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Year: 2022

Version: Accepted version

Please cite the original version:

Alola, Andrew Adewale (2022). The nexus of renewable energy equity and agricultural commodities in the United States: Evidence of regime-switching and price bubbles. *Energy* 239, Part D, 122377. https://doi.org/10.1016/j.energy.2021.122377

The nexus of renewable energy equity and agricultural commodities in the United States: evidence of regime-switching and price bubbles

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Abstract

The opportunity cost of producing efficient energy from renewable energy sources especially from agricultural products amid increasing threat of food insecurity has remained policymakers' nightmare. On this note, this study employed the regime inference (the Markov switching model) to examine the response of renewable energy equity in relative to prices of corn, soybean and wheat for the United States over the period 20/01/2012 -2/08/2018. Additionally, the SADF (Supremum Augmented Dickey Fuller) test is further employed to investigate the evidence of speculative bubbles in the prices of the concern commodities. With a significant evidence of regime switching, the study reveals positive impact of soybean and wheat on the renewable energy equity in both regimes while the impact is negative in the regimes for corn prices. The positive impact of soybean is an indication that the share of renewable energy and share of its export is highest while corn is being recently preferred and consumed as stable food rather than a source of renewable energy. Furthermore, a sparing evidence of explosive process and collapse bubbles is observed in all the examined commodities except for soybeans. Moreover, with the frequency domain Granger causality approach, the results show overwhelming evidence of bidirectional Granger causality especially between renewable energy equity and the agricultural commodities at varying frequencies. Thus, the study offers effective policy frameworks through the lens of renewable energy development and agriculture for the United States and for other similar economies.
Keyword: agricultural prices; renewable energy equity; speculative bubbles; frequency domain causality; United States.

JEL: C34, Q130, Q420

Nomenclature

ADF: Augmented Dickey Fuller
BDS: Broock et al (1996) Test.
EIA: Energy Information Administration
FRED: Federal Reserve Bank of St. Louis
IEA: International Energy Agency
IEEA: International Renewable Energy Agency
KPSS: Kwiatkowski, Phillips, Schmidt and Shin
MS: Markov Switching
Requity: Renewable Energy Equity
RES: Renewable Energy Sources
SADF: Supremum Augmented Dickey Fuller
Sbeans: Soybeans
SBI: Schwarz Bayesian Information
Tindex: Trade-weighted US dollar index
TWH: Terawatts per hour
TPES: Total Primary Energy Sources
US: United States of America
USDA: US Department of Agriculture
USD: United States Dollars
ZA: Zivot-Andrew

1. Introduction

Studies have shown that alternate source of energy remained a key determinant of sustainable environmental and economic development (Usman et al., 2019; Alola & Saint Akadiri; Kirikkaleli et al., 2020). In sustaining a desirable status of socio-economic development that has continued to justify the search for alternative sources of energy, there has been an increased need for energy sources diversification especially of the renewable energy sources (RES). Based on the advantages of RES, especially that it is capable of enhancing and guaranteeing pollution-free and cost-effective energy source, energy from agricultural sources are increasingly being considered. This is aimed at replacing the bioenergy, geothermal, hydropower, ocean, solar and wind energy sources that have remained the most utilized sources of renewable energy i.e. a regenerated source of energy unlike the fossil fuels (International Energy Agency, IEA 2018). Although fossil fuels are currently reported to account for 80% of the global total primary energy sources/consumed (TPES) especially among the large economies (Alola & Nwulu 2021; Saint Akadırı et al., 2021), biofuels (Kikas et al. 2016; Umar et al., 2021), hydrogen (Abdel-Basset et al., 2021), natural gas (Alexopoulos, 2017; Etokakpan et al., 2021) and synthesis gas are the four supposedly important source of energy in the nearest future (Adedoyin et al., 2020; Adedoyin et al., 2021).

Importantly, the International Energy Agency (IEA) put the current statistics of the RES as: bioenergy and biofuels accounts for about 9% of TPES, hydropower accounts for about 17% of TPES (largest source of renewable electricity globally), ocean energy accounts for smallest TPES, solar energy accounts for over 1% of global power output, wind energy account for about 4% of global electricity generation, and geothermal energy provides about 90 Terawatts per hour (TWh) globally. Among the above RES, bioenergy is mostly utilized across the globe because the source is readily available as natural resources, environmental-friendliness, biodegradability, and among other factors. For instance, biomass (a bioenergy) which is primarily the first energy source harnessed by human, has remained a highly sort-after energy source by about half of the world population. (Qiao et al. 2016). Additionally, the biodiesel, which are proportionately mixed with hydrocarbon fuels is biodegradable and less pollutant. Thus, biodiesel and other agro-based fuels accounts for the reason agricultural crops and residues are important in the production of renewable energy.

Moreover, in respect to the agro-based fuels, some of the agricultural residues utilized for renewable energy include residues from arable plant/crops and animals. As several studies have continued to add to document energy sources especially within the framework of renewable energy, the important of RES to humankind and development across the sector of the economy remains crucial. For instance, the work of Apergis and Payne (2010) is among the existing literature that studied renewable energy consumption in relation to economic growth. In the context of renewable energy, studies have continued to examine the broad range of factors that contributes to RES development and some of the related factors include income growth, health-related factors, advanced technology, resource and environmental depletion, sectoral development, and financial development (Jennings, 2009; Mumtaz et al. 2014; Adämmer & Bohl, 2015; Wakil et al., 2016; Rezec & Scholtens, 2017; Asonja et al., 2017; Umekwe & Baek, 2017; Alola & Alola, 2018).

