

Professor Veli YILANCI, PhD

E-mail: veliyilanci@gmail.com

Faculty of Political Sciences, Department of Economics

Canakkale Onsekiz Mart University, Canakkale, Turkey

Assistant Professor Onder OZGUR, PhD (Corresponding Author)

E-mail: oozgur@ybu.edu.tr

Department of Economics, Ankara Yildirim Beyazit University

Ankara, Turkey

Assistant Professor Abdulkadir ALTINSOY, PhD

E-mail: aaltinsoy@sakarya.edu.tr

Department of Labour Economics and Industrial Relations

Sakarya University, Sakarya, Turkey

THE DEPENDENCE OF CLEAN ENERGY STOCK PRICES ON THE OIL AND CARBON PRICES: A NONLINEAR PERSPECTIVE

Abstract. *Climate change, rising environmental concerns increased scholar's awareness of the complex ties between clean energy stock prices and various environmental indicators. A clearer understanding of the potential ties between indicators and clean energy stock prices is critical for determining the financial performance of clean energy companies. This study adds to the literature by testing the existence of the long-run relationship between clean energy stock prices, and oil prices, carbon prices, technology stock prices, and interest rates by considering nonlinearity in the context of a structural change. The results show the existence of the cointegration relationship. The results of long-run estimation show that before the structural break date, technology stock prices, oil prices, and interest rates positively affect clean energy stock prices, and after this date, the effects of carbon prices and interest rates are reversed. Our results present some implications for both investors and policymakers.*

Keywords: *Clean Energy Stock Prices; Nonlinearity; Structural Change; Carbon Prices; Oil Prices.*

JEL Classification: C32, C58, Q42, Q43

1. Introduction

The rapid industrialization to boost economic growth has increased the energy demand for several decades. Fossil fuels around the world still meet a great deal of global energy needs (Kocaarslan and Soytaş, 2019). Fossil fuels clarify

about 80 % of the world energy usage in the last decade (WDI, 2018). The extensive use of fossil fuels has increased environmental damage, accelerated concerns about climate change and global warming, and caused a threat to the globe (Hansen and Skinner, 2005). The primary reason for the steady rise in global warming is the release of greenhouse gas emissions into atmosphere. CO₂ concentration has remained calm for thousands of years but increased tremendously after industrialization (Henriques and Sadorsky, 2008). According to the British Petroleum Statistical Review (2019), global CO₂ emissions have gradually increased year to year, and the total release of CO₂ emissions is tripled between 1965 and 2018.

Clean energy sources seem to a feasible way to battle against greenhouse gas emissions. Clean energy sources can be described as the carbohydrate-free energy that do not emit carbon dioxide (Lee, 2013), and they are key drivers of a low carbon future (Kocaarslan and Soytaş, 2019). In this context, renewable energy investments have become more popular recently, despite the associated profitability and financial risks (Reboredo and Ugolini, 2018). The International Energy Agency (2019) declares that in 2018, total global renewable energy investment adjusted for the costs increased by 55 % since 2010. Thus, it is critical for investors and decision-makers to understand the volatility in clean energy stocks and analyze the possible links and dynamic relations of clean energy stock prices (CESP from here) with fossil fuel prices and other financial market indices such as technology stock prices (TSP from here), and carbon prices (Sadorsky, 2012a; Dutta et al, 2018).

One of the factors that encourage renewable energy investments is oil prices (Kumar et al, 2012). Economic agents are urged to find possible alternative energy sources, and the cost of the alternative energy stocks rise when oil prices increase (Managi and Okimoto, 2013). Better analysis of the possible links between oil prices and alternative energy stock prices is crucial to evaluate the financial performance of the alternative energy companies (Henriques and Sadorsky, 2008). Also, the impact of fossil fuel prices on the clean energy sector is critical for policymakers to canalize public expenditures into alternative energy investments and lower fossil fuel dependency (Reboredo, 2015).

Kocaarslan and Soytaş (2019) propose two mechanisms in which oil prices could affect the CESP. First, they argue that higher oil prices lead to higher stock prices for renewables because of the substitution motive and short-run speculative trading. As the cost of production of fossil fuels rises, fossil fuels are replaced by renewable energy sources. (Sadorsky, 2012b). Second, oil price hikes, coupled with the economic downturn, might result in worsening expectations for the profitability of the clean energy projects in the long run. Therefore, the influence of the oil prices might be dissimilar in the short and long-run. There is also an indirect mechanism in which oil prices might exert its effect on the CESP. This mechanism argues that rising oil prices lead to an increase in overall inflation, which in turn

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central banks respond by raising policy rates. As a result, the contractionary monetary policy may lead to falling stock prices (Broadstock et al. 2012).

