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The Nexus between Green Investments and Crude Oil Prices Using Linear and Nonlinear Approaches

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ABSTRACT

We examine the relationship between green investments and crude oil prices. The results show that there is a long-run equilibrium relationship and indicate asymmetric co-integration between the variables. In addition, the result of linear Granger causality finds that green investments lead crude oil prices in one direction. However, green investments have a bi-directional relation with oil prices using the nonlinear Granger causality test. The results of this paper provide the government agencies and market participants with valuable information on decision makings.

JEL Classifications: C22, G11, G17

Keywords: crude oil prices, clean energy stock index, ARDL co-integration, linear and nonlinear granger causality

I. INTRODUCTION

In the past hundred years, the use of non-clean energy such as oil and coal has promoted positive economic growth. In the meantime, a large amount of greenhouse gases has generated, causing environmental pollution and damage. The uptrend in global warming temperature is extremely obvious. Therefore, how to slow down the phenomenon of global warming to avoid catastrophic risks such as extreme weather, food crises, species extinction, and sea level rise is a global consensus that the governments worldwide should take determinate actions to respond to this as soon as possible.

In contrast, the renewable energies, such as hydropower, solar energy, wind energy, geothermal energy, ocean energy, etc., can be restored and replenished by itself after being consumed with few pollutants produced. Almost all the countries of the world are stepping up to develop clean energy technologies to gain a balance between economic development and environmental protection. In recent years, the clean energy industry has become one of the fastest growing and noticeable industries among the energy industries. Therefore, the renewable energy has gradually played an important role in the world's energy development.

Furthermore, the 2030 Agenda for Sustainable Development (United Nations, 2015) is the main framework for achieving economic sustainable development. One of the goals (SDG 7) promotes the development of affordable clean energy. The goal is to substantially increase the share of renewable energy in the global energy mix by 2030. As meteorologists indicate, the progress of developing renewable energies has become essentially crucial in solving energy problems and climate change issues, thus encouraging the energy exhausting enterprises to make green investments to improve environmental quality. However, such a development is largely obstructed by the relatively low prices of traditional fossil energy when the tradeoff between the pollution reduction and the green investment increase is considered.

The oil price hike is likely to provide a strong incentive for those firms attempting to control pollutions while more green investments on pollution reducing equipment are driven by traditional energy cost savings. This would result in the increase of the revenue of the firms selling green energy equipment, thereby possibly pushing up clean energy stock index. Base on this reasoning, we try to investigate the nexus between green investment made by firms and oil prices, and further the link of the clean energy stock index with the oil prices using appropriate time series econometric methodologies including linear/ nonlinear ARDL and Granger causality approaches. Long run equilibrium relationships between the two variables are surveyed in the linear and nonlinear senses. Particularly, whether there an asymmetric effect exists during the rising price and the declining price periods is also examined in this study. In addition, the lead-lag relationships between the variables employing linear/ nonlinear Granger causality approaches are investigated. Hopefully, some important results concerning the nexus between green investments and crude oil prices may offer constructive implications for mutual fund managers, market investors, and government agencies.

The remaining part of the paper is organized as follows: Section II describes the literature on the relationship between green investments and oil prices. Section III presents the data and methodological approaches. Section IV reports the findings. Section V summarizes the study with policy implications derived from our findings.

II. LITERATURE REVIEW

With regard to the development of energy policies and sustainability goals, the literature on the relationship between green investments and crude oil prices has become more and more important in recent years. Some past studies (Managi and Okimoto, 2013; Bondia et al., 2016; Dutta, 2017) have shown that fossil energy and renewable energy have a relatively high degree of interdependence. Xia et al. (2019) believed that the growth and sustainability of the clean energy industry cannot be separated from the crude oil market in an increasingly interdependent market. Reboredo (2015) used Copulas to find significant time-varying average and symmetric tail dependence between crude oil returns and clean energy indices. In addition, Maghyereh et al. (2019) found a bidirectional evidence of return and risk transfer from crude oil to the renewable energy industry. These results emphasize the significance of certainty and stability in the fossil fuel market for the development of renewable energy. In other words, the price of the crude oil affects the investment and return of clean energy in the stock market, because of the substitutive relationship between oil and clean energy. When the price of crude oil rises, the incentive to invest in clean energy becomes stronger, which causes the stock price of renewable energy companies to rise.