In this case, the study of the response of renewable energy vis-a-vis renewable energy equity (Requity) to the prices of agricultural commodities i.e corn, wheat and soybeans prices in the United States is carefully examined. This study employed the daily datasets spanning from 20 January 2012 to 2 August 2018 and use the Markov

Switching (MS) regression model. Additionally, the evidence of speculative price bubbles for these commodities is investigated. The evidence of speculative bubbles will give credence to the perceived dynamics of the agricultural commodity prices in the United States. The motivation for exploring the study of renewable energy in this perspective is in folds. Firstly, agriculture is imperatively one of the sources of biofuels that contributes about 5% of the total primary energy sources in the country (Energy Information Administration, EIA, 2020). Among these sources are the agricultural residues such as the cornstalks, straws, corncob and tree/plant/fruit orchards pruning residues. Secondly, the US has continued to present interesting energy-mix dynamics, thus the country has remained one the highest energy consuming countries. The current government policy regarding climate change, which is noticeable in the country's recent proposed withdrawal from the 2015 Paris climate agreement, suggests an interesting perspective. Until now, the country's primary energy sources are the fossil fuels, nuclear energy and the RES. However, the proportion of these energy sources utilized in the United States is sector-specific. For instance, biofuels and waste such as from agriculture account for about 4.2% of TPES of electricity generation. Lastly, although the United State economy is not agriculturally driven primarily, the country produces vast agricultural products/wastes (Adämmer & Bohl, 2015; Umekwe & Baek, 2017). As such, the dilemma of meeting the country's energy and especially the renewable energy demand amid food security challenge presents an interesting study.

In the light of the highlighted motivation above, the current study further advanced the key knowledge in the combined studies of Adämmer and Bohl (2015) and Rezec and Scholtens (2017). While Adämmer and Bohl (2015) pointed out the importance of Corn, Soybeans and Wheat prices to crude oil prices and real exchange rates of the United States, Rezec and Scholtens (2017) expressed the significance of renewable energy equity indices in financing energy transformation. Hence, in novelty, this study hypothesizes the likelihood of regime inference(s) that arises from the dynamics of the renewable energy equity as caused by the daily trends in agricultural prices. On one hand, the global energy diversification policy resulting from the climate change challenges necessitate desire to explore potential regime switching evidence. On the other hand, the regime-switching evidence could be linked with the agricultural-related policy of the United States such as the recent trade in agricultural product disruption between the United States and China. As such, due to potential evidence of nonlinearity among the aforementioned variables, a regime-switching inference approach is best suited for the study (Alqaralleh, 2020). Like Adämmer and Bohl (2015), the agricultural prices employed are the prices of corn, soybeans and wheat because they account for the three largest crop production in the United States.

The rest of the sections are ordered accordingly. Section two presents an overview of renewable energy and selected agricultural crops produced in the United States. In section three, the empirical methodologies are illustrated while are the empirical findings are subsequently discussed in section four. Lastly, the concluding remarks with relevant policy pathway are provided in section five.

2. RES in the US: A synopsis

In recent times, greater importance has consistently been attached to the traditional sources of energy as evident in the US Federal policies toward attaining cleaner energy policy. In the United States, due to the persistent surge in the growth of renewable energy, the TPES from the renewables by 2040 is expected to be about 12.1% with electricity generation projected at about 16% (International Renewable Energy Agency, 2018). While hydropower production suffered a decline of about 2.6% of TPES from 2003 to 2013, energy generation from solar power was observed to double during the same period. Biofuels and waste were noted to have expanded by about 30.6% of TPES, while 6.2% of TPES was added by geothermal. But globally, the United States is the world leader and highest installer of geothermal energy capacity. In 2014, the United States accounts for 58 hydroelectric power plants which are capable of powering 3.5 million homes and generating one billion USD in revenues. While the goal to double the country 's renewable electricity from wind power, solar power and geothermal resources were achieved in 2013 (from 2008 baseline), the US has again set a new target to double the same energy source by 2020 using the baseline of 2012.

The importance of biofuel in the energy structure of the US accounts for the active research and development collaborations of government agencies like the US Department of Agriculture (USDA), Department of Environment. The policies and measures of the government on renewable energy like the production and investment tax credit and renewable portfolio standards have continued to constitute renewable energy market and equity guide. Through the enacted tax reforms like the corporate tax reforms which have subsequently reduced the corporate income tax, the tax liabilities of the energy companies has subsequently declined. As such, institutional energy investors often benchmark their financial performance using renewable energy indices (i.e. baskets of investments/projects) as an instrument for measuring potential energy project debt and investable assets (Rezec & Scholtens, 2017).

However, there is evidence of persistence shock on renewable energy utilization especially in the United States, In that direction, Lee et al (2021) employed the quantile unit-root test with smooth breaks to examine the evidence of persistence shock on renewable energy consumption in the United States' overall economy and the 50 states plus the District of Columbia over the period 1960–2017. Uniquely, the study revealed that null hypthesis of unit root for renewable energy consumption series is rejected for the country (United States') series in addiion to the rejection of the unit root null hypothesis for 32 states. Additionally, the investigation found a significant presence of asymmetric responses to shocks for different states. The result from Lee et al (2021) largely compliment the recent evidence in Kassouri et al (2021) that positive shock on oil prices is a potential boaster for renewable energy investment.