Another possible link exists between the TSP and the CESP. It is claimed that the performance of alternative energy companies is correlated with the introduction of new technologies (Sadorsky, 2012a). Investors also might see the performance of the technology stocks similar to those of the CESP (Kumar et al. 2012). To put it another way, the market-based incentives to invest in clean energy stocks and technology stocks might have similar patterns. The carbon permitting prices may also be a significant determinant of the CESP. The primary motivation to produce clean energy sources is to reduce carbon emissions. One can argue that higher carbon permitting prices might foster a clean energy generation (Dutta et al, 2018). Therefore, we can expect that the carbon permitting prices and the CESP are positively associated since the release of additional emissions increase the cost of using fossil fuels (Kumar et al. 2012).

Climate change, increasing environmental concerns, and increases in oil prices and related risks increase understanding of clean energy sources among scholars (Kocaarslan and Soytas, 2019). A number of studies aimed at analyzing the factors influencing the financial performance of the clean energy stocks, focusing primarily on the conventional energy prices (i.e., oil prices), market forces (i.e., interest rates, TSP) and regulatory measures (carbon permitting prices). However, the number of studies is still scarce and there is a potential room for contribution. This study, therefore, aims to enlarge the literature. This study's main aim is to analyze the cointegration relationship in a five-variable system by using data in daily frequency from January 2, 2008, to September 20, 2019 by using a nonlinear cointegration test that allows for an endogenous structural change proposed by Schweikertert (2019). The study further analyzes the causality relationship for each pair by using the Hacker-Hatemi causality test.

This study considers nonlinearity and uses the threshold cointegration test because stock prices, oil prices, and interest rates are very sensitive to business cycles. Also, since oil prices are about to have structural changes in this period it is realistic to consider the possible structural break in an analysis (Managi and Okimoto, 2013). Thus, we aim to contribute to the literature in a number of ways: Although there have been some studies to analyze the impact of related variables on CESP, there has not been any study to consider both a structural break and nonlinearity in the cointegration relationship. This study uses a cointegration model with SETAR adjustment which, in effect, allows the detection of potential evidence for asymmetric adjustment among the variables and controls for the endogenous structural break. This is therefore the first research to consider both structural changes and nonlinearity in the analysis of the factors affecting the CESP. Besides, this study contributes to the literature by analyzing the effect of prices of CO₂ emissions, oil prices, interest rates, and the TSP on two different measures of the CESP.

We can outline the rest of the paper as follows: Section 2 briefs the related literature. Following part describes the dataset and methodology. The fourth part includes the empirical results. Finally, the last part concludes the study.

2. Literature Review

There are a small number of studies aimed at investigating factors that affect CESP, albeit with mixed results. The literature on this issue is evolved, coupled with the introduction of the new econometric techniques. Earlier studies that analyze the link between the CESP and various indicators generally employed the vector autoregressive (VAR) models. Henriques and Sadorsky (2008) is the first study to assess the relationship between crude oil prices and returns from the renewable energy stock market. The study determined that oil prices affect equity returns. Likewise, their study provided evidence for the casual connection between oil prices and the renewable energy price stocks in the United States. Employing a VAR model, Kumar et al. (2012) showed that higher oil prices have a positive impact on clean energy investments. Therefore, their findings suggest that higher oil prices increase awareness of the use of renewable sources and economic agents are turning to investments in renewable energy. A further finding of their study is that interest rates and the TSP have a substantial impact on clean energy stock prices. However, carbon prices do not have any significant impact on the CESP. Managi and Okimoto (2013) developed a four variable Markov-switching VAR model to study the nexus among such macroeconomic indicators and the CESP. They concluded that oil prices have risen dramatically due to policy actions taken to reduce the impacts of the recent global financial crisis, which in turn has increased the attractiveness of clean energy investments.

Some of the previous studies looked at CESP's relationship with oil prices and focused on the impact of volatility spillovers. Sadorsky (2012b) pointed to the risk factors of renewable energy companies and their investments. He argued that rising oil prices are helping to reduce the risks faced by renewable energy companies, which in turn, are promoting demand for stocks of clean energy. Wen et al. (2014) observed that market prices of renewable energy and fossil fuel stock prices produce simultaneous volatility. They also reported that, compared with fossil fuel equities, renewable energy stocks bear more risks. Dutta (2017) used multiple volatility metrics and evaluated the relation between the difference in returns from alternative energy stocks. They found that the most important element in understanding the instability in renewable energy stock returns was the volatility of oil markets and rising uncertainty.

