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Oil Costs and Prices: An Empirical Causality Analysis

Pedro Moreno Alonso*, Antonio Muñoz San Roque

Comillas Pontifical University, Spain. *Email: pmoreno@comillas.edu

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ABSTRACT

This study analyzes the causal relationship between oil prices and production costs and their implication over hedging in production companies. Two different data sets have been used as a proxy for production costs: (1) monthly product price index related to oil activities from the Bureau of Labour of Statistics; (2) yearly data obtained from reports of publicly traded oil companies. For the oil price, different future contracts of Brent (1M, 12M, 24M, 60M) have been explored. Based on Granger's definition of causality, and using the Toda and Yamamoto (1995) methodology, both causal directions have been tested. The results obtained indicate that oil prices (any term of the curve) Granger-cause production costs, and not the other way around (as it has been considered for many specialists) in any term of the curve.

Keywords: Oil Price, Production Costs, Hedging, Granger Causality, Toda-Yamamoto
JEL Classifications: Q41, Q47

1. INTRODUCTION

In an efficient market, the marginal cost of production of a particular product should establish a clear benchmark for its price. According to the theory of Exhaustible Resources (Hotelling, 1931), for a resource like oil, non-renewable and limited, the price should exceed the marginal cost before the possibility of future scarcity by introducing a premium. Supply and demand shocks may produce price deviations over time, which should be initially addressed with inventory variations. Considering the market structure, competition among producers should return the price to the path of marginal cost, adding supply, or eliminating it according to market needs. On the demand side, there should also be a competition that tends to stabilize the market. This breakeven is not so simple to calculate and more dynamic than anyone could imagine (Kleinberg et al., 2017), but it should be the reference for the hedging strategy of the companies. Since the beginning of 21st century, the oil price has been a roller-coaster market with extreme fluctuations (Figure 1). This volatility makes investment planning extremely difficult for companies, having severe implications on economic decisions (e.g., inflation, salaries, and available resources) (Baumeister, 2016).

In the late '90s, the petroleum reached historical minimums at $11/bbl. Then, the new century began with a recovery in the price of oil, leaving behind the crisis of the Asian economies. However, it relapsed again with the puncture of the Dot-com bubble and the post-September-11 instability. After that, the second Gulf War and steady growth of the world economy, led by emerging countries, caused historical high oil records in both nominal and real prices. During the years between 2003 and 2008, the price went from $25 to $148/bbl with an inability of the supply to cope with the rapid increase of demand (2%/year). Traditionally, this dramatic price increase would have caused extremely negative consequences in the global economy. However, in this case, the strength of the economy was the main responsible for skyrocketing prices (Kilian, 2009). Given the need to increase the oil offer, new deposits that had not been used until now were explored. In "Resources to Reserves 2005" (OECD Publishing and International Energy Agency, 2005), is included the cost curve for different technology deposits (Figure 2) for the first time in IEA research. With oil peaking above $60/bbl, there were large volumes of oil not yet exploited that were beginning to be competitive to face the rising prices.

Just 1 year later, in April 2006, with Brent trading above $70/bbl, "The Economist" (The oil industry: Steady as she goes. 2006) published new price ranges at which unconventional or unexploited oilfields would be viable (Figure 3). Shale oil appears with a breakeven of $50/bbl, and biofuels starting at $60. These figures almost doubled the numbers published by the IEA in the previous year. However, these new sources did not seem mature enough to be able to contribute to the supply in the short term, and the price rally continued for a couple of years more. Shale Oil production did not take off until 2010, and it does not acquire relevance until 2014 with sustained production of 3.5Mbbl/d and higher costs than estimated previously.

Figure 1: Chronology of cited figures along with monthly average brent price

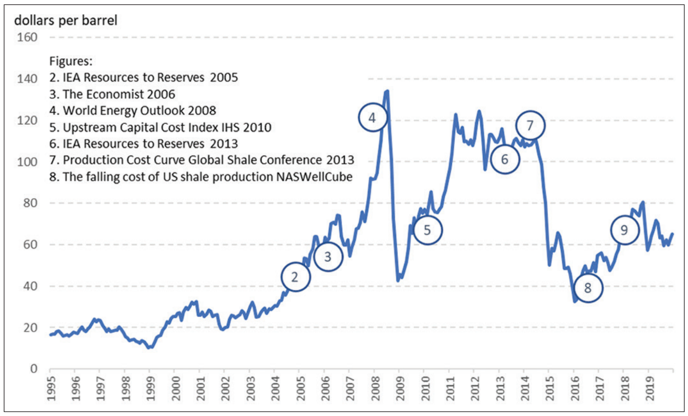
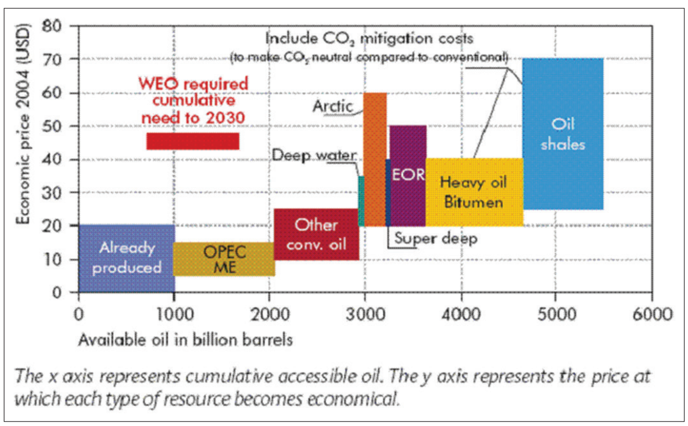
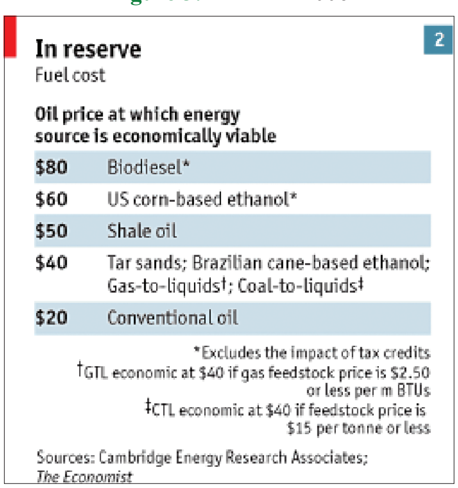