2.1 Renewable energy and agricultural prices

On one hand, agricultural crops or plants and wastes have consistently been utilized as sources of renewable energy fuels. The quality of RE from agricultural would largely depend on both the agricultural product and the method of production. For instance, transesterification methods that could be acidic, base lipase-catalyzed are common methods of producing biodiesels (Wakil, 2016). In addition, the yield of bioethanol and biogas is reportedly dependent on the level of cellulose and lignin in the biomass respectively (Kikas et al. 2016; Osundina et al., 2019). Moreover, on the other hand, the increase in agricultural prices that are largely responsible for the hike in food prices have a huge impact on inflation, and the living standard of the people. Notably, Reboredo (2012) linked the association between energy and agricultural prices to the fact that energy is utilized in agricultural production, even as soybean and corn remain heavily demanded. Similarly, Adämmer and Bohl (2015) considered the prices of corn, soybean and wheat while investigating the potential bubbles in US agricultural prices. Additionally, Nazlioglu (2011) observed a statistically significant cointegration evidence when examining agricultural commodity prices in relation to world oil prices

However, several other relevant studies have further shown the dynamics of renewable energy from similar perspectives (Ozturk, 2015; Al-Mulali et al., 2016; Troster, Shahbaz & Uddin, 2018; Sinha, Shahbaz & Sengupta, 2018). For instance, Al-Mulali et al (2016) investigated the relationship and the effect of the production of renewable energy sources with the ecological footprints of land and water in 58 developed and developing countries between 1980 and 2009. In their study, it is revealed that renewable energy production exerts positive effect on the ecological footprint of land and water, thus it increases the footprints vis-à-vis the inefficiency of water and land footprints. Additionally, Troster et al (2018) specifically studied the causal nexus of renewable energy consumption, oil prices and economic growth for the case of the United States between July 1989 and July 2016. Although the study found a causal relationship between the changes in renewable energy consumption and economic growth at the lowest tail of the quantile distribution, the investigation opined that renewable energy consumption lead economic growth at the highest tail of the quantile distribution.

3 Data and estimation method

In this section, a detail information about the dataset in addition to the statistical properties (see Table A of appendix) are provided. Additionally, the econometric approach, starting from the preliminary diagnostics are illustrated.

3.1 Data description

Based on one sector (agricultural) analysis as obtainable in Adämmer and Bohl (2015), the data for corn, soybeans (sbean) and wheat prices with other independent variables in the study were collected from the Federal Reserve Bank of St. Louis (FRED) where the agricultural prices of the three commodities are the non-seasonally adjusted Producer Price Index (index 1982 = 100). The trade-weighted US dollar index[1] (tindex) is employed to control for the unobserved variable (i.e global financial market,

[1] The Trade weighted US dollar is the weighted index is the average of the foreign exchange value of the U.S dollar against major trade partner currencies and obtained from the FRED (Federal Reserve Bank of ST.LOUIS.

the United States dollar exchange rate, e.t.c.). Additionally, the dependent variable employed is the renewable energy equity index (requity) and it is sourced from the Thomson Reuters DataStream. Renewable energy equity is the aggregate equities of the renewable energy market, comprising of the renewable energy companies in the United States. The aforementioned datasets span from 20/01/2012 to 02/08/2018. By illustrating the potential relationship between the concern variable, the combined time plot indicated in Figure 1 further provides visual evidence of their relationship. Additionally, the correlation information and the descriptive statistics are provided in the appendix because of space constraint.

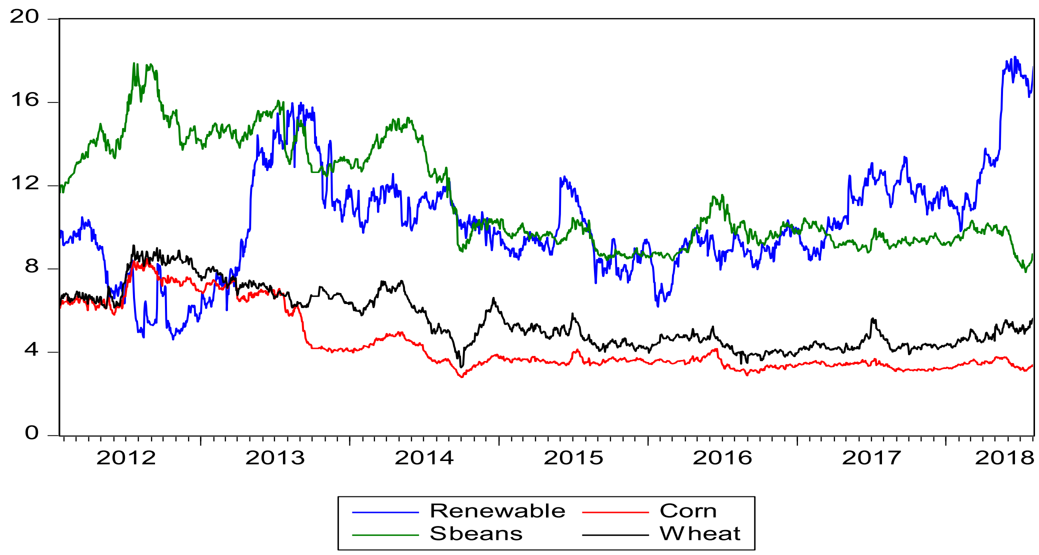


Figure 1: The Relational Behaviour of the Variables.