Previous studies have dedicated less attention to examining the CESP's asymmetric connections with different financial influences. Bondia et al. (2016) perused the long-term association between oil price returns and renewable energy market indices by using a nonlinear cointegration test. They discovered that the term relationship of global oil markets and renewable energy market indexes are

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subject to two endogenous structural breaks. Reboredo et al. (2017) explored the common trend and causal correlation between renewable energy stock prices and oil prices. They found that nonlinear causality runs from renewable energy indicators to oil prices at different domains. More recently, Kocaarslan and Soytaş (2019) have used the non-linear ARDL model and have shown that the CESP is influenced by increased spending, speculation attacks and increasing oil prices in the short term. They also argued that oil stock prices are more prone to long-term fluctuations.

There are also some studies considering the link between gold prices and clean energy share prices. Baur and Lucey (2010) investigated whether gold acts as a safe shelter by examining the relationship between gold prices in the United State of America, United Kingdom and Germany. The findings confirmed that gold acts as a safe fund during inconsistent periods. Elie et al. (2019) examined the relationship between crude oil and gold, clean energy stock indices in their research by using the nonparametric tail dependency tests and stated that gold is a more reliable fund than crude oil in case of excessive market movements.

The literature shows that there is a small number of studies evaluating the impact of various global macroeconomic factors on clean energy stock prices. However the macroeconomic variables and financial indicators are primarily prone to nonlinearity, and the literature seems to deserve further research.

3. Data and Methodology

In this study, we employ daily data from January 2, 2008, to September 20, 2019, and excluded the observations that are missing because of holidays, etc. from all series mutually. The study employs WilderHill Clean Energy Index (ECO) and the S&P Global Clean Energy Index (SPGTCED) for the CESP. While the ECO is a modified equal-dollar index that includes US companies who engaged in the business of advancement and conservation of cleaner energy, the SPGTCED is composed of 30 largest and most liquid listed companies worldwide operating in clean energy-related businesses. We also take the daily spot prices of the European Emission Allowances (EUA) into account to assess whether carbon prices have stimulated investments in renewable energy firms. The carbon emission market is now in Phase III, and the sample period of this study covers Phase II, and about six and half years from Phase III.

Since rising oil prices are expected to create incentives to substitute conventional energy sources with clean energy sources (Dutta 2017; Kocaarslan and Soytaş, 2019), this study uses the average of the historical spot prices of West Texas Intermediate and Brent crude oil prices (see Managi and Okimoto, 2013) as denoted by OIL to better understand the potential ties between oil prices and the CESP. Since we expect that the interest rates, commonly used monetary policy indicator, would be significant on the stock markets which is also the case in the

previous literature, we take a 3-month US Treasury bill (IR) as a proxy for the measure of interest rates. Finally, we also want to examine the link between the TSP and the CESP, since the level of high technology is a precondition for successful clean energy projects, and clean energy stocks and technology firms are very close to investors (Kumar et al, 2012). So, we employ the ARCA Tech 100 index (PSE)¹ as a proxy for technology stock prices.

We collect ECO, EUA, PSE, and SPGTCED data from the Bloomberg Data Service, and IR and OIL data from FRED. Figure 1 presents time series graphs for our series. From the figure, it can be seen that except the EUA, and the IR, all series fluctuate around its mean over time. The reason for the upward shift of the EUA in January 2009 seems to represent the change in the phase of the carbon emission market.

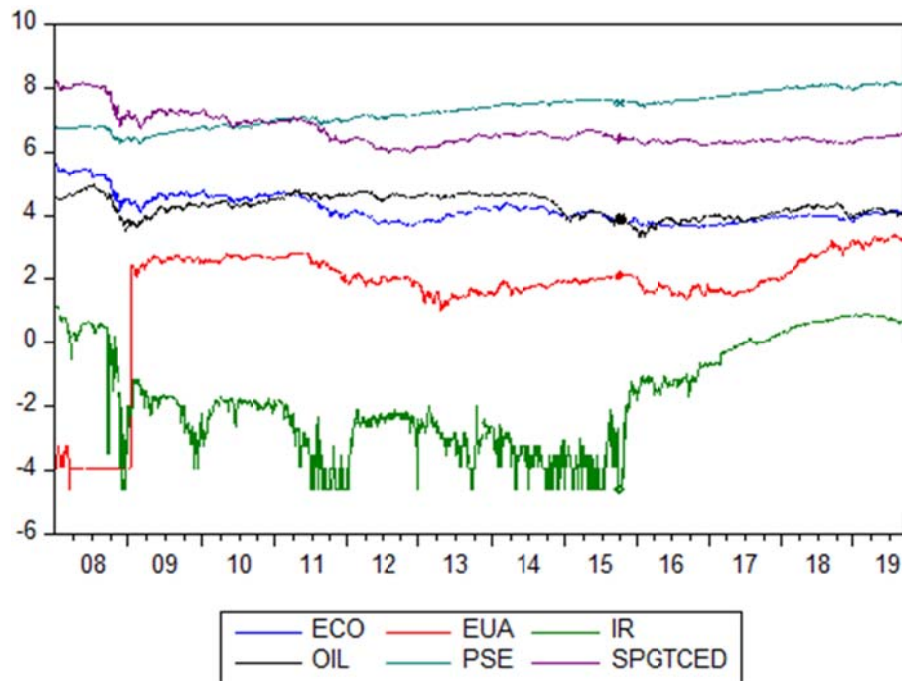


Figure 1. Time Paths of the Variables

¹ The PSE includes companies that employs innovative technologies to conduct their business.