Figure 2: Production Cost by kind of oilfield 2004



Source: IEA, Resources to Reserves - Oil and Gas Technologies for the Energy Markets of the uture, 2005, p. 17

Figure 3: Fuel cost 2006



In reserve

Fuel cost

Oil price at which energy source is economically viable

$80	Biodiesel*
$60	US corn-based ethanol*
$50	Shale oil
$40	Tar sands; Brazilian cane-based ethanol; Gas-to-liquids†; Coal-to-liquids‡
$20	Conventional oil

*Excludes the impact of tax credits

†GTL economic at $40 if gas feedstock price is $2.50 or less per m BTUs

‡CTL economic at $40 if feedstock price is $15 per tonne or less

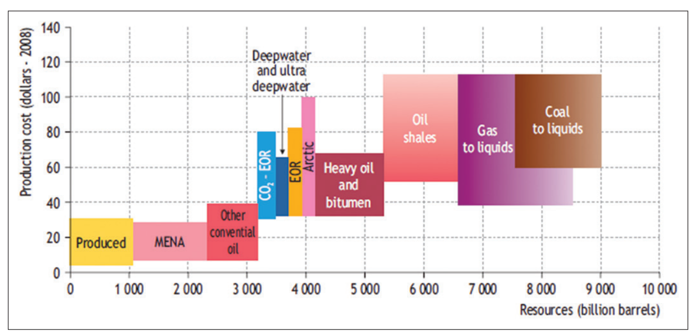
Sources: Cambridge Energy Research Associates; *The Economist*

Sources: Cambridge Energy Research Associates; The Economist

The World Energy Outlook of 2008 (International Energy Agency, 2008) devotes an entire chapter to the cost increase of new production capacity, and the graph of the cost curve is updated (Figure 4). It shows the concern for both the delay in capital expenditures by companies and an environment of rising costs, which reduces the investment impact. This fact leads us to consider that the breakeven calculated with oil prices at 2006 levels will no longer be valid with the oil at historically high values. An increase in costs was one of the main arguments to justify the highs reached in July 2008. On the 25th of June 2008, Daniel Yergin (Chairman of Cambridge Energy Research Associates) explained to the US Congress Joint Economic Committee the causes of the price of oil, pointing out the increase in production costs (Yergin, 2008). He argues that costs have been doubled between 2004 and 2008, according to the indexes calculated by his organization (Figure 5).

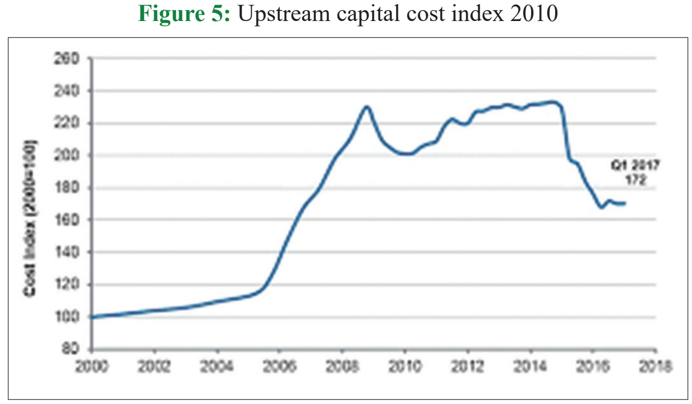
The 2008 Financial Crisis spread to oil in the second half of the year. Oil price plummeted until $40/bbl by the end of the year. Later, in 2009, oil almost doubled its price. Reluctantly, the investment in new capacity was recovered after the announcement of budget cuts in public companies at the beginning of the year. In the following years until Q4 2014, oil continued escalating and consolidating the $100/bbl.

Figure 4: Production cost by kind of oilfield 2008



Source: World energy outlook 2008, IEA

Figure 5: Upstream capital cost index 2010



Source: IHS

During these years, it was accepted that the structure of the oil sector had changed due to its scarcity, stated by James Hamilton. So, in order to exploit the new oilfields, oil needed to stabilize at a price close to $100/bbl (Hamilton, 2014).

The theory of Hubbert's Peak was also attracting supporters in the analyst community. This theory highlighted that since 2005 oil production has been practically stagnant (Chauvet et al., 2012). The increase in output would have been faced by spared capacity, not by new projects. Due to the strengthening of demand, the physical balance would be pushing up the price of oil permanently.