3.2 Model representation and estimation

In order to investigate the dynamics between the variables of concern, a handful of procedures that include both the preliminary tests and model estimation are performed.

3.2.1 Preliminary tests

Before applying the Markov Switching approach, the applied stationarity tests (Kwiatkowski, Phillips, Schmidt & Shin, 1992), the KPSS revealed that the variables are stationary at $I(1)$ and corroborated by Zivot and Andrews (1992) unit root for single breaks as observed in Table 1. In addition, the results of the Zivot and Andrews (1992) unit root for single breaks further provides information of potential breaks which can be corroborated by significant event(s) during the observed year(s). In addition to the preliminary tests, the evidence of non-linearity is validated by using the BDS independence test of Broock et al (1996). Given the non-linearity evidence in Table B of the appendix, it provides a suitable foundation for the use of a non-linear estimation approach.

3.2.2 The Markov-Switch approach

The basic procedure for the Markov Switch approach include the use of a multivariate approach model such that the variables are expressed in an ordinary least squares (OLS) regression model as

$$requity_{i,t} = \beta_{o,i} + \beta_{1,i}Corn_t + \beta_{2,i}Sbean_t + \beta_{3,i}Wheat_t + \beta_{4,i}Tindex_t + \varepsilon_{i,t} \quad (1a)$$

where *t* is the daily periods, ε_t is the error term, and slope parameter to be estimated ($\hat{\beta}$) for each corresponding independent variable. Also, from (1a), $Corn_t$, $Sbean_t$, $Wheat_t$, and $Tindex_t$ are the corn price shocks, soybeans price shock, wheat price shock, and the trade-weighted shock. When the switching intercepts are incorporated, the Markov switching dynamic regression of Hamilton (1989) as simplified by Uddin et al (2018) and Reboredo (2010) is presented as follows as:

$$requity_{i,t} = \beta_{o,i,rt} + \beta_{1,i,rt}Corn_t + \beta_{2,i,rt}Sbean_t + \beta_{3,i,rt}Wheat_t + \beta_{4,i,rt}Tindex_t + \varepsilon_{i,t} \quad (1b)$$

Given that for all $\varepsilon_t \sim N(0,\sigma^2_{st})$, the switching intercept and variance of error are respectively $\beta_{0,i,rt}$ and σ^2_{st}. Also, the effect of the prices of $Corn_t$, $A_i = \phi_1 A_{i-1} + \phi_2 A_{i-2} + \dots + \phi_p A_{i-p}$ and $Wheat_t$ on the equity of *renewable energy* ($requity_{i,t}$) in different regimes are respectively $\beta_{1,i,rt}$, $\beta_{2,i,rt}$, $\beta_{3,i,rt}$, $\beta_{4,i,rt}$ where r_t (regime dependent) is a discrete regime variable. A latent unobserved state variable, *i* takes on values 1 and 2 such that state 1 and state 2 (state of the economy) are respectively known as the *high* and *low* regimes.

Further to the original Hamilton specification of a constant Markov switching model[2], a Markov switching specification is employed. In this case, a stochastic regime switching process that follows homogeneous, ergodic, and first order Markov chain with constant transition probabilities and two (2) regime numbers is assumed. As such, and in the regression, the dynamic transition probability of the matrix is given as:

$$P(t) = \begin{bmatrix} P_{11t} & 1 - P_{22t} \\ 1 - P_{11t} & P_{22t} \end{bmatrix} \tag{2}$$

The probability of transmission from regime 1 at time period t to regime 2 at time period *t + 1* depends entirely on the regime at time period *t*. And, given the dynamics of both the renewable energy equity in respect to the prices of corn (*p*), soybean (*q*), wheat (*r*) and unobservable factor (*tindex*) is a time-varying possibility of regime switching which is associated with dynamic transition probabilities;

$$P11_t = \frac{\exp\left\{\gamma_1 + x_1 p_{t-1}^{Corn} + u_2 q_{t-1}^{Sbean} + v_1 r_{t-1}^{Wheat} + w_1 s_{t-1}^{Tindex}\right.}{1+\exp\left\{\gamma_1 + x_1 p_{t-1}^{Corn} + u_2 q_{t-1}^{Sbean} + v_1 r_{t-1}^{Wheat} + w_1 s_{t-1}^{Tindex}\right.} \text{ and}$$

$$P22_t = \frac{\exp\left\{\gamma_2 + x_2 p_{t-1}^{Corn} + u_2 q_{t-1}^{Sbean} + v_2 r_{t-1}^{Wheat} + w_2 s_{t-1}^{Tindex}\right.}{1+\exp\left\{\gamma_2 + x_2 p_{t-1}^{Corn} + u_2 q_{t-1}^{Sbean} + v_2 r_{t-1}^{Wheat} + w_2 s_{t-1}^{Tindex}\right.} \tag{3}$$

From the equation 3 above, the significant value of the parameters x_1 and x_2, u_1 and u_2, v_1 and v_2 in addition to w_1 and w_2 respectively determines the impact of corn price, soybean price, wheat price and the control variable on the regime transition

[2] Detail of the constant Markov switching model is not expressed here because of space constrain and can be followed up in Hamilton (1989).

probabilities. Also, γ_1 and γ_2 are responsible to give the regime transition probabilities. Given an increase in the independent variables, renewable energy equities are likely to remain in regime 1 as the coefficient of the independent variable(s) is/are positive(s) and vice versa in the case of regime 2. Moreover, information from the filtered regime probabilities, the diagnostic residual test and the forecast estimate are further investigated in order to validate the robustness of the estimate.

