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Determination of Causality in the Prices of Crude Oil

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ABSTRACT

Price determination through demand and supply forces is the most efficient pricing mechanism. But, these forces should be real rather than artificial. Speculative trade creates artificial market forces, which bounds to disturb real economy. It is argued that the demand and supply forces are primarily driven by speculation rather than fundamentals in the presence of commodity derivatives. The aim of this study is to empirically test this argument through causality analyses. Crude oil and USA has been selected as a typical case. Daily spot prices of west texas intermediate crude oil and future prices from New York Mercantile Exchange from January 2nd, 1986 to March 6th, 2017 has been analyzed. Granger causality test and vector error correction model are applied to find out the causal relationship between spot and futures prices. Results show that causality runs from runs from crude oil futures to spot prices, crude oil is just one of the numerous commodities, which are being speculatively traded through derivatives.

Keywords: Causality Analysis, Crude Oil Pricing, Futures, Spot Prices, Vector Error Correction Model
JEL Classifications: D40, D49, E44, F01

1. INTRODUCTION

There can be various angles to gauge impact of derivatives on economy. One of the aspects is the influence of commodity derivatives prices on the spot prices. In a market economy, prices should be determined by demand and supply forces. But, these forces should be real rather than artificial. Artificial forces refer to speculative demand and supply, which bound to create disturbance for real sector. There is an argument that future markets are supposed to provide an efficient price discovery mechanism. But with speculative trading, equilibrium prices cannot be determined.

Several studies have been conducted to determined causality or lead–lag relationship between spot price and futures prices. Diversified findings demand to check causal linkage empirically with more comprehensive approach. Crude oil has been selected as an underlying commodity, and US market as typical case, to perform causality analysis. The rationale of taking crude oil for analysis has several advantages. Firstly, future trading of crude oil is relatively higher than other commodities. Secondly, price fluctuation in crude oil is also evident internationally. Thirdly, the impact of oil prices is quite high as fuel prices are associated with cost of living as well as cost of production.

Price determination of spot through futures is not an issue per se, but future prices are driven by speculation, which is problematic. It is argued that the price fluctuations in crude oil markets is largely because of speculative trading of commodity derivatives. This argument can be tested empirically through causality analysis to examine lead lag relation of prices Kaufmann and Ullman (2009) have stated that if price changes appear first in spot prices, determinants of the prices would be fundament; otherwise, speculation would be determining the prices.

2. LITERATURE REVIEW

Theoretically speaking, spot and futures prices should reflect same value for a commodity except the time value component; and

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even if they differ, arbitrage would come into play to eliminate the imbalances. Thus, there should not be lead-lag relationship as such between spot and futures prices. However, there are diversified findings in research studies especially in case of crude oil; most of them have indicated the impact of futures on spot prices. These studies present an argument that new information swiftly incorporated in futures as compared to spot prices because of ease of transaction, leverage and short selling.

Initially, Garbade and Silber (1983) have presented a price discovery mechanism through futures; they examined the effect of arbitrage on spot and futures prices of commodities and supported the notion that future prices lead spot prices. In few studies causality is reported to be bi-directional. Kawaller et al. (1988) argued that both futures and spot prices are affected by each other through their past and concurrent information. Quan (1992) has found that spot prices contain info about futures prices, but futures prices do not contain any information about spot prices. Schwarz and Szakmary (1994) found bilateral causality or feedback mechanism between spot and futures prices. Moosa and Al-Loughani (1995) studied the role of arbitrageurs and speculators. Ederington et al. (2019) have reviewed the relation between crude oil and petroleum products.

Silvapulle and Moosa (1999) have argued that there is a lagged reaction in spot prices as execution of spot transactions requires time. Bekiros and Diks (2007) showed Granger causality from futures to spot prices. Nath and Lingareddy (2008) has stated that commodities futures for various commodities were introduced in India, but later on due to pressure on spot prices these derivatives were banned for few commodities. Nikitopoulos et al. (2017) have recently analyzed the determinants of crude oil prices.

Kaufmann and Ullman (2009) found weak causal linkage between futures and spot prices of crude oil from Africa, North America, Europe, to the Middle East. Chevallier (2010) has concluded that the futures prices lead the price discovery process in the EU markets; his research was on CO_2. Zhou and Wu (2016) performed vector auto-regression (VAR)-MGARCH analysis on high frequency data of China financial futures exchange, and found that the impact of the CSI 300 index futures prices on its underlying spot market has been strengthened over the time. There are few studies which propounds causality from spot to future prices such as Moosa (2002). whereas Sterlacchini (2019) has investigated trends in oil price.