With oil price consolidated above $100/bbl, IEA published "Resources to Reserves 2013," pointing out that production costs for shale oil (kerogen) were between $60/bbl and $100/bbl dollars (Figure 6). The development of technology for this type of oilfield was becoming active, and some cost containment was beginning to be seen at the same time. In fact, in March 2014, Ivan Sandrea makes a complete review of the American industry of Shale gas and oil. It showed how the majority of shale oil projects were profitable, while shale gas projects were not (Sandrea, 2014). It should be mentioned the wide variability between projects, ranging from $34/bbl to $91/bbl, as it is shown in the cost curve (Figure 7).

In the last quarter of 2014, there is a sharp drop in the oil price close to 50%. The oil price level will keep lowering until 2016 when it reaches a value below $30/bbl (the lowest level since 2003). Several studies associate this slump with three principal causes (Baumeister and Killian 2016). Two of them would be predictable and would have accounted for half of the fall in 2014: a slight global slowdown demand and a positive surprise of supply. The remaining factor is the unexpected weakening of the world economy at the end of 2014 that lead to the fall in oil price expectations. Given such a fall in prices, it is argued that supply adjustments are needed, and the most expensive producers should limit their output volumes.

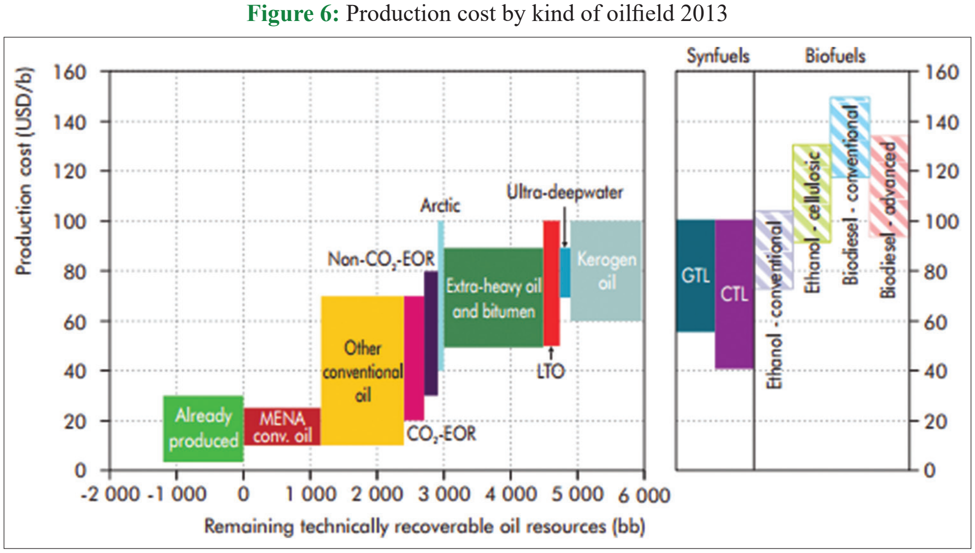
In this market situation, it appears that the references used as cost proxy have ceased to be valid. According to Rystad Energy for different Shale Oil fields, their production costs were halved between 2013 and 2016 (Figure 8) while keeping their supply during the price drop. Surprisingly, some of the technologies being considered expensive were able to reduce the production costs.

Both Verleger Jr (2015) and Behar and Ritz (2016) affirmed that the justification for the price collapse is a change in the oil industry structure. This change is a consequence of the production restrictions withdrawal by the OPEC, which ruled during decades until 2014. Without these restrictions, each country is allowed to produce according to its needs and criteria. This lack of quotas would have caused an offer at a much lower cost, leading to a price collapse.

From the '90s until nowadays, oil price analysts have described numerous episodes of dramatic movements. Economists and industry experts have used the production costs as one of the critical variables which drive these movements being used to predict, most of the time, unsuccessfully, oil price trend (upwards or downwards). The cost curve seems to be a useful tool (Figure 9), which should indicate production loss directly if prices fall. This reduction in supply should underpin prices. However, for some oil production technologies, the price of energy itself is a source of cost, so its variation will be closely related. For that reason, it is not clear which connexions are between oil prices and production costs.

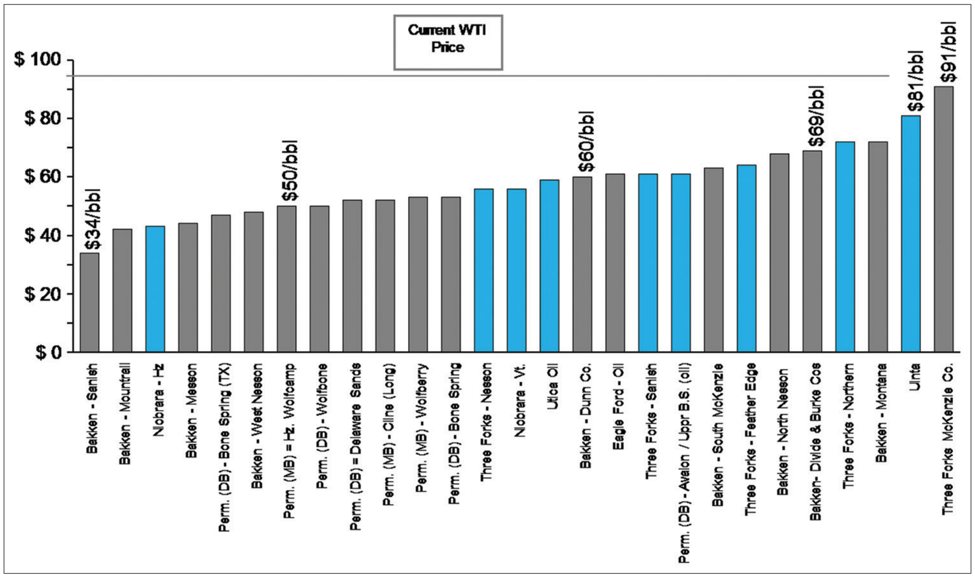
Literature dealing with this relationship is not as abundant as references in newspapers when significant movements in oil prices happen. Some researchers have approached the connection between oil prices and costs in the industry by estimating a structural model (Toews and Naumov, 2015). They find that a 1% increase (decrease) in oil price increases (decreases) global drilling activity by 1% and costs of drilling by 0.5% with a lag of a year. However, shocks to the costs of drilling do not have a permanent effect on the oil price. A different approach (Anderson et al., 2014) using a Hotelling model explores drilling activity, prices, and costs for a local production area (Texas). Their main