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Table 1 presents the descriptive statistics for the variables:

Table 1. Descriptive statistics

Series	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
ECO	4.189	4.074	5.661	3.598	0.436	1.139	3.941	731.722*
EUA	1.650	2.003	3.393	-4.605	1.798	-2.471	7.992	5946.074*
IR	-1.697	-1.897	1.160	-4.605	1.638	0.134	1.886	158.064*
OIL	4.289	4.312	4.974	3.271	0.343	-0.321	2.077	152.186*
PSE	7.332	7.385	8.169	6.248	0.490	-0.088	1.961	133.856*
SPGTCED	6.661	6.467	8.257	5.973	0.491	1.456	4.678	1361.517*

Note: * shows the significance at the 1% level.

Table 1 shows PSE has a higher mean than both the ECO and the SPGTCED, while ECO has the minimum standard deviation that shows most of the observations close to the average, compared to the PSE and the SPGTCED. On the other hand, the JB test statistics demonstrate that all series are non-normally distributed.

While testing the stationarity of the series, or examining the long run relationship between the series, ignoring either structural changes or nonlinearity in the data generation process, can cause inaccurate results. Therefore, the relatively new path of time series analysis developed by considering structural changes and non-linearity. For instance; in unit root testing literature, Perron (1989), Perron (1997), and Lee and Strazicich (2012) allow structural changes, among others, while Caner and Hansen (2001), and Kruse (2011) take nonlinearity into consideration. On the other hand, the literature on cointegration tests also takes account of structural changes (Johansen, 2000, and Carrion-i-Silvestre and Sansó, 2006), and non-linearity (Kapetionios et al. 2006, and Enders and Siklos, 2001) The main problem encountered in these studies is that they consider only nonlinearity or structural changes. Fortunately, Schweikert (2019) has introduced the literature a new nonlinear cointegration test, that considers a structural break in the cointegration relationship.

By following Gregory and Hansen (1996) model description, the testing equation of Schwikert (2019) cointegration test can be showed as follows:

$$\begin{aligned}
 CE_t = & \beta_1 + \beta_2 D_{t,\tau} + \alpha_1 PSE_t + \alpha_2 OIL_t + \alpha_3 EUA_t + \alpha_4 IR_t + \alpha_5 PSE_t D_{t,\tau} \\
 & + \alpha_6 OIL_t D_{t,\tau} + \alpha_7 EUA_t D_{t,\tau} + \alpha_8 IR_t D_{t,\tau} + u_{t\tau}
 \end{aligned} \tag{1}$$

Where CE shows the CESP, while PSE, OIL, EUA , and IR defined as the previous section. Both dependent and independent variables are supposed to be differenced-stationary (I(1)) variables. To consider a structural shift in the cointegration relation, one can define the dummy variable, $D_{t,\tau}$, as follows:

$$D_{t,\tau} = \begin{cases} 1 & \text{if } t \geq [T\tau] \\ 0 & \text{if } t < [T\tau] \end{cases}$$

where t , and T denote the time and number of observations, respectively. $\tau \in (0,1)$ shows the relative timing of the change. So, in Eq. 1, β_1 , and β_2 represent the constant term before the breakpoint date and the change in the constant at the time of the change date, respectively. On the other hand, $\alpha_1, \alpha_2, \alpha_3$, and α_4 show the slope coefficients before the time of the break, while $\alpha_1 + \alpha_5, \alpha_2 + \alpha_6, \alpha_3 + \alpha_7$, and $\alpha_4 + \alpha_8$ are the slope coefficients after the shift date. Schweikert (2019) propose to estimate Eq. 1 for each breakpoint after trimming 0.15 from the beginning and end of the sample², and estimate two-regime momentum threshold autoregressive (MTAR) model to account for asymmetric adjustment as follows:

$$\Delta u_{t,\tau} = \rho_1 u_{t-1,\tau} I(\Delta u_{t-1,\tau} \geq \lambda^*) + \rho_2 u_{t-1,\tau} I(\Delta u_{t-1,\tau} < \lambda^*) + \sum_{j=1}^K \gamma_j \Delta u_{t-j,\tau} + \varepsilon_{t,\tau,K}. \quad (2)$$

