OPEC production levels were not selected as a factor in any of the models, suggesting that OPEC has a lesser degree of control over long-term movements in oil prices than one would expect. This is also consistent with the =low correlation between OPEC crude oil production and changes in Brent Crude price (0.08 for the 2008 to 2020 data series). This finding probably explains why OPEC needed to expand its market influence by creating the OPEC+ alliance.

Challenges faced and suggestions for further research

A significant challenge that we faced while carrying out this project was data availability and inconsistencies. While we had intended to use monthly data for the analysis, the team had to revert to using annual data as many of the factors only had annual data or had incomplete monthly data. Furthermore, there were many inconsistencies in data from different sources. In the end, the project team had to apply judgment in selecting and collating the data used for this research.

Another challenge was with the yet unfolding effects of the COVID-19 pandemic, with significant swings of crude prices observed in recent times. While it would have been desirable to do more work on this as part of this project, the absence of clarity on the real impact of the pandemic made it impossible to do any meaningful analysis on its singular effect on oil price.

We suggest that this area be considered for further research as soon as it is feasible.

V.   Conclusion

The importance of crude oil to the daily life of every society and nation cannot be overemphasized. Therefore, analyzing the variables that impact crude oil prices is an important, albeit challenging task. The interplay amongst these variables and others yet to be identified will continue to make this subject matter an interesting one for ongoing research.

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