Figure 6: Production cost by kind of oilfield 2013



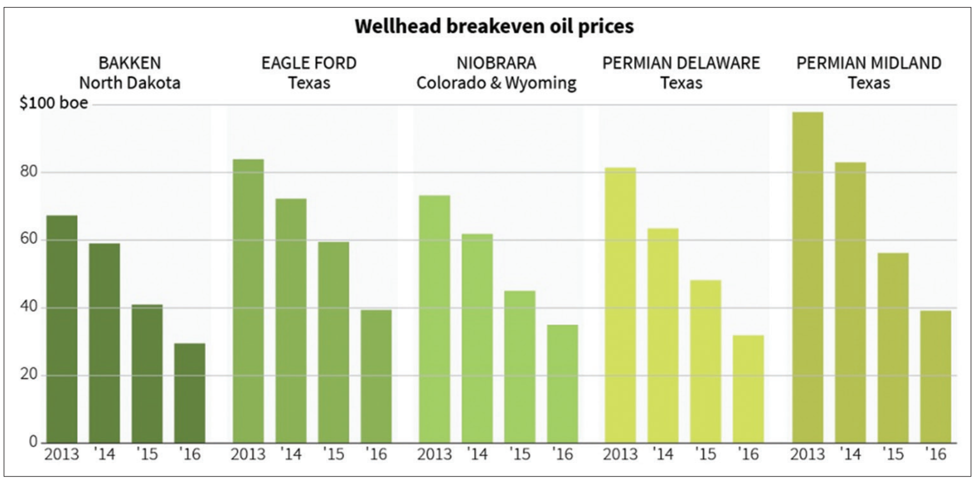
Source: Resources to reserves 2013 IEA

Figure 7: Production cost curve



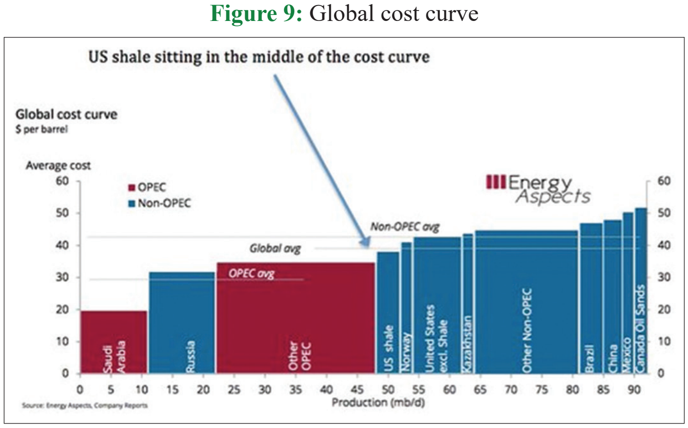
Source: TPH and HPDI (Global Shale Conference, 21 November 2013)

Figure 8: The falling cost of U.S shale production



Source: NAS Well cube rystad energy

Figure 9: Global cost curve



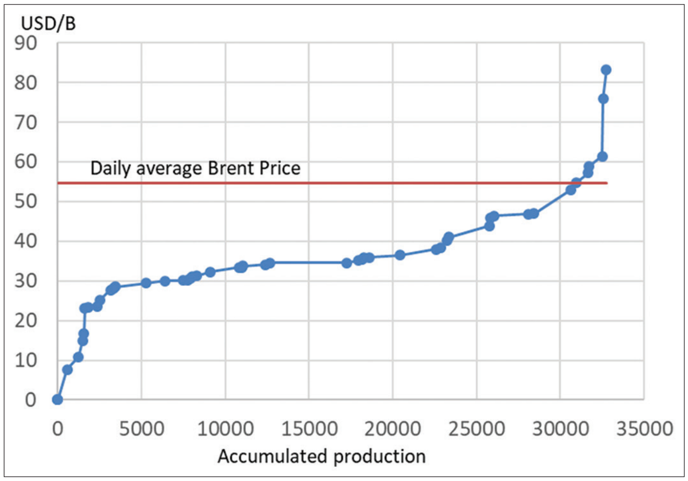
Source: Energy aspects

finding is that pre-existing wells do not respond to oil price shocks while new wells and drilling rig rentals rates are strongly co-varying with oil prices. Other relationships among variables (rig counts) have also been studied (Khalifa et al., 2017). They verify that the impact of changes in oil prices on rig counts lags up to one quarter.