Table 1: The KPSS stationarity Test and Zivot-Andrew (ZA) Unit Root Test under Single Structural Break

Variables	Level: with intercept	Level: intercept and trend	Δ: with intercept	Δ: intercept and trend	Conclusion
Requity	0.869*	0.361*	0.139	0.062	*unit root*
Corn	3.797*	0.844*	0.094	0.076	*present at level*
Sbean	3.973*	0.543*	0.098	0.083	*and*
Wheat	3.962*	0.584*	0.085	0.072	*stationary at Δ*
lnTindex	4.715*	0.635*	0.069	0.070	

Zivot Andrew	Level: ZA_I	Level: ZA_T	Level: ZA_{IB}	Δ: ZA_I	Δ: ZA_T	Δ: ZA_B
Requity	-2.96	-2.76	-3.14	-41.69*	-41.59*	-41.79*
	3/9/2014	*9/8/2017*	*7/7/2015*	*4/9/2013*	*8/8/2017*	*9/7/2013*
Corn	-5.83*	-3.83	-5.65	-18.03*	-18.00*	-18.26*
	23/7/2013	*10/7/2014*	*12/7/2013*	*21/3/2013*	*25/7/2013*	*1/10/2013*
Sbean	-5.34*	-4.13	-5.32**	-41.19*	-41.21*	-41.30*
	30/6/2014	*13/8/2015*	*30/6/2014*	*6/10/2014*	*13/8/2014*	*29/9/2014*
Wheat	-4.28	-4.14	-4.42	-18.67*	-18.66*	-18.80*
	9/5/2014	*12/8/2016*	*9/5/2014*	*2/10/2014*	*25/2/2013*	*2/10/2014*
lnTindex	-3.64	-2.53	-3.71	-17.06*	-16.93*	-17.21*
	30/10/2014	*9/11/2015*	*19/6/2015*	*18/12/2015*	*3/11/2014*	*12/1/2017*

Note: Level and Δ respectively indicates estimates at the level and first difference. Automatic lag selection by SIC (maxlag=24) for unit root test and maxlag=4 for ZA). ZA is the Zivot & Andrews (1992) for a unit root structural break test where $ZA_{I,}$ ZA_T & ZA_B are an intercept, trend and intercept with the trend of ZA estimates.

3.2.3 Testing for speculative bubbles

Following the evidence of regime switching as illustrated above, the evidence of price bubbles is also investigated for corn, wheat, soybeans, and renewable energy equity for the United States. To examine the price bubbles in the agricultural commodity market, the SADF (Sup-Augmented Dickey Fuller) approach that is known as the right-tailed unit root test by Phillips, Wu and Yu (2011)[3] is employed. By employing the unit root test from the Augmented Dickey Fuller (ADF) test from equation (4) and thereafter the equation (5), the SADF test is applied to test the existence of price bubbles (İskenderoğlu and Akdağ 2019). The SADF test employed is derived from the ADF test that is illustrated as:

$$Y_t = \gamma + \lambda y_{t-1} + \sum_{i=t}^{p} \alpha_i \Delta y_{t-i} + \varepsilon_t,\ \varepsilon_t \sim iid\ \mathrm{N}(0,\sigma^2),\ \mathrm{t} = 1, \dots, \mathrm{T} \quad (4)$$

and

$$ADF_{r_1,r_2} = {}^{\lambda_{r_1,r_2}}\!\big/_{se(\lambda_{r_1,r_2})} \quad (5)$$

where *Y* is the price of each commodity (corn, wheat, soybeans, and renewable equity) employed such that the time *t* and the optimal lag length *k* is chosen by the Schwarz Information Criterion. The ε, σ^2, and *se* are the error that is supposedly identical independently distributed (*iid*), the variance and standard deviation respectively.

Subsequently, the SADF test procedure which is a modification of (4) and (5) as expressed in the studies of Phillips, Shi and Yu (2015a, 2015b) is further presented as the SADF test equation as

$$SADF_{r_2} r(0) = sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \quad (6)$$

[3] Phillips, P. C., Wu, Y., & Yu, J. (2011). Explosive behavior in the 1990s Nasdaq: When did exuberance escalate asset values? *International economic review*, *52*(1), 201-226.

From the application of the SADF unit root, the prices of the concerned variables are tested for whether a bubble exists or not by using the equation (6). Specifically, the procedure include the use of the subsets (r) of the sample data incremented by one observation recursively. Thereafter, the time series of the recursive test statistic ADF_r is matched against the right-tailed critical values of the asymptotic distribution of the standard Dickey–Fuller t-statistic. In this case, the continuous days of bubbles is the observed number of days for which the computed t-statistic is greater than the critical value. In previous studies, the evidence of bubbles in the oil market and other oil-related commodities have been investigated by employing similar approach as the SADF test (Narayan et al., 2013; El Montasser et al., 2015).