However, some other studies (Henriques and Sadorsky, 2008; Sadorsky, 2012) showed that fossil fuel and renewable energy no more compete in the identical market. Renewable energy produces electricity, while crude oil produces transportation fuel. Ferrer et al. (2018) found that crude oil prices would not be the main driving force for the performance of the renewable energy stock in the short run or long run, implying that the renewable energy industry has decoupled from the traditional energy market. Gullaksen and Auran (2017) found that the influence of oil prices on renewable energy has been significantly reduced since 2008. Furthermore, Ahmad (2017) indicated that oil price shows limited interdependence with technology stocks and renewable energy. It is worthwhile to paying attention to a novel study of Mallett and Michelson (2010) on the field of green investments is toward the performance comparison between sustainable investments and social responsible funds.

Overall, the empirical findings indicate that researchers have no consensus on the relationship between the stock prices of clean energy and oil prices. In order to clarify the relationship between these two and further investigate whether their symmetric relations or not, we use appropriate time series econometric methodologies including linear/ nonlinear ARDL and Granger causality approaches.

III. DATA AND METHODS

A. Data

Following Alam and Masoom (2018), we consider the WilderHill Clean Energy Index (labeled ECO) as a proxy for green investment. The ECO measures the performance of the large company's stocks in global alternative energy industries. WTI crude oil prices are considered as the prices of the worldwide oil market. The data covers 1,695 daily observations running from March 11, 2014 to November 30, 2020. The notations of the two variables surveyed here are abbreviated as ECO for the WilderHill Clean Energy Index and WTI for WTI crude oil prices. Table 1 presents the descriptive statistics of the variables. We can note that the skewness for all data is skewed towards the right with positive numbers. Kurtosis shows a leptokurtic result meaning that the data has a higher peak than a normally distributed data set.

Table 1
Descriptive statistics.

Variables	Mean	Standard Deviation	Skewness	Kurtosis	Jarque-Bera Test
ECO	58.12	21.21	2.83	13.44	9956.98*** (0.00)
WTI	55.73	17.74	0.99	4.75	490.77*** (0.00)

Notes: *** indicates 1% level of significance. p-values are given in parentheses.

B. Autoregressive Distributed Lag (ARDL) Models

This paper analyzes the long-term equilibrium relationship between clean energy index (ECO) and crude oil price (WTI). The linear ARDL approach proposed by Pesaran and Pesaran (1997) can be used to solve this problem when inconsistency of integrated orders of time series data exists, that is, the variables might be I(0) or I(1). This method was further developed by Pesaran et al. (2001) and Narayan (2004) to include intercept, time trend and error correction terms. Based on our research variables, the linear ARDL model, expressed as $ARDL(p, q)$, in this study has the following form:

$$\Delta \mathrm{ECO} = c_0 + \pi_1 ECO_{t-1} + \pi_2 WTI_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta ECO_{t-i} + \sum_{j=1}^{q} \delta_j \, \Delta WTI_{t-j} + \varepsilon_t \tag{1}$$

where π_1 and π_2 are the parameters of independent and dependent variables with one-period lag, p and q are lag orders indicated by the Schwarz's Bayesian information criterion (SBC), and γ and δ are the parameters of the *i*th and the *j*th difference in independent and dependent variables, respectively. c_0 represents the constant term and ε_t is white noise. In conducting cointegration test, we adopt the critical value suggested by Pesaran et al. (2001) and Narayan (2004) to determine whether to accept the hypothesis.

C. Nonlinear Autoregressive Distributed Lag (NARDL) Models

Furthermore, in the case where variables have nonlinear relationships, particularly independent variable asymmetrically affecting dependent variable, the linear ARDL method is not appropriate. According to Shin et al. (2014), different responses of the dependent variable to the positive or negative changes in the independent variable itself are shown to measure the asymmetric dynamics. The nonlinear ARDL is as follows:

$$\triangle ECO_t = c_0 + \pi_1 ECO_{t-1} + \pi_2 WTI_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta ECO_{t-i} + \sum_{j=1}^{q} (\delta_{j1} \Delta WTI_{t-j}^{+} + \delta_{j2} \Delta WTI_{t-j}^{-}) + \varepsilon_t \tag{2}$$

where δ_{j1} and δ_{j2} are the parameters in ΔWTI_{t-j}^{+} and ΔWTI_{t-j}^{-}, respectively; $WTI^{+} =$

$\sum_{j=1}^{q} \Delta WTI_j^+ = \sum_{j=1}^{q} \max(\Delta WTI_j, 0)$ and $WTI^- = \sum_{j=1}^{q} \Delta WTI_j^- = \sum_{j=1}^{q} \min(\Delta WTI_j, 0)$.

As proposed by Pesaran et al. (2001), using the bounds test approach is also suitable by measuring the critical value and the f-statistic to confirm long-run co-integration.