2. METHODOLOGY

In order to determine the direction of causality between variables, the Granger Causality Test is a widely used and helpful tool (Granger, 1969). This test tries to distinguish mere correlation from causality. A universally accepted definition of causation may well not be possible. Still, a definition that seems reasonable to many is the following: "Let Ω_n represent all the information available in the universe at time n. Suppose that at time n optimum forecasts are made of X_{n+1}, using all of the information in Ω_n and also using all of this information apart from the past and present values Y_{n+j}, $j \geq 0$, of the series Y_t. If the first forecast, using all the information, is superior to the second, then the series Y_t has some specific information about X_t, not available elsewhere, and Y_t is

Figure 10: 2017 oil cost built from publicly companies reports



Source: Bloomberg and Companies Reports

said to cause X_t" (Schmalensee et al., 1980). The test is based on linear regression modelling of stochastic processes.

The initial idea is to compare two linear regression models. The first one, the autoregression of Y, explained with its own lags (restricted Model):

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-1} + \ldots + \alpha_j Y_{t-j} + \varepsilon_t \quad (1)$$

The second one is the previous model augmented by including lagged values of X:

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \ldots + \alpha_j Y_{t-j} + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \ldots + \beta_j X_{t-j} + u_t \quad (2)$$

The null hypothesis for Granger causality test is that lagged values of *X* are not statistically significant, so do not improve the explanation of the variation in *Y*. Granger Causality test compares the Sum of Squared Error of the restricted model (SSE_r) with the Sum of Squared Error of the unrestricted model (SSE_u) using an F-test. The F-statistic is given by:

$$F = \frac{(SSE_r - SSE_u)/m}{SSE_u/(n-k)} \quad (3)$$

where *m* is the number of lagged *X* values used in the unrestricted regression, *n* is the number of observations in our sample, and *k* is the number of parameters estimated in the unrestricted model (constant included).

To conduct the test, the time series involved need to follow stationary processes. In the case of integrated processes, as it is the case with oil prices, Gujarati (2006) had shown that the F-test procedure is not valid, as the test statistics do not have a standard distribution.

To deal with integrated time series, Toda and Yamamoto (1995) propose an interesting and straightforward procedure, estimating an augmented Vector Autoregressive model VAR (order p^*), with *d* extra lags, where *d* is the order of integration of the variables. This modification guarantees the asymptotic distribution of the Wald statistic since the testing procedure is robust to the integration and cointegration properties of the process. The first step is to determine the order of integration of the time series through the Dickey-Fuller test (Dickey and Fuller, 1981). An information criterion is used (Akaike Information Criterion [Akaike, 1974] or Bayesian Information Criterion [Schwarz, 1978]) to determine the optimal lag length of the VAR model. The order of the VAR model could be increased in case there is serial correlation in the residuals, to define the appropriate model:

$$Y_t = C_1 + \sum_{i=1}^{p} \alpha_i Y_{t-i} + \sum_{i=1}^{p} \beta_i X_{t-i} + u_{1t} \quad (4)$$

$$X_t = C_1 + \sum_{i=1}^{p} \gamma_i X_{t-i} + \sum_{i=1}^{p} \delta_i Y_{t-i} + u_{2t} \quad (5)$$

The next step is to estimate a VAR adding *d* lags, so the model contains *p* plus *d* lags in total. The null hypothesis for Granger non-causality test is that lagged values of *X* are not statistically significant, so do not improve the explanation of the variation in *Y*. Therefore, the null hypothesis is for equation 5:

$$H_0 : \sum_{i=1}^{p} |\beta_i| = 0$$

While the alternative hypothesis:

$$H_1 : \sum_{i=1}^{p} |\beta_i| \neq 0$$

It is important to note that coefficients for the extra *d* lags are not included when performing the Wald tests. They are added to fix up the asymptotic, but not used afterward. The Wald test statistics will be asymptotically chi-square distributed with *p* degree of freedom. The rejection of the null hypothesis supports the presence of Granger causality.

Therefore, the outcomes obtained for both time series are if XàY (notation for X Granger causing Y) and also if YàX (Y Granger causing X). For that reason, four different outcomes are explored:

1. Unidirectional causality XàY but not YàX
2. Unidirectional causality YàX but not XàY
3. Dual causality where XàY and YàX
4. No Granger causality.

3. DATA AND MATERIALS

Development time in the upstream industry could last from some months to years, depending on the features of the project and the sector activity. For that reason, in addition to this methodology, the lead-lag effect between different variables with the oil price will be shown. It is a simple method, but the study of correlations between oil price and the other variables (leading up to 9 periods, and lagging up to 5 periods) will provide more evidence in terms of temporal precedence. Changes in revenues could modify company decisions, but the effects between variables are not instantaneous.

The upstream industry involves crude oil exploration, development, and extraction. The time series, whose causality will be investigated, are the price of oil and some production cost indicators. In order to have a broader view of the sector, two sources of data have been used.

The Brent price is the reference selected considered as the benchmark for the oil price worldwide (Bossley, 2017). In order to determine if companies could be using longer terms of the oil curve for hedging, four price contracts are going to be explored (1 month, 12, 24 and 60 months). Descriptive statistics of different contracts of Brent are shown in Table 1.