Where $I(\cdot)$ shows the Heaviside indicator function, and λ represents a threshold value. MTAR model captures the likelihood of asymmetrically steep residual movements, which is the case when the declines are fast while the increases are slow. After estimating the MTAR model, one can compute the test statistic for the null of no cointegration $\rho_1 = \rho_2 = 0$ for each sequence of residuals as:

$$F_\tau = \frac{t_1^2 + t_2^2}{2}$$

² That is, trimming regions is; $T = (0.15, 0.85)$, this selection will eliminate the potential power reduction problem of the test (see Andrews (1993), and Caner and Hansen, 2001)).

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Where t_1 , and t_2 are the t ratios for ρ_1 and ρ_2 from regression two. Following supremum statistic can be used for checking the null of no cointegration against the alternative of threshold cointegration with a structural break:

$$F^* = \sup_{\tau \in T} F_\tau$$

The necessary critical values are tabulated in Schweikert (2019).

4. Empirical Results

Before proceeding into cointegration analysis we first need to determine the integration levels of the series. Hence, we employ Augmented Dickey-Fuller (ADF), Dickey-GLS (DF-GLS) unit root tests, and Kwiatkowski et al. (KPSS) stationarity test, and present the results in Table 2.

Table 2. Results of unit root tests

	ADF		DF-GLS		KPSS	
	Constant	Constant & Trend	Constant	Constant & Trend	Constant	Constant & Trend
ECO	-3.049 (0.031)**	-2.312 (0.427)	0.264	-0.511	4.158*	0.749*
D(ECO)	-11.696 (0.000)*	-11.875 (0.000)*	- 5.874*	-8.255*	0.465* *	0.057
EUA	-3.090 (0.028)**	-2.917 (0.157)	0.126	-1.160	1.542*	0.531*
D(EUA)	-11.538 (0.000)*	-11.589 (0.000)*	- 11.488 *	-11.447*	0.179	0.086
IR	-1.758 (0.402)	-2.517 (0.320)	-0.837	-0.869	2.101*	1.342*
D(IR)	-12.238 (0.000)*	-12.338 (0.000)*	- 11.820 *	-12.300*	0.360* **	0.053
OIL	-2.112 (0.240)	-2.377 (0.392)	-1.444	-2.382	2.150*	0.540*
D(OIL)	-9.438 (0.000)*	-9.436 (0.000)*	- 5.725*	-8.235*	0.069	0.069
PSE	-0.127 (0.945)	-3.437 (0.047)**	1.501	-1.571	6.571*	0.158**
D(PSE)	-10.488 (0.000)*	-10.503 (0.000)*	- 9.208*	-10.256*	0.117	0.065
SPGTCED	-2.748 (0.066)***	-2.163 (0.510)	0.222	-0.660	3.888*	1.066*
D(SPGTCED)	-9.348 (0.000)*	-9.509 (0.000)*	- 8.673*	-8.943*	0.555* *	0.057

Note: D shows the differenced data. The numbers in the parenthesis show the p-values. *, **, and *** indicate the significance at the 1%, 5%, and 10% levels.

Although the findings of the unit root tests seem contradictory, since both the DF-GLS unit root test and the KPSS stationary test yield similar results, we can conclude that all variables stationary at the first differences. Since the root test of the ADF unit has low strength, the test usually generates conflicting results.

Once we determined the order of variables' integration levels, we can conduct the cointegration analysis. To test the existence of cointegration relationship between the variables, we estimate the regime switch model (Model C/S) as is the case in Schweikert (2019). Table 3 illustrates the cointegration test results³.

Table 3. Threshold Cointegration Results

Dependent Variable	F^*	k	Date of Break	ρ_1	ρ_2	$\rho_1 = \rho_2 = 0$
ECO	33.307 *	1	4.8.2011	-0.059	-0.020	11.043*
SPGCTED	35.903*	1	24.10.2011	-0.065	-0.027	13.719*

Note: Critical values for F^* at the 1, 5, and 10% levels are 21.10, 23.22, and 27.89, respectively. * denotes significance at the %1 level.

Table 3 shows that for both measures of the CESP, the null hypothesis of no cointegration can be rejected. Thus, it can be concluded that there is a cointegration nexus between clean energy stock price indexes and the PSE, OIL, EUA, IR. The existing cointegration relationship clearly shows us that the CESP move together with those of oil prices, carbon emission prices, interest rates and technology stock prices. In this sense, one might also conclude that shocks to these variables might have an impact on the long-term values of the other variables.