D. Linear Granger Causality Test

Granger causality approach by Granger (Granger, 1969) is employed to examine the lead-lag relations between the variables. The vector autoregressive (VAR) model could be designed to execute Granger causality test. The VAR model with variables has the following form:

$$\Delta ECO_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1,i} \Delta WTI_{t-i} + \sum_{i=1}^{p} \alpha_{2,i} \Delta ECO_{t-i} + \alpha_3 ect_{t-1} + \varepsilon_t \quad (3)$$

$$\Delta WTI_t = \beta_0 + \sum_{i=1}^{p} \beta_{1,i} \Delta ECO_{t-i} + \sum_{i=1}^{p} \beta_{2,i} \Delta WTI_{t-i} + \beta_3 ect_{t-1} + v_t \quad (4)$$

where α_0 and β_0 are the constants in (3) and (4), respectively; ect_{t-1} is the error correction term; the other parameters are defined as above. The null hypothesis that ECO (WTI) does not Granger-cause WTI (ECO) is accepted when no lagged values of WTI (ECO) are retained, which means that either α_1 or β_1 is insignificantly different from zero.

E. Nonlinear Granger Causality Test

The above method is appropriate for testing linear relationships between the two variables. Nevertheless, it cannot detect Granger causality in nonlinear relationships. Diks and Panchenko (2006) proposed the nonlinear Granger causality test to overcome this problem. This novelty method is defined as follows:

$$T_n(\varepsilon_n) = \frac{n-1}{n(n-2)} \sum_i (\hat{f}_{X,Y,Z}(X_i, Z_i, Y_i) \hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,Z}(Y_i, Z_i) \quad (5)$$

Where $\hat{f}_w\ (W_i)$ is a local density estimator of a d_w – variate random vector W at W_i defined by $\hat{f}_w(Wi) = (2\varepsilon_n)-^{dw}(n-1)^{-1} \Sigma_{j\ j\neq i}\ I_{ij}^w$ that $I^w{}_{ij} = I(\| W_i - W_j \| < \varepsilon_n)$ with the indicator function $I(.)$ and the bandwidth ε_n, depending on the sample size, n.

For the bandwidth $\varepsilon_n = Cn^{-\beta}$ with $C > 0$ and $\beta \in (1/4, 1/3)$, and the test statistic $T_n(\varepsilon_n)$ satisfies

$$\sqrt{n} \frac{T_n(\varepsilon_n) - Q}{S_n} \to N(0,1) \quad (6)$$

where ε_n is an appropriate bandwidth sequence associated with the sample size n, and S_n denotes the robust estimation of the asymptotic variance of $T_n(\cdot)$.

IV. EMPIRICAL RESULT AND ANALYSIS

A. Unit Root Test Results

To check whether the variables are stationary, we use the PP test and ADF test. In Table 2, the results of unit root test show that the series of petroleum prices (WTI) and clean energy stock index (ECO) exhibit I(1).

Table 2
Results of unit root tests.

Variables	ADF Tests		PP Tests	
	level	1st difference	level	1st difference
ECO	4.5407	-12.826***	5.0624	-42.187***
WTI	-2.4792	-37.425***	-2.6211	-59.399***

Note: *** indicates statistically significant at 1% level.

B. Results of the ARDL Test

We apply linear ARDL to investigate the influence of the oil prices on the clean energy stock index. Schwarz's Bayesian information (SBC) criterion is used and the optimal lag order is set to 3. Table 3 indicates that the clean energy stock index (ECO) is positively impacted by oil price (WTI), but it is negatively influenced by one-period and two-period lags for oil price.

Moreover, Table 3 indicates that the clean energy stock index (ECO) is significantly positively related to the long-run oil price (LWTI). The long-run coefficient is 0.61, which implies that 1% increase (decrease) in the LWTI causes to 0.61% rise (decline) in the clean energy stock index.

Table 3
Results of linear autoregressive distributed lag (ARDL).

Variables	WTI→ECO Coefficient	t-Statistic
Constant	-0.140085	-1.031
ECO_{t-1}	0.968***	39.702
ECO_{t-2}	0.151***	4.422
ECO_{t-3}	-0.110***	-4.493
WTI	0.104***	6.764
WTI_{t-1}	-0.0441**	-2.400
WTI_{t-2}	-0.066***	-4.250
L_{WTI}	0.608***	2.605
ECM(-1)	0.0086***	6.154
B.T.	12.607***	
Adj R^2	0.996	

Notes:
1.The upper-bound critical values are 4.16, and 5.58 for 5%, and 1%.
2.*** and ** indicate statistically significant at 1% and 5% levels, respectively.