There are some difficulties when trying to calculate the cost in any industry, so there is no single cost index. Two sources of data have been chosen with relevant time series that reflect the costs experienced by the oil industry:

3.1. Producer Price Indexes from the US Bureau of Labour Statistics

Three different Producer Price Indexes, published by the US Bureau of Labour Statistics, are employed: Drilling Oil and Gas Wells (Drilling), Support Activities for Oil and Gas Operations (Support), and Oil and Gas Field Machinery and Equipment (Machinery). Their higher calculation frequency and greater consistency provide them excellent suitability for the needs of the study. There are other production cost indices, such as those published by IHS/CERA or those that can be extracted from the companies' balance sheets but present some difficulties in terms of periodicity. The period of time considered for this analysis is from January 1995 to December 2019. Monthly data are going to be used. Descriptive statistics of our four variables are shown in Table 2.

3.2. Cost built from the Oil and Gas Companies Reports

Data from 20-F reports and Annual Reports have been analysed for the 47 largest public oil companies to establish the global cost of production. In order to compute this number, an annual curve cost has built, starting from finding, development and acquisition (FD&A) costs, lifting costs and selling, general and administrative (G&A) costs. FD&A refers to costs incurred when a company purchases, researches, and develops properties in an effort to establish oil reserves. FD&A costs are calculated by adding exploration costs, development cost, and acquisition cost and dividing by the adding oil reported by the company (discoveries, improvements in recovering and revisions). This term is the most volatile cost because investment in one year could bloom in the following years. Lifting costs (also called production costs) are the costs to operate and maintain wells and related equipment and facilities per barrel of oil equivalent (boe) of oil and gas produced by those facilities after the hydrocarbons have been found, acquired, and developed for production. Lifting costs and selling, general and administrative costs are obtained directly from SEC reports.

Since the output of these companies also includes gas, an exercise of splitting expenses has been completed. It has been considered that costs incurred have been proportional to revenues obtained in the production of that oil or gas at the average price of the year. For doing that distribution, it has considered that a barrel oil equivalent -boe- of gas is equivalent to 5.8MMBTU. If 1 barrel of oil is around $60 and the price for an MMBTU of gas is about $3, the revenue from one boe of oil is higher than income for one boe of gas ($60 versus $17.4). When companies allocate resources, costs, and revenues should keep close. The 2017 production cost curve obtained is shown in Figure 10, and the list of the companies is exhibited in Table 3. Integrated Oil Companies, like BP or Shell, have a diversity of oilfields which provides a lower cost of production. Producers related to shale oil, like Suncor or Cenovus Energy, have, in general, higher costs, as it could be expected. In this case, the period of time considered is from 1998 to 2019 on an annual basis. Descriptive statistics of our variables are shown in Table 4. Two production costs have been considered in the study. The "Cost 100%" consider the marginal cost as the highest cost of all companies. The "Cost 90%" is the highest cost covering the 90 percentile of total production. This last measure seems to be more robust and meaningful as the marginal cost of oil production. Since the Granger Causality Test requires determining the order of integration of time series, the Dickey-Fuller test (Dickey and Fuller, 1981) has been evaluated. As Tables 1, 2 and 4 show, every single time series involved in the study is integrated of order one. A transformation will be done previously to the use of the Granger Causality Test to the oil. In order to reduce observed heteroscedasticity, a logarithmic transformation is applied.

Table 1: General statistics

Monthly	1M	12M	24M*	60M**
Average	55.50	55.16	59.35	77.36
SD	32.86	32.74	30.98	17.37
P95	112.36	107.66	105.04	102.79
P05	15.61	15.93	16.12	55.93
Integrated	I (1)	I (1)	I (1)	I (1)
AugD-F Test	−1.545	−1.415	−1.476	−1.497

*Data from January 31, 1998
**Data from January 31, 2006

Table 2: General statistics

Monthly	Drilling	Support	Machinery	Production
Average	271.05	164.10	215.15	85.59
SD	111.78	34.96	46.81	9.14
P95	442.36	199.61	269.00	100.31
P05	110.39	110.60	152.10	71.48
Integrated	I (1)	I (1)	I (1)	I (1)
AugD-F Test	−1.467	−1.508	−1.595	−0.560

4. EMPIRICAL RESULTS

4.1. Producer Price Indexes from the US Bureau of Labour Statistics

Table 5 shows the P-values of the Toda-Yamamoto causality test for the data set related to industry costs. Values below 0.05 will be showing Granger-causality with a 95% confidence level. The main conclusion is that no factor has been identified to Granger cause the price of Brent. The hypothesis of higher/lower costs results in higher/lower oil price does not seem to be valid. Some bidirectional relationships among the other variables have been