3.2.4 Robustness check

To further establish the objective of the study that is designed at illustrating the association between the renewable energy equity and the major agricultural commodities in the United States, the Granger causality technique is employed. Considering the frequency (high) of the dataset in the current study, the Breitung and Candelon (2006) is adjudged a potent choice to provide Granger causality relationship in frequency domain even at I (1) order of integration of the variables and no evidence of cointegration. By following the Granger causality build-ups of Granger (1969), Geweke (1982), and Hosoya (1991), the latest Breitung and Candelon (2006) approach modified and built on the newer approaches (Toda & Yamamoto, 1995; Dolado & Lütkepohl, 1996) that leverage on the Wald test of the Granger causality even without evidence of cointegration. Thus, by assuming that $d_{max} > 0$, Breitung and Candelon (2006) opined that the modified approach for the frequency domain test is given as

$$x_t = c_1 + \sum_{j=1}^{p} \alpha_j x_{t-j} + \sum_{j=1}^{p} \beta_j y_{t-j} + \sum_{k=p+1}^{p+d_{max}} \alpha_k x_{t-k} + \sum_{k=p+1}^{p+d_{max}} \beta_k y_{t-k} + \mu_t \quad (7)$$

where x_t and y_t are respective pair of variables (such corn and sbeans) over the daily period starting 20 January 2012 to 2 August 2018 for frequency ω, and lag length j = 1, …, p. Then the null hypothesis H_0: = $M_{y \rightarrow x}$(ω) = 0 (of no Granger causality from *y* to *x*) involving only β_j is now estimated. Other details of the estimation procedures are not provided here for space constraint.

4. Empirical findings

Following the series time series stationarity KPSS test which indicates that the series is *I(1)* and the corroboration of the ZA (1992) unit root single structural break test as shown in Table 1, the Markov switching estimate result and other diagnostic tests are presented in Table 2. Justifying the evidence of structural change (given the ZA structural break test), on one hand, the energy sector in the United States has experienced significant changes in the last decades arising from the global response to climate change through energy transition and energy efficiency policies. On the other hand, the agricultural sector of the United States (the country is the largest producer and exporter of corn), and especially for the examined commodities has also experienced market interruption arising from the shock associated with the United States and China trade tussle in recent years. Thus, these structural changes that are potentially brought about by the market movements in the sectors are clear indicators of regime variation.

Table 2: Constant Markov Switching Model

Parameters	Regime 1	Regime 2		
$\beta_{0,i}$	40.292*	-165.944*	P11	ERD
$\beta_{1,i}$	-1.858*	-1.7182*	0.996	[241.313] erd
$\beta_{2,i}$	0.549*	0.883*		
$\beta_{3,i}$	0.157*	3.124*		
$\beta_{4,i}$	-6.433*	33.747*	P22	ERD
σ_i	-0.226*	0.443*	0.994	[172.154] erd
log-likelihood	-0.262*	0.655*		
Residuals (Diagnostic test)				
	Skewness	0.410		
	Kurtosis	4.382		

Note: Regime 1 implies i=1 and regime 2 implies i=2. In addition, λi, χi, and ϕi are respectively coefficient of the alternative effect of prices of Corn, Sbeans (Soya beans) and Wheat on the equity of renewable energy. * implies the statistical significance at 1% level and erd the regime expected duration.

Furthermore, the appropriateness of the Markov switching model is shown in the significant evidence of the switching parameters 40.292 and -165.944 (of high and low) indicated in Table 2. Additionally, by rejecting the null hypothesis of independent state variables as shown in the significance of the state variables support, the employed Markov switching model is justified. The log-likelihood of the regimes are also significant (-0.262 and 0.655). Importantly, the Markov switching model with a constant parameter for the United States shows that the equity market of renewable energy responds differently with a significantly varying degree in each of the regimes (i.e. High regime = regime 1 and low regime = regime 2). Although the impact of corn prices is significantly negative on RE equities in both regimes, such impact is lower in regime 1. Similarly, the prices of soybeans and wheat are significantly positive in the regimes, these impacts are also lower in regime 1. However, the trade-weighted in US dollars (control variable) exhibit a significant and negative (positive) impact in regimes 1 (2). Furthermore, with a 99.59% probability of ensuring a persistent regime 1 (i.e. 0.41% of switching to regime 2), and a 99.42% of a persistent regime 2 (i.e. 0.58% of switching to regime 1), the regimes are found to be persistent and remain so for 241 days and 172 days respectively. In addition to the robustness evidence is the desirable result of the filter regime probabilities of the regimes (Figure 2) and the residual diagnostic (i.e skewness = 0.41 and kurtosis = 4.38) of as illustrated above.

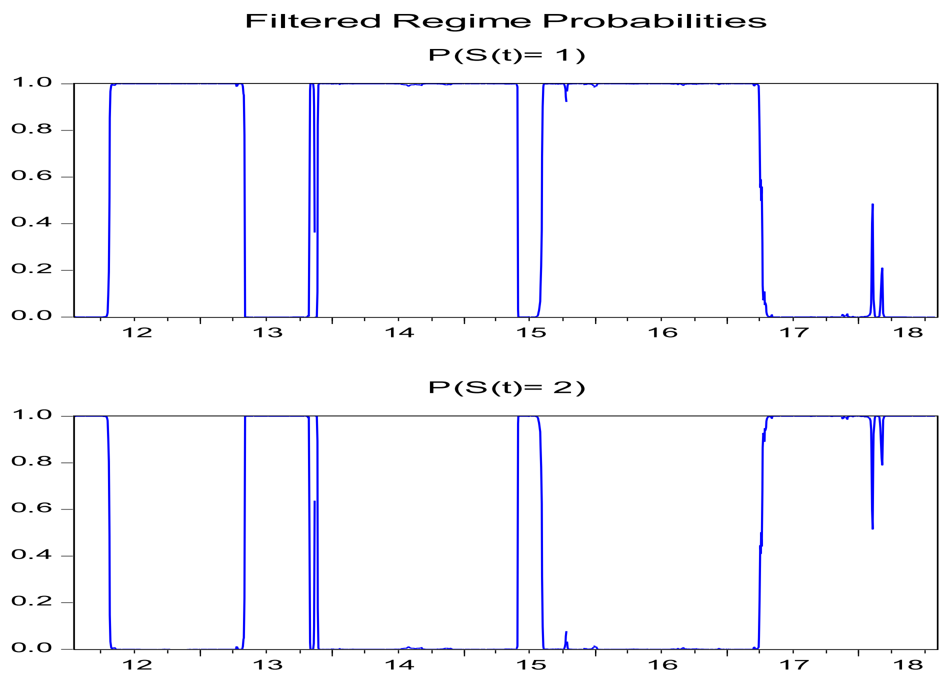


Figure 2: The Filter Regime Probabilities of the Regimes.