C. Linear Granger Causality Test Results

To investigate the short-run linear relationship between the clean energy stock index and the oil price, we employ the linear Granger causality approach. The results of the linear Granger causality test are shown in Table 4, which indicates that the clean energy stock index Granger causes the oil price at 1% significance level since the null hypothesis is rejected, with the F value being 9.95 (p-value = 0.0000), but not for the oil prices. Therefore, the clean energy stock index can be applied to forecast the oil price in a one-way direction under the linear VAR framework.

Table 4
Results of the linear Granger causality between ECO and WTI .

Causality Direction	*F*-Statistic	Optimal Lag
WTI→ECO	1.3197	3
ECO→WTI	9.9476***	3

Notes: *** indicates statistical significance at 1% level.

D. Brock–Dechert–Scheinkma (BDS) Test Results

We adopt the BDS test (Brock, Dechert and Scheinkman, 1996) to detect if the VAR residuals exhibit nonlinearity. As shown in Table 5, which indicates the presence of nonlinear dependence in the residuals under different dimensions.

Table 5
Results of BDS statistics from VAR residuals.

Dimension	BDS Statistic	
	ECO	WTI
2	0.0401*** (0.00)	0.0096*** (0.00)
3	0.0801*** (0.00)	0.0180*** (0.00)
4	0.1110*** (0.00)	0.0235*** (0.00)
5	0.1307*** (0.00)	0.0268*** (0.00)
6	0.1386*** (0.00)	0.0298*** (0.00)

Notes:
1.The values in the parenthesis are p-values.
2. *** indicates statistical significance at 1% level.

E. Nonlinear Autoregressive Distributed Lag (NARDL) Test Results

We further examine the asymmetric effects of oil price on the clean energy stock index. Table 6 indicates that the clean energy stock index is nonlinearly cointegrated with oil price since the F value (12.58) is significant at 1% level.

With the estimated long-run coefficients of 0.63 and 0.66, there are significantly long-run positive relationships between the clean energy stock index and a rise in oil price, WTI+ and between the clean energy stock index and a decline in oil price, WTI－, respectively. We find that 1% rise in the oil price results in a 0.63% increase in the clean energy stock index, and 1% decline in the oil price causes the clean energy stock index to decrease by 0.66%. The nonlinearity between the change in oil prices and the change in the clean energy stock index almost holds.

Table 6
Nonlinear autoregressive distributed lag (NARDL) test results.

Variables	WTI→ECO Coefficient	t-Statistic
Constant	-0.5869***	-4.342
ECO_{t-1}	0.9800***	40.622
ECO_{t-2}	0.1372***	4.051
ECO_{t-3}	-0.1099***	-4.487
WTI^{+}	-0.0046**	-2.034
WTI^{-}	0.1365***	6.800
WTI^{-}_{t-1}	-0.1413***	-6.960
L^{+}_{WTI}	0.6319**	2.124
L^{-}_{WTI}	0.6633**	2.270
B.T.	12.5782***	
ECM(-1)	0.0071***	6.791
$AdjR^2$	0.9961	

Notes:
1. The superscripts "+" and "–" represent the positive and negative changes, respectively.
2. L＋WTI and L－WTI are the long-run coefficients related with positive and negative changes in the clean energy stock index.
3.*** and ** indicate statistically significant at 1% and 5% levels, respectively.

F. Nonlinear Granger Causality Test Results

In order to test the nonlinear causality between the variables, the DP test developed by Diks and Panchenko (2006) is employed to implement this task. By the DP test, maximum lag (l) and bandwidth parameter (ε_n) should be set to lx = ly = 1, 2, 3, choosing the optimal bandwidth, ε_n=1.3 for the number of sample size, n = 1,694. Table 7 shows that there are bidirectional causalities between the variables in dimensions lx = ly = 1, 2, and 3. Obviously, the empirical results of nonlinear Granger causality test indicate that the clean energy stock index and the oil price have asymmetrically bidirectional causalities at usual significance levels.

Table 7
Results of nonlinear Granger causality between ECO and WTI.

$l_x = l_y$	H_0：ECO does not cause WTI t-Statistic	H_0：WTI does not cause ECO t-Statistic
1	2.193***	1.679**
2	2.443***	1.972**
3	2.208**	1.673**

Notes: ** and *** represent significance at 5% and 1% levels, respectively.