Table 3: Companies included in cost curve 2017

Company	Country	Production Kb/d	% Oil	Cost 2017 USD/Bbl
Rosneft Oil Co	Russia	5.718	80,05	34,59
Petro China Co	China	3.994	60,85	43,93
Exxon Mobil Corp	USA	3.985	50,89	46,81
Royal Dutch Shell	UK	3.664	49,81	36,47
BP	UK	3.551	60,92	37,99
Petrobras	Brazil	2.767	79,33	52,97
Chevron Corp	USA	2.728	63,16	33,40
Total	France	2.566	52,46	34,05
Lukoil	Russia	2.269	79,51	29,38
Equinor ASA	Norway	2.080	54,76	30,03
ENI	Italy	1.816	46,92	32,26
Novatek	Russia	1.410	16,72	14,87
Conoco Phillips	USA	1.377	52,36	35,09
CNOOC	China	1.288	82,67	30,11
Oil and Natural Gas Corp	India	1.268	53,69	10,83
China Petroleum and Chemical Corp	China	1.209	67,14	61,40
Ecopetrol	Colombia	715	76,22	23,50
Repsol	Spain	695	36,69	38,37
Suncor Energy	Canada	685	100,00	57,17
Anadarko Petroleum Corp	USA	672	52,83	47,01
EOG Resources	USA	609	55,30	35,97
Occidental Petroleum Corp	USA	602	63,29	40,13
Chesapeake Energy Corp	USA	548	16,50	33,78
Devon Energy Corp	USA	543	44,94	31,30
Cenovus Energy	Canada	471	72,83	54,85
Apache Corp	USA	457	53,41	34,58
Marathon Oil Corp	USA	397	51,13	46,35
Noble Energy	USA	381	34,38	28,48
OMV	Austria	348	51,65	83,33
Imperial Oil	Canada	335	94,03	30,16
Husky Energy	Canada	323	66,55	23,39
Encana Corp	Canada	313	24,36	35,97
Hess Corp	USA	306	57,84	28,01
Pioneer Natural Resources	USA	272	58,23	30,51
Continental Resources	USA	243	57,06	25,14
Concho Resources	USA	193	61,82	33,41
Crescent Point Energy Corp	Canada	176	79,54	41,00
Seven Generation Energy	Canada	175	31,81	75,93
Murphy Oil Corp	USA	164	54,54	31,06
WPX Energy	USA	110	55,83	23,11
MOL Hungarian Oil & Gas	Hungary	99	38,06	58,78
GALP	Portugal	93	87,37	16,82
Diamondback Energy	USA	79	74,07	45,93

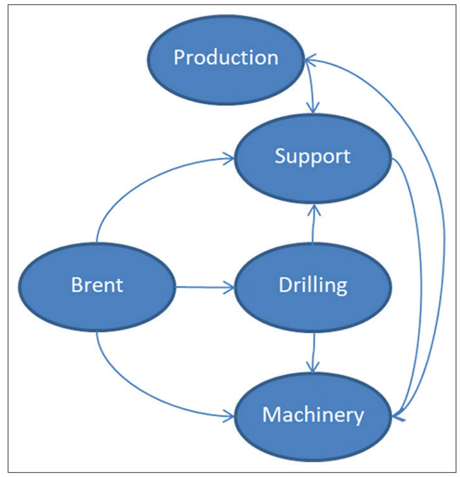
found. In addition, there is strong evidence that the price would cause every cost variable analyzed.

In order to visualize the interactions, a diagram relating to causality has been elaborated. Relationships between variables with P = 0.05 have been considered. In those cases where both directions are involved, a bold double arrow is used. The dynamic system proposed is summarized in Diagram 1.

Table 4: General statistics

Yearly	Cost 90%	Cost 100%
Average	44.41	64.57
SD	23.30	28.51
P95	70.34	94.19
P05	12.08	22.65
Integrated	I (1)	I (1)
AugD-F test	-1.353	-1.448

Diagram 1: Causality direction relationship among variables



Since oil companies normally hedge their production some months or even years ahead, the effect of the cost of production could be affecting in other contracts instead of the closest to maturity one. For that reason, the calculus has been repeated with the 12-, 24- and 60-months contract. In Tables 6 and 7 P-value from Toda-Yamamoto Causality test are shown. The relationships between the different contract prices and the cost indices remain in the same direction.

Even in the maturities dominated by production oil companies, the longest one, it is not able to find a relationship that the production cost would be causing the oil price (Table 7). It would imply that oil cost would not be the main driver in determining the heading price in the strategy of companies. It is obvious that production cost is an essential figure, really hard to determine, for an oil producer but with no direct impact in the market oil price.

Trying to provide further evidence to this conclusion, the cross-correlation of Brent with the other variables (up to ±9 periods) has been calculated. When variables within the same industry respond in the same instant to shocks, it is said that they are coincident. In that case, the correlation between variables reaches its highest value when comparing contemporary time series. For that reason, causal relationships could be found in any of the two-way directions (or even dual). In the case of dual causality, it could be the response for both variables to another inceptive factor. However, when a variable leads another, it is likely that causality in one direction but not in the other.

We have restricted our study to Brent as the primary variable. As it is shown in Table 8, in the cases of Drilling cost, Support Activities cost, and Machinery cost, the maximum occurs with oil

Table 5: Toda-Yamamoto causality test (P-value)

	P-values				
Brent 1M	--	**0.00028****	**0.0072****	**0.00043****	**0.051**
Drilling	0.970	--	**0.000024****	**0.0042****	0.620
Support	0.450	0.720	--	**0.0033****	0.330
Machinery	0.094	0.087	**0.046***	--	**0.0042****
Production	0.820	0.180	**0.011***	0.028*	--
Granger Cause -->	Brent	Drilling	Support	Machinery	Production

*95% confidence level, **99% confidence level

Table 6: Toda-Yamamoto causality test (P-value) Brent Granger-cause

Granger cause -->	Drilling	Support	Machinery	Production
Brent 1M	0.00028**	0.0072**	0.00043**	0.051
Brent 12M	0.0000037**	0.0024**	0.000024**	0.055
Brent 24M	0.0000038**	0.00013**	0.017*	0.0015**
Brent 60M	0.0011**	0.000058**	0.079	0.041*

*95% confidence level, **99% confidence level

Table 7: Toda-Yamamoto causality test (P-value) Cost Granger-causesW

Granger Cause -->	Brent 1M	Brent 12M	Brent 24M	Brent 60M
Drilling	0.970	0.960	0.770	0.970
Support	0.450	0.810	0.440	0.940
Machinery	0.094	**0.060**	**0.062**	0.170
Production	0.820	0.980	0.580	0.510

*95% confidence level, **99% confidence level

leading between 7 and 9 months. This fact means that changes in oil price this month would imply changes in the other variables that will take place several months from now. So, speaking in temporal precedence, Brent would be the cause for the movements of the other variables.