3. RESEARCH METHODOLOGY AND DATA

We used Granger causality and vector error correction model (VECM) to find out causal relationship between spot and futures prices of crude oil. Engle and Granger (1987) have presented that if the time series are cointegrated, then causality should be tested with VECM instead of unrestricted VAR model.

After presenting descriptive and covariance statistics, analysis starts with the checking of normality assumptions through Jarque-Bera test and stationarity of variables with Augmented Dickey-Fuller (ADF) unit-root test. In order to analyze causality, Granger causality test is applied first, and then VECM is used to find out long term as well as short term relationship between spot and futures prices, as well as to verify the causality between them.

Data set comprises on daily time series of crude oil prices from west texas intermediate (WTI) - Cushing, Oklahoma, also called as Texas Light Sweet. These prices are in denominated in USD for one barrel and not adjusted for seasonal factor. WTI crude oil is a global benchmark for oil prices. Various studies like Bekiros and Diks (2008), and Lee and Zeng (2011) have also used the same benchmark for fuel prices. Bekiros and Diks (2008) have used VECM and suggested bidirectional causality under linear methods, and unidirectional causality between spot and futures oil prices under non-linear methods. WTI is also the underlying commodity of New York Mercantile Exchange (NYMEX) for oil futures contracts. The sample period for the study is sfrom 02 January 1986 to 06 March 2017, which comprises of 7816 data points with 5-days week. Price data is downloaded from the website of Energy Information Administration, USA (EIA).

Five different time series have been incorporated in the analysis, the first one is the spot rate of crude oil while other four are the prices of future of crude oil traded at NYMEX. The contract size of crude oil futures is 100 barrels. The maturities of the contracts are from 1 month to 4 months. Prices of refined petroleum products have been ignored, as Kaufmann and Ullman (2009), and other studies have shown that causality run from prices of crude oil to refined petroleum products.

4. ANALYSES

According to Chevallier (2010), with risk-neutral approach and rational expectations, unexpected shocks are only supposed to deviate future spot prices from futures prices. In case of these restrictive assumptions, the theoretical relationship between spot and future should be:

$$S_t = F_t + \varepsilon \tag{1}$$

In such regression, futures prices coefficients should be one, constant term should be zero and white noise error term should have zero mean. But, this ideal relationship is hard to find in speculation driven markets. A better approach would be to investigate causality. In the Table 1, descriptive statistics is presented to have a look on the basic statistical characteristics of the data.

Descriptive statistics of all five time-series are exhibiting almost same characteristics, their central tendencies, dispersions, and skewness etc., are very similar to each other. Chevallier (2010) have argued that spot and future price should reflect the actual value of underlying asset. But this scenario also implies presence of causality. This implication can be reaffirmed before actually checking the causality through correlational analysis, which shows how closely these series are moving together.

4.1. Checking Data for Statistical Assumptions

4.1.1. Normality

Jarque-Bera test have been applied to the check the normality of the price of crude oil spot and futures contracts.

Results of Jarque-Bera test are significant and can be seen in Table 3, means that the data series are non-normal. According to Brooks (2014), violation of the normality assumption virtually has no consequences for large samples and estimates would still be unbiased and consistent.

4.1.2. Stationarity

Among various unit root tests, author has applied ADF test (See Table 4).

All five data series are not stationary at level as the results are not significant, but they become stationary at first difference.

5. RESULTS

5.1. Granger Causality Test

The test was introduced by Granger (1969) for determining the direction of causality and feedback mechanism in a two variable relationship. In Granger causality test, causality is not tested as cause-effect relationship in physical or philosophical sense, it is rather precedence.

$$Y=\sum\beta_1 X_{t-i}+\sum\beta_2 Y_{t-i}+u_a \quad (2)$$

$$X=\sum\beta_3 X_{t-i}+\sum\beta_4 Y_{t-i}+u_b \quad (3)$$

Where, X and Y are two time-series variables for which causal relation is tested, subscript of $t–i$ is denoting lags whereas βs are the coefficients of lags with summation operator. Granger causality test is applied here to examine the causalities of the spot and futures prices of crude oil so that the argument of speculation being the driving force of the petroleum prices can be empirically verified. In case, futures prices are unilaterally Granger causing the spot price, this will support our argument. Granger causality test has been performed with default lag selection. There are five data series i.e., spot rate and 4 future contracts. Each future contract has been analyzed for causality with spot rate. Results of the Granger causality test are presented in Table 5.

Table 2, It can be observed from the results that only one equation is showing unilateral causal relationship that is between spot and 1-month futures prices, while other three relationships are bilateral.