V. CONCLUSION

This research examines the relationship between green investments and crude oil prices. We adopt linear/ nonlinear ARDL approach and linear/ nonlinear Granger causality approach. The findings indicate that there is a long-run equilibrium relationship using the linear/ nonlinear ARDL test. Furthermore, the NARDL test can find that the declining oil price had a greater positive effect on the green investment than the rising oil price, thus showing asymmetric co-integration between them. The results of linear Granger causality test indicate that green investments lead crude oil prices in one direction. Nevertheless, the results of the nonlinear Granger causality test show that green investments have a bidirectional nonlinear causality with crude oil prices. To compare the findings of literature with those of this paper, our results are similar to Managi and Okimoto (2013), Bondia et al.(2016), Dutta (2017), and Xia et al. (2019), but are quite different from Henriques and Sadorsky (2008), Sadorsky (2012), Gullaksen and Auran (2017), and Ferrer et al. (2018).

In general, oil prices are closely related to the renewable energy stock index. When oil prices rise, the demand for alternative energy sources increases, thereby driving the rise of the renewable energy stock index. Under the trend of sustainable development, the use of petroleum fuels will inevitably be reduced in the future based on the requirement of gradual decrease in the emission of carbons. Coupled with advances in alternative energy technologies, the relationship between the green investments and crude oil prices is worthy of more considerable attention. Finally, we suggest that fund managers should invest more (less) money in the clean energy component stocks when the crude oil prices rise (decline). Individual investors do it like this. Most importantly, the government agencies should set the relevant laws to provide positive incentives for the firms with high pollution to make more green investments in protecting our living environments.

REFERENCES

Ahmad, W. (2017). On the dynamic dependence and investment performance of crude oil and clean energy stocks. *Research in International Business and Finance*, *42*, 376-389.

Alam, L., & Masoom, M. R. (2018). 'Green Investing'as an Approach to Make 'Green Bangladesh': the Role of Stock Exchanges. *American Journal of Trade and Policy,* 5(3), 121-130.

Bondia, R., Ghosh, S., & Kanjilal, K. (2016). International crude oil prices and the stock prices of clean energy and technology companies: Evidence from non-linear cointegration tests with unknown structural breaks. *Energy*, *101*, 558-565.

Broock, W. A., Scheinkman, J. A., Dechert, W. D., & LeBaron, B. (1996). A test for independence based on the correlation dimension. *Econometric reviews*, *15*(3), 197-235.

Diks, C., & Panchenko, V. (2006). A new statistic and practical guidelines for nonparametric Granger causality testing. *Journal of Economic Dynamics and Control*, 30(9-10), 1647-1669.

Dutta, A. (2017). Oil price uncertainty and clean energy stock returns: New evidence from crude oil volatility index. *Journal of Cleaner Production*, *164*, 1157-1166.

Ferrer, R., Shahzad, S. J. H., López, R., & Jareño, F. (2018). Time and frequency dynamics of connectedness between renewable energy stocks and crude oil prices. *Energy Economics*, 76, 1-20.

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: journal of the Econometric Society*, 424-438.

Gullaksen, J. F., & Auran, I. K. (2017).Time-varying Risk Factor Models for Renewable Stocks (Master's thesis, NTNU).

Henriques, I., & Sadorsky, P. (2008). Oil prices and the stock prices of alternative energy companies. *Energy Economics*, *30*(3), 998-1010.

Maghyereh, A. I., Awartani, B., & Abdoh, H. (2019). The co-movement between oil and clean energy stocks: A wavelet-based analysis of horizon associations. *Energy*, 169, 895-913.

Managi, S., & Okimoto, T. (2013). Does the price of oil interact with clean energy prices in the stock market ? *Japan and the world economy*, *27*, 1-9.

Mallett, J. E., & Michelson, S. (2010). Green investing: is it different from socially responsible investing?. International Journal of Business, 15(4), 395.

Narayan, P. (2004). Reformulating critical values for the bounds F-statistics approach to cointegration: an application to the tourism demand model for Fiji (Vol. 2, No. 04). Australia: Monash University.

Narayan, S., & Narayan, P. K. (2005). An empirical analysis of Fiji's import demand function. *Journal of Economic Studies.*

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*,16(3), 289-326.

Pesaran, M.H.; Pesaran, B. Working with Microfit 4.0: Interactive Econometric Analysis; Oxford University Press: Oxford, UK, 1997.

Reboredo, J. C. (2015). Is there dependence and systemic risk between oil and renewable energy stock prices ? *Energy Economics*, 48, 32-45.

Sadorsky, P. (2012). Correlations and volatility spillovers between oil prices and the stock prices of clean energy and technology companies. *Energy economics*, *34*(1), 248-255.

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In Festschrift in honor of Peter Schmidt (pp. 281-314). Springer, New York, NY.

Xia, T., Ji, Q., Zhang, D., & Han, J. (2019). Asymmetric and extreme influence of energy price changes on renewable energy stock performance. *Journal of Cleaner Production*, 241, 118338.