4.2. Cost Built from the Oil and Gas Companies Reports

In the case of cost built from the oil companies reports, the conclusion is similar to the previous case. There is no evidence that production costs Granger-causes Brent price as it is shown in the first column of Table 9 (values above 0.05). Besides, it can conclude that the level of Brent price Granger-causes the costs reported by the companies and these relationships remain along the futures curve too. It does not matter the cost percentile used.

The explanation would be that when companies detect an alteration in the level of their incomes (different prices), they react correcting the budget in exploration and production to the new situation (changing the cost of the industry). In a period of high prices, the increase in Capital Expenditure creates a scarcity of resources. Companies of oilfield services will use the opportunity to increase the prices up. The opposite seems to happen when the oil prices go down.

When creating the cost curve, FD&A costs are volatile and are difficult to impute to an exact period. Furthermore, alteration on results on exploration from previous expectations on oil recovery could alter figures in both directions. If revisions have increased/reduced the amount of oil found, the costs would be underestimated/overestimated. In order to minimize this volatility, an analogous exercise has been completed using the three-year average of finding costs with similar results.

Table 8: Lead-lag cross-correlations brent versus other variables

Brent	Months	Drilling	Support	Machinery	Production
Lagging	t=−5	0.855	0.875	0.826	0.732
	t=−4	0.864	0.880	0.831	0.734
	t=−3	0.873	0.885	0.836	0.737
	t=−2	0.883	0.890	0.842	0.739
	t=-1	0.893	0.896	0.847	0.741
	t=0	0.903	0.902	0.852	0.744
Leading	t=+1	0.912	0.907	0.857	0.748
	t=+2	0.921	0.913	0.862	0.751
	t=+3	0.928	0.918	0.865	0.750
	t=+4	0.934	0.922	0.869	0.750
	t=+5	0.939	0.925	0.873	0.750
	t=+6	0.943	0.927	0.876	0.749
	t=+7	0.945	0.928	0.880	0.748
	t=+8	0.946	0.927	0.883	0.746
	t=+9	0.946	0.926	0.885	0.746

Table 9: Toda-Yamamoto Causality Tests (P-value)

Companies	P-values		
Brent 1M	--	**0.00071****	**0.0067****
Perc90	0.390	--	
Perc100	0.810		--
Granger Cause -->	Brent	Perc90	Perc100

*95% confidence level, **99% confidence level

5. DISCUSSION

As a recap of the results, it is essential to highlight that the study seeks to determine the relationships (and the direction of these) between the price of oil and production costs (upstream). In that sense, none of the analyzed cases indicate that the production costs would be causing the price of oil. In fact, it seems that it is just the opposite. Brent is the inception that would affect drilling, machinery, and support costs. These, in turn, would cause changes in the rest of the variables analyzed.

In order to find an explanation for the business of the upstream industry, these relationships indicate that a change in the price of oil would be transferred to the producing companies in the form of a change in income. The higher or lesser availability of revenues would motivate these companies to modify their budgets for the future, thus adapting their needs for the development of new oilfields. Depending on these needs of labour, machinery, and material, this change would also be reflected in the cost indicators. The connexion between production and oil prices is not well defined, but in any case, the causality relationship would be that high prices incentives higher production.

The observed delay between the price of oil and the activities related to oil extraction is part of the investment cycle in the industry. Prospecting projects can take from a quarter to several years to start operations from the investment decision. This delay may have been identified in our study. The apparent lag that production costs take to react to higher oil prices seems to be between 7 and 9 months. It could be considered even a short period for the complexity of the projects in this industry.

The marginal costs obtained would be more accurate if the curve were built from the oilfields instead of the companies. Wood McKenzie and Rystad Energy are some of the companies that are collecting these data. Due to budget limitations, the study has not included these time series.

6. CONCLUSION

Production costs of oil have been a recurrent justification for the rise in oil prices during the last decades. No evidence of that justification has been found in this study. New technology and regulation have allowed exploiting shale-oil fields and other unconventional resources, triggering higher-cost production but this would not be the reason for the increase in oil prices. In fact, the possibility of exploiting fields with higher costs would be given by the rise in the price of oil.

Based on Granger's definition of causality, and using the Toda-Yamamoto methodology, this study has been able to analyze the interactions between price and production costs. According to the results obtained, changes in the price of oil would lead to changes in the rest of the variables. The explanation of this relationship would imply that an increase (decrease) in Brent, would cause an increase (decrease) in revenues in oil-producing companies. Considering that companies prefer to maintain dividends steady, budget in exploration and drilling would increase (reduce), pressing (softening) the prices of professionals, machinery and raw materials and increasing (decreasing) production costs.

Exploring the Brent future curve has shown that production costs would not be the main driver in determining the heading price in the strategy of companies. There is no change in the relationships between oil prices and production costs when conducting the study with longer futures contracts.

Therefore, when trying to explain or predict the movement of oil prices in the future, we should not consider as explanatory variables the related costs of the industry (unfortunately often used). It is the price of oil that precedes the movements of production costs. The direction of this causality has been well observed in many cases, especially during the correction of 2014-2015.

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