Test results also provide the date for the regime change⁴. We see that the structural break exists in 2011 in both models, and these break dates coincide with the tremendous rise in oil prices in the year 2011. The yearly average of the Brent oil price reached up to 111 US dollars in 2011 due to the Arab Spring and rose in the demand of emerging economies (EIA, 2012). Therefore, it is clear that the rise in oil prices seem to provide a structural shift in the existing cointegration relationship among these variables. We can explain the role of oil price changes on stock market prices in the following way. Since oil prices are an important component of business cycles, and stock market prices are responsive to business cycles (Kumar et al. 2012), the extraordinary increase in oil prices in 2011 might affect the cointegration relationship between employed variables. Overall, these

³ We apply the cointegration test by also excluding the IR variables, the results show that we cannot reject the null hypothesis of no-cointegration.

⁴ To detect the cause of the break, we test the stationarity of all variables using Zivot and Andrews (1992) unit root test with an endogenous structural break, results show that there is a break occur in July 2011, in both ECO and SPGCTED variables. The findings are same as the results in traditional unit root tests and available from authors upon request.

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results demonstrate the importance of considering regime changes in the cointegration relationship among the CESP, oil prices, technology stock prices, carbon permitting prices and interest rates. In other words, it is clear that one might get misleading conclusions if do not take the probability of structural changes in a relationship among stock prices and such global macroeconomic indicators. Policy changes in any of these regimes might create different impacts since there is a regime change in the long-term cointegration relationship among the set of selected variables.

Given the long-run relationship between variables, it is also essential to demonstrate whether these global macroeconomic indicators have a significant impact on the CESP. As such, the next step is to estimate long-term coefficients and the study provided the impact of these variables on the CESP under two regimes. The long-term model coefficients appear in Table 4.

Table 4. Long-Run Estimation Results

Dependent Variable	β_1	D_t	PSE_t	OIL_t	EUA_t	IR_t	$D_t * PSE_t$	$D_t * OIL_t$	$D_t * EUA_t$	$D_t * IR_t$
ECO	2.303 (11.439) *	-3.811 (- 16.358)*	0.124 (2.533)**	0.413 (12.525) *	-0.039 (- 18.745)*	0.119 (25.716) *	0.3594 (7.117)*	-0.069 (- 2.021)**	0.124 (19.782) *	-0.208 (- 40.625)*
SPGTCED	9.630 (43.117) *	-7.916 (- 30.122)*	-0.759 (- 14.210)*	0.694 (19.607) *	-0.037 (- 16.226)*	0.158 (36.121) *	1.322 (23.732) *	-0.645 (- 17.549)*	0.046 (6.103)*	-0.252 (- 49.88)*

Note: Numbers in the parentheses show t-statistics. *, and ** denote significance at the %1 and %5 levels.

Table 4 shows that the TSP, oil prices, carbon permitting prices, and interest rates significantly affect the CESP, so that play an active role in determining the trend of the CESP both before and after the structural break. On the one hand, TSP, oil prices, and interest rates positively affect ECO, while the impact of the carbon prices is negative on ECO before the break. However, the effect of the technology stock prices turns to be negative on the CESP when we use SPGTCED as a measure of the clean energy stock price index. Since SPGTCED is a global index while the ECO includes companies solely from the US, one can infer that for investors in the US, clean energy stocks are similar to technology stocks up to October 2011. The positive impact of the stock prices of technology firms are in line with the expectation that investors have in common with clean energy stocks and technology stocks (Kumar et al, 2012).

Our findings demonstrate that when oil prices increase, alternative energy prices become relatively inexpensive, investors invest more in clean energy projects (Managi and Okimoto, 2013). As is the case in other studies, the rise in oil prices increases the attractiveness of clean energy investments and result with the rise in clean energy stocks. Besides, the significantly negative impact of the carbon permitting prices is not consistent with prior expectations. It might be argued that the EUA is not a significant incentive mechanism for investors to reduce their

release of carbon emissions and invest in cleaner technologies. Since in the rising period of the business cycles monetary authorities increase interest rates to provide price stability and mitigates the upward pressures on price level, the significantly positive coefficient of interest rates seems to be related to a business cycle implication that interest rates are higher in economic upturns (Henriques and Sadorsky, 2008). Therefore, the positive effect of interest rates on the CESP coincides with the business cycle expansions.

On the other hand, the impact of these global indicators is identical on both measures of the CESP in the second regime. However, after the break, our results change considerably. First, the impact of oil prices on the CESP seems to be negative. Thus, as noted, one can infer that the rise in oil prices, coupled with the economic downturn worsens the financial performance of clean energy companies in the long run (Kocaarslan and Soytas, 2019). Second, after the break, our results are consistent with the proposition of finance theory since the sign of the carbon permitting price variable is significantly negative. This theory proposes that regarding the inverse relationship between carbon permitting prices and stock returns the market punishes the companies (Tian et al. 2016). Companies that have any harm on an environment needs to pay much, therefore it directs the market participants to invest in clean energy technologies and investments.