4.1 Evidence of price bubbles

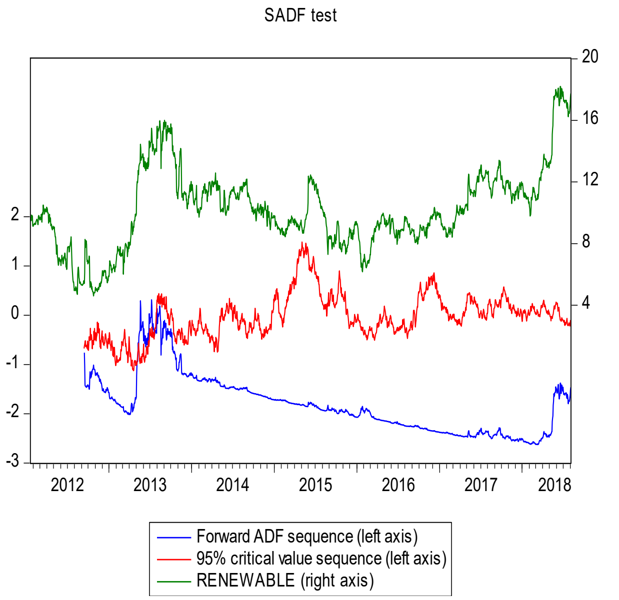
Having estimated the SADF as expressed in equation (6) above, the result of the estimate is indicated in Table 3 and subsequently in Figure 3. Although the result illustrates that, there is no statistical evidence of price bubbles as regard the variables especially with the t-statistic, visual evidence of prices bubbles are observed in the graphical presentations in Figure 3. The contradiction in the two aforementioned observations could be due to the brief event or period that is characterized with the prices bubbles (a non-persistence price bubbles) which has not necessarily persisted, thus making the statistical detection difficult. However, this event is best explained in the transition period of the regime switching.

Table 3: SADF Test

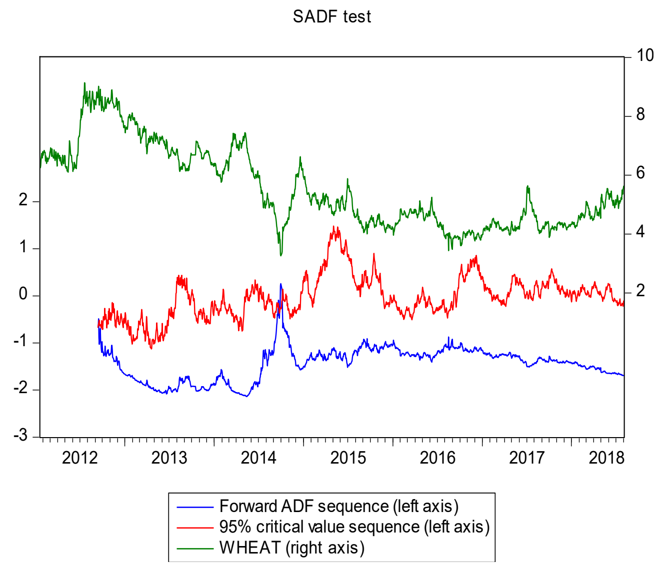
	Variable			
	requity	corn	wheat	sbeans
t-Statistics	0.313	0.241	0.261	-0.569
p-value	0.600	0.600	0.600	0.700

Note: The t-statistic and p-value are the test statistics and probability value. Sbeans and requity are the soybeans and the renewable energy equity.

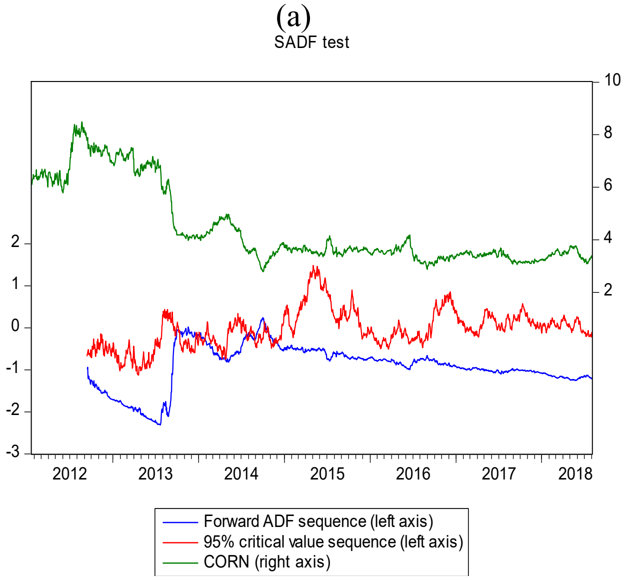
Indicatively, the evidence of partially explosive process and collapsing price bubbles in the renewable energy equity (requity) can be observed in the later period of 2012 to toward the early period of 2013 (see Figure 3a). Similarly, the evidence of price bubbles can be observed in the early periods of 2013 and 2014 where the t-statistics is slightly above the critical statistics. While no evidence of price bubbles is observed in soybeans in the entire period (see Figure 3d), price bubbles evidence is equally observed in the early period of 2014 for wheat (see Figure 3c). The evidence of price bubble could be associated with the speculative transactions that are potentially explosive as a result of sudden price changes (decrease), thus causing economic crises. However, the lack of evidence of price bubbles in the majority of the estimated period is due to the fact that price movements are driven by core values, thus supporting the hypothesis of efficient markets or no evidence of deviation from the values based on market fundamentals. In a similar study by Gutierrez (2012), an explosive process and collapsing bubbles were reported for wheat and corn while there was no reported evidence of exuberance for soybeans prices.