Table 1: Descriptive statistics

Measure	Oil_spot	Oil_future_1	Oil_future_2	Oil_future_3	Oil_future_4
Mean	43.03247	43.0483	43.1628	43.22422	43.24358
Median	28.3	28.245	27.985	27.515	27.075
Maximum	145.31	145.29	145.86	146.13	146.43
Minimum	10.25	10.42	10.54	10.58	10.71
SD	30.14658	30.17085	30.34713	30.48383	30.58439
Skewness	0.970772	0.967688	0.947633	0.931903	0.919806
Kurtosis	2.678998	2.670701	2.614791	2.567969	2.53058

SD: Standard deviation

Table 2: Correlation and t statistics

	Oil_spot	Oil_future_1	Oil_future_2	Oil_future_3	Oil_future_4
Oil_spot	1				
Oil_future_1	0.999921	1			
	7045.034	-			
Oil_future_2	0.999485	0.999649	1		
	2752.263	3333.703	-		
Oil_future_3	0.998747	0.998974	0.999801	1	
	1763.799	1949.645	4425.202	-	
Oil_future_4	0.997879	0.998155	0.999341	0.999862	1
	1354.815	1453.198	2433.298	5311.992	-

Table 3. Jarque-Bera Test for normality

Test	Oil_spot	Oil_future_1	Oil_future_2	Oil_future_3	Oil_future_4
Jarque-Bera	1260.865	1254.836	1217.819	1191.773	1173.575
Probability	0	0	0	0	0

Table 4: Augmented dickey-fuller test statistic (unit root test)

At level	Oil_spot	oil_future_1	Oil_future_2	Oil_future_3	Oil_future_4
t-statistic	−1.570945	−1.573164	−1.477186	−1.411125	−1.363738
Prob.*	0.4975	0.4963	0.5454	0.5784	0.6016
Lag Length: 1 (Automatic - based on SIC, maxlag=35)					
At 1st difference	**Oil_spot**	**Oil_future_1**	**Oil_future_2**	**Oil_future_3**	**Oil_future_4**
t-statistic	−90.32038	−90.3598	−89.55888	−89.54404	−89.95016
Prob.*	0.0001	0.0001	0.0001	0.0001	0.0001
Lag Length: 0 (Automatic - based on SIC, maxlag=35)					

*MacKinnon (1996) one-sided *P* values (Rejected at 5%)

The unilateral causality between spot and 1 month futures contract is indicative of the fact that speculation is playing dominant role in price determination for the crude oil and subsequently for the petroleum products; and this is problematic for real economy.

5.2. VAR

VAR is a system of regression equations, like simultaneous equations models, it contains several endogenous variables. Each variable is regressed with its own lag and the lags of other endogenous variables. Thus, VAR is a generalization of Granger Causality. According to Engle and Granger (1987) argument that if the time series are cointegrated, then causality should be tested with VECM instead of unrestricted VAR model. Here, VAR is being applied in order to find out suitable lag length, rather than for causality. Hamilton (1996) has recommended that the lag order for VECM should be chosen through minimalizing the value of usual information criteria. Here, Akaike information criterion and Schwarz information criterion have been employed for lag selection (See Table 6).

AIC is recommending 8 lags whereas SC is recommending 5 lags. To make the VECM analysis parsimonious, Schwarz information criterion is preferred. Following are the results of Johansen cointegration test:

Data should be at level for the application of Johansen cointegration test (See Table 7). Results of the test as per Trace statistics and Maximum Eigenvalue test indicate four cointegrating equations at first difference at the 0.05 level with 1-5 days lags; as fifth null hypothesis of "at most 4 equations are cointegrated" cannot be rejected. It means that all five variables are cointegrated at first difference. Having multiple cointegrating relationships is problematic theoretically, because ideally there should single long run equilibrium position once all the data series are cointegrated at certain point. Statistical implication of having five cointegrated terms is to apply VECM with five error correction terms.

5.3. VECM

When similar random trends are present in a set of variables, such variables can be referred as cointegrated and the trend they commonly share is known as cointegrating relationship or equilibrium relationship. The linear combinations of these integrated variables are stationary. Cointegrating relationships among various integrated variable can be modelled in a system of variables through restricted VAR, which is also known as VECM. Several linearly independent cointegrating vectors may be present in VECM, linear combinations of these vectors are also stationary as cointegrating variables were stationary.

After having spot and futures prices of crude oil cointegrated at first difference through Johansen cointegration test, VECM can be applied now to verify the causality of spot and futures prices. The advantage of VECM is that it bifurcates causality in short run and long run. The first term of the VECM equation denotes long run causality, which is the coefficient of cointegrating equation; it is also called Error Correction term. The inverse of error correction terms exhibits the speed of adjustment towards long term equilibrium. All subsequent terms in VECM equation represents short run causality, which are variable wise jointly tested through Walt test.