Finally, the expansionary impact of the interest rates seems to outweigh in the second regime. The significantly negative coefficient of the interest rates on the CESP argues that the rise in interest rates either through market activities or the introduction of contractionary monetary policies have a contractionary impact on the expected future profitability of firms and the stock market activities. Therefore, it seems that the negative coefficient of interest rate variable is in line with the theoretical propositions of the monetary transmission mechanisms.

The study next explores the causality relationship among these variables. In the causality analysis, therefore, uses the Hacker-Hatemi causality test and reports the causality test results in Table 5 and Table 6.

Table 5. Results of Causality Test for ECO

Null Hypothesis	VAR Lag	dmax	Test Statistics	1% CV	5% CV	10% CV
PSE $\rightarrow$ ECO	2	1	0.812	10.014	6.21	4.766
ECO $\rightarrow$ PSE	2	1	2.263	8.531	5.611	4.451
OIL $\rightarrow$ ECO	2	1	2.142	9.208	5.975	4.513
ECO $\rightarrow$ OIL	2	1	25.198*	8.959	5.867	4.537
IR $\rightarrow$ ECO	5	1	2.913	15.013	11.121	9.317
ECO $\rightarrow$ IR	5	1	10.646***	15.324	11.2	9.219
EUA $\rightarrow$ ECO	1	1	11.486*	11.335	4.298	2.754
ECO $\rightarrow$ EUA	2	1	3.733***	8.84	4.288	2.422

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Note: dmax; show the maximum integration of the corresponding variables. We obtain critical values using 10000 simulations. *, **, and *** denote significance at the %1, %5, and %10 levels, respectively.

Table 5 tabulates the causality results for ECO to be a measure of the CESP. The results show that the null of no causality for the unidirectional causality running from ECO to OIL, and from ECO to IR can be rejected. This means that our results provide evidence to support the causal link between ECO to OIL and ECO to IR. It can therefore be inferred that oil prices and interest rates are not necessarily leading indicators for CESP, but CESP has predictive power over future oil price and interest rate values. The one likely reason may be that the prices of clean energy stocks are a good predictor of future economic activity, and the predictive ability of clean stock prices for oil prices derives from demand-driven shifts in oil prices.

Furthermore, we found evidence of two-way causality between ECO and EUA. Therefore, the two-way causality relationship between carbon permit prices and CESP demonstrates that carbon permit prices have considerable power to explain the future prices of clean energy stocks and vice versa. This ensures that the EU emissions trading market and CESP provide each other with valuable information.

Table 6 shows the results of the causality test when we use the SPGTCED, as a measure of renewable energy stock prices.

Table 6. Results of Causality Test for SPGTCED

Null Hypothesis	VAR Lag	dmax	Test Statistics	1% CV	5% CV	10% CV
PSE $\rightarrow$ SPGTCED	2	1	34.117*	9.373	6.206	4.83
SPGTCED $\rightarrow$ PSE	2	1	6.475**	8.741	5.979	4.613
OIL $\rightarrow$ SPGTCED	2	1	3.239	9.36	6.265	4.634
SPGTCED $\rightarrow$ OIL	2	1	7.996**	9.429	5.973	4.518
IR $\rightarrow$ SPGTCED	7	1	26.905*	19.02	14.074	11.972
SPGTCED $\rightarrow$ IR	5	1	21.577*	19.558	14.583	12.221
EUA $\rightarrow$ SPGTCED	2	1	11.494**	14.67	6.192	4.141
SPGTCED $\rightarrow$ EUA	2	1	8.74**	16.648	6.303	4.281

Note: dmax; show the maximum integration of the corresponding variables. We obtain critical values using 10000 simulations. *, **, and ** denote significance at the %1, %5, and %10 levels, respectively.

The results demonstrate that the null of no causality is rejected for all pairs except for the causal link between OIL and SPGTCED. Empirical findings demonstrate that there is no causality running from oil prices to the CESP. In terms

of an existing causal linkages, there are bidirectional causal ties between the CESP and each of TSP, interest rates, and carbon permitting prices. Therefore, TSP, interest rates, and carbon permitting prices seem to be significant tools to predict future movements in the CESP and vice versa. In other words, these findings suggest that TSP, interest rates, and carbon permitting prices lead the CESP and vice versa. Also, one probable explanation for the bidirectional causal connection between interest rates and the CESP is that stock shares and bonds might be either substitute or complement (Moya et al, 2015). However, oil prices seem to be irrelevant in forecasting the movements of the CESP, while the CESP seem to have explanatory power on the future values of oil prices. The absence of the unidirectional causality running from OIL to the CESP demonstrates that the reason for investing in clean energy investments is not a result of rising oil prices (Bondia et al, 2016). Comparing with the results of ECO as a clean energy stock price measure, there is no significant role of oil prices in determining the future values of the CESP.