Long run causality is presented, which is gauged through error correction term. Since there are four cointegrating equations, therefore there will be four error correction terms. The causal relationship is established if coefficients are significant with negative sign. Results of VAR analysis performed with spot prices as dependent variable are compiled in Table 8.

In Table 8, it can be observed that only the first error correction term is significant as well as negative. Thus, it can be concluded that there is only one long term causal relationship from futures prices to spot prices. The value of the coefficient of error correction term is -0.658, which indicates that almost 66% of spot prices are adjusted in 1 day. In order to check long run bilateral causal relations, VECM analysis have also been performed with future prices as dependent variable. Condensed results are given in Table 8.

Out of sixteen error correction terms, only four are significant and negative. Although spot prices are involved in all four terms, but with interaction of futures prices. This situation led to perform VAR analysis separately with each of the futures contract price steam as dependent variables and spot price as independent variable. Lag lengths are selected through Schwarz information criterion separately for each VECM equation. The scenario of bilateral causality or feedback gets clear from the Table 9.

Table 5: Pairwise granger causality tests

Null hypothesis	Obs.	F-statistic	Prob.
D_future_1 does not granger cause d_sPOT	6967	8.64225	2.00E−04
D_spot does not granger cause d_future_1		0.41543	0.6601
D_future_2 does not granger cause d_spot	6967	15.6237	2.00E-07
D_spot does not granger cause d_future_2		4.93309	0.0072
D_future_3 does not granger cause d_spot	6967	8.25007	0.0003
D_spot does not granger cause d_future_3		5.19617	0.0056
D_future_4 does not granger cause d_spot	6967	5.77674	0.0031
D_spot does not granger cause d_future_4		6.00198	2.50E-03

Table 6: Lag length selection

Info. Criterion\lag	0	1	2	3	4	5	6	7	8
AIC: Akaike	11.771	−0.774	−0.947	−1.018	−1.061	−1.091	−1.103	−1.104	−1.11*
SC: Schwarz	11.777	−0.739	−0.883	−0.924	−0.938	−0.94*	−0.922	−0.893	−0.870

It is evident from the above table that there is no long term causality running from spot prices to futures prices, as there is no significant error correction term with negative sign (See Table 10). These findings are at variance from Granger causality test, which advocated bilateral causality for two, three and 4 month's causality. This difference may be due to the fact that Granger causality test does not bifurcate causality into short run and long run whereas VECM does. From these results, the notion of futures prices driving spot prices is further reinforced.

In VECM, short term causality is checked by jointly testing the coefficients of the error correction terms through Wald statistics. Wald test has been applied variable wise; all five lags of single variable are jointly tested:

It is evident from the result presented in Table 11 that 1 month's, 2 months', and 3 months' future contracts are causing spot prices in short run along with the lags of the spot price itself. 4 month's futures contract prices are insignificant in determining spot prices. The short term bilateral causality is being approached in similar fashion as in the case of long term causality. Joint Wald test has been applied to the lags of spot only, not to the lags of dependent futures contract.

According to the results in Table 12, spot prices are causing all four futures contracts in the short run, as all four equations statistically significant. Combining the results of Tables 11 and 12, there is short term bilateral causality or feedback mechanism between spot prices and futures prices.

Table 7: Unrestricted cointegration rank test (trace)

No. of CE (s)	Eigenvalue	Statistic	Critical value	Prob.
None*	0.103103	1256.253	69.81889	1
At most 1*	0.072555	583.4536	47.85613	0.0001
At most 2*	0.014127	117.7422	29.79707	0
At most 3*	0.004632	29.77318	15.49471	0.0002
At most 4	0.000173	1.067883	3.841466	0.3014

*Denotes rejection of the hypothesis at the 0.05 level

6. CONCLUSION

Results of the causality analyses supports that the market forces are primarily driven by speculation rather than fundamentals in the presence of commodity derivatives as far as crude oil is concerned. Daily prices of five data streams including spot prices of WTI crude oil and future prices from 1 month to 4 month's contracts of NYMEX from 2 January 1986 to 6 March 2017 has been analyzed. Descriptive and correlation analysis suggest that all the five data series are demonstrating similar statistical characteristics and are highly correlated to each other. Variables are stationary at first difference.

In order to analyze causal relationship between spot and futures prices on crude oil, Granger causality test is applied in first instance. Results show that causality runs from 1 month futures prices to spot prices, evidencing that in the presence of derivatives, prices of crude oil are driven by speculation rather than fundamentals. Bilateral causality also exists between spot prices and 2 months, 3 months, and 4-months future contracts.

In order to go into depth of causality and verification of findings from Granger causality test, VECM has been applied. All the five variables are cointegrated at first difference as per Johansen cointegration test. It fulfills the precondition for VECM. Johansen cointegration test also advocated 4 cointegration equations. Schwarz information criterion suggests 5 lags order to be used for VECM. Causality is bifurcated into short and long run in VECM. VECM is run with spot prices as dependent variable and having four cointegration equations, out of which only one equation is found to be significant with negative sign. This shows that there is a long run causal relation, runs from crude oil futures contract

Table 8: Long term causality, future to spot

Equation	Coefficient	Std. error	t-statistic	Prob.
Cointegration equation 1	−0.65854	0.073565	−8.951832	0
Cointegration equation 2	0.564738	0.107069	5.274516	0
Cointegration equation 3	0.387879	0.259292	1.495915	0.1347
Cointegration equation 4	−0.400295	0.364011	−1.099678	0.2715

Table 9: Long term causality with each of futures contract and spot prices separately

Dependent variable	Coefficient	Std. error	t-statistic	Prob.
1 month's futures contract	0.141609	0.059692	2.372328	0.0177
2 month's futures contract	0.027883	0.015657	1.780858	0.075
3 month's futures contract	0.011945	0.009098	1.312904	0.1893
4 month's futures contract	0.005505	0.006712	0.820199	0.4121

Table 10: Long term causality taking each of the futures contract as dependent variable

Dependent variable	Coefficient	Std. error	t-statistic	Prob.
1 month's futures	−0.14802	0.072446	−2.04322	0.0411
2 month's futures	−0.13823	0.067532	−2.04689	0.0407
3 month's futures	−0.15317	0.065632	−2.33371	0.0196
4 month's futures	−0.15944	0.064268	−2.48093	0.0131

Table 11: Wald test - short run causality

Hypothesis	Test statistic	Value	Df	Prob.
lags of spot is causing spot	Chi-square	14.14157	5	0.0147
lags of F1 is causing spot	Chi-square	65.49171	5	0
lags of F2 is causing spot	Chi-square	59.09897	5	0
lags of F3 is causing spot	Chi-square	23.01464	5	0.0003
lags of F4 is causing spot	Chi-square	4.400492	5	0.4933

Table 12: Short term causality with spot price as independent variable

Dependent variables	Test statistic	Value	df	Prob.
1 month's futures contract	Chi-square	12.74016	4	0.0126
2 month's futures contract	Chi-square	46.47058	6	0
3 month's futures contract	Chi-square	36.08311	6	0
4 month's futures contract	Chi-square	34.23659	6	0

prices to spot prices. This finding endorses the results of Granger causality test.

As far as long term bilateral causality is concerned, it tends to appear in system of equations of futures contracts and spot prices, but it disappears when each futures contract is individually put with spot prices in VECM. On the other hand, there is bilateral causality in short run between spot prices and futures contracts prices of crude oil with the exception of 4-months futures contract, where causality runs only from futures prices to spot prices. Having bilateral causality or feedback mechanism between spot and futures in short run means that neither speculation nor fundamentals are dominating each other, rather both the factors are playing role in price determination of crude oil.

Based on the findings of VECM performed on the daily crude oil prices, it can be concluded that speculative trading of fuel or energy derivatives are driving spot prices of crude oil in long run whereas there is feedback mechanism between spot and futures prices in short run. Unilateral causality running from futures prices to spot prices is evidencing that the speculative trading is dominating over fundamentals in determining the crude oil prices. The same phenomenon would also be transmitted to the finished products of petroleum as the prices of these products are predominantly depends on crude oil (Kaufmann and Ullman, 2009). Crude oil is just one of the numerous commodities, which are being speculatively traded through derivatives.

Derivatives are written for wide range of commodities; most of the derivatives are cash settled and they are being traded among financial institutions and investors rather than among industrial units and commercial businesses - the end-users. This situation is clearly indicating the domination of speculative trade over fundamental forces in price determination of such products. This argument can further be researched and verified through similar sort of causal analysis on other commodities like gold, copper, cotton, rice and other innumerable products which are vital for either domestic or industrial usage.

Price determination through speculative trading of commodities via derivatives is problematic for real economy from various angles. It puts an artificial inflationary pressures on prices, which results in hyperinflation; it also inculcates volatility in price, which increases systematic risk, Speculation driven prices have also disturbed financial planning for corporate and government sectors, and renders corporate as well as government policies ineffective.

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