Because our results provide no evidence of the causality from oil prices to stock market indices, it can be concluded that oil prices have no role in the financial performance of clean energy projects (Reboredo et al. 2017). One might conclude that the clean energy investments and stock prices of these clean energy companies might be affected by long-term changes in global macroeconomic indicators. The carbon permitting prices do, however, lead the clean energy stock market, which in turn demonstrates the significant role of regulatory measures in forecasting the CESP.

4. Conclusion and Policy Implications

The objective of this study was to analyze the factors affecting clean energy inventory prices from a non-linear perspective. The specified model evaluates the cointegrating relationship in the five-variable system using daily frequency data from January 2, 2008 to September 20, 2019. The study employs the WilderHill Clean Energy Index (ECO) and the S&P Global Clean Energy Index (SPGTCED) as two measures of the CESP, the daily spot prices of European Emission Allowances (EUA) for the carbon permitting prices the average of the closing prices of West Texas Intermediate and Brent crude oil prices, the 3-month US Treasury bill (IR) interest rate and ARCA Tech 100 index (PSE). This research utilizes a recently implemented Schweikert (2019) threshold cointegration test that allows for endogenous structural change. The study also analyses the causal relationship between variables using the Hacker-Hatemi causality test.

Our empirical findings show that the CESP, the price of oil, the carbon permitting prices, the price of technology shares, and interest rates have long-term implications. The existence of cointegration suggests that the impact of these variables on the CESP is significant. Besides, our results provide evidence for asymmetric adjustment among the variables in the long run. The long-term

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coefficients of all variables are also significant, which in turn demonstrates that all of these variables play a role in the determination of the CESP level. This suggests that global macroeconomic indicators have a significant impact on CESP.

The study uses threshold cointegration test and it provides evidence for the presence of the structural break in 2011. In this manner, the significant factor for the structural break in this study seems to be oil prices. The break date coincides with the oil price hikes in 2011. Since there are considerable changes in the effect of the TSP, oil prices, carbon permitting prices, and interest rates after the onset of the oil price hikes in 2011, the structural change significantly affects the relationship between a set of factors and the CESP.

Before the structural break, it seems that the TSP, oil prices, and interest rates positively affect the CESP. However, after the break (a), the impact of the oil prices on the CESP seems to be negative, (b) there is an inverse relationship between carbon permitting prices and stock returns, and (c) the coefficient of the interest rate is significantly negative.

Therefore, these findings provide some implications for investors and policymakers as well. For investors, these results might be beneficial to design their portfolio allocation decisions and forecast future trends of the CESP (Dutta et al. 2018). Since they are significant on the CESP, investors should focus on the factors creating fluctuations in the TSP, oil prices, carbon permits, and interest rates to make their portfolio decisions on clean energy stocks. Of these indicators, factors pushing oil prices up seem not to provide market-based incentives for investing in clean energy projects. Carbon permits exhibit that the penalty for the use of high-carbon fuels encourages clean energy investments (Dutta et al. 2018). Lastly, interest rates seem to have a significant negative impact on the CESP, which means that monetary expansions trigger stock markets and create a stimulus for clean energy investments. Overall, the existence of the cointegration relationship between the CESP, oil prices, interest rates and the TSP indicates that keeping all these assets in their portfolios simultaneously does not reduce their potential risks as they all tend to respond to the shocks at the same time.

From a policymaker perspective, since the rise in oil prices do not provide adequate incentives for clean energy investments, public expenditures need to be canalized to support the clean energy sector and reduce the release of greenhouse gases (Reboredo et al. 2017). During high oil price periods regulatory measures provide more incentive for clean energy investments. Hence, policymakers could construct more effective measures to foster clean energy investments. The significantly positive impact of the carbon permits on the CESP is a signal for policymakers that punishment mechanisms for extra carbon emissions could be effective. Thus, such measures could help to stimulate clean energy investments. The significant role of low interest rates to boost clean energy investments demonstrate that monetary authorities could implement expansionary policies, and governments should adopt appropriate measures do not exacerbate market interest

rates. Apart from conveying relevant information for the future values of clean energy stock prices, these global factors seem to create spillover benefits for the environment. In other words, these measures should also be viewed as a way to protect the environment, reduce greenhouse gas emissions and foster sustainable growth.

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