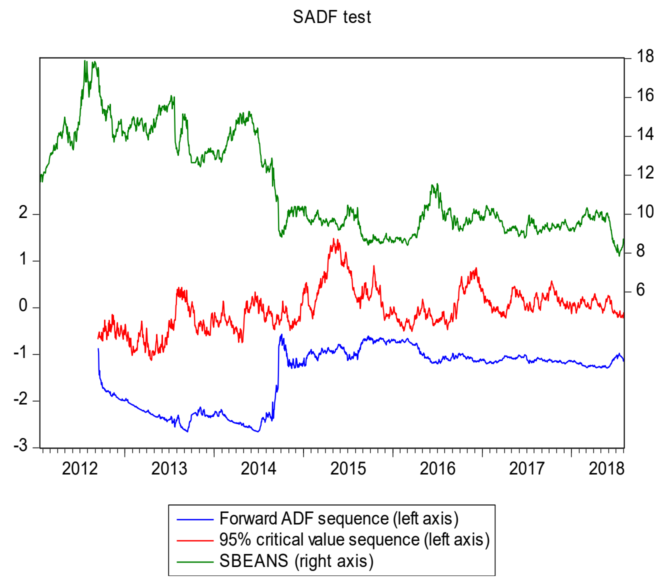
(a)



(c)



(b)



(d)

Figure 3: The SADF Monte Carlo estimation for renewable energy equity (requity), corn (b), wheat (c), and sbeans (d).

4.2 Granger causality evidence

As illustrated with the results of the Breitung and Candelon (2006) in Figures 4-11, there is largely a statistically significant evidence of Granger causality between the dependent variable (renewable energy equity) and the independent variables (except for tindex). For instance, there is a statistically significant evidence of Granger causality from corn to requity (see Figure 4) between the frequency 0.8 to 2.4 with respective Wald statistics 4.610 to 4.950 at 10% significant level and between the frequency 1.4 to 2.1 with respective Wald statistics 6.116 to 6.602 at 5% significant level. The reverse is also true (see Figure 5) from frequency 0 to 0.1 with Wald statistics 6.889 at 5% statistically significant level and from frequency 0 to 0.15 with Wald statistics 5.950 at 10% statistical level. There is no evidence of Granger causality from soybeans to renewable energy equity (see Figure 6), however, the Granger causality from renewable energy equity to soybeans (see Figure 7) is statistically significant at 5% from frequency 0 to 0.30 (Wald statistics = 6.044) and statistically significant at 10% from frequency 0 to 0.60 (Wald statistics = 4.952). Lastly, the Granger causality from wheat to renewable energy equity (see Figure 8) is statistically significant 5% in frequency (1.0, 1.5) with Wald statistics (6.195, 6.810) and statistically significant at 10% in frequency (0.8, 1.70) with Wald statistics (5.112, 5.14). Meanwhile, the Granger causality from renewable energy equity to wheat is statistically significant at 10% in frequency (0.0, 1.30) with the Wald statistics of 5.600.

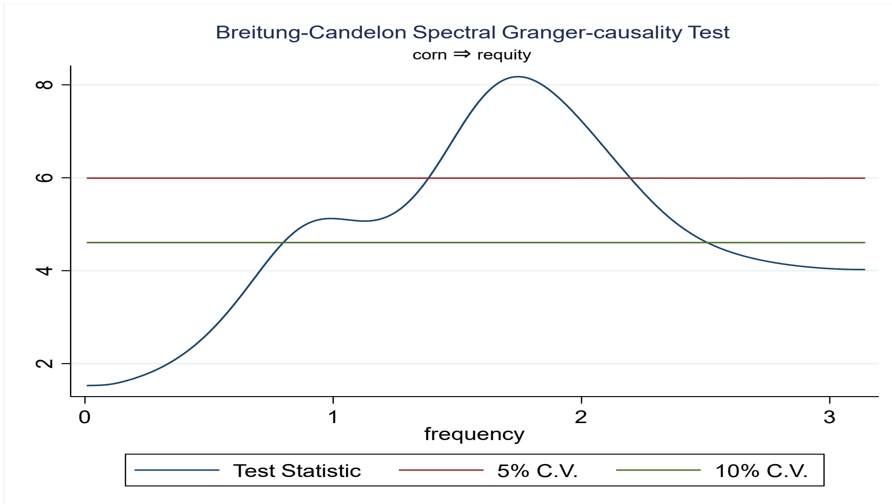


Figure 4: Granger causality from corn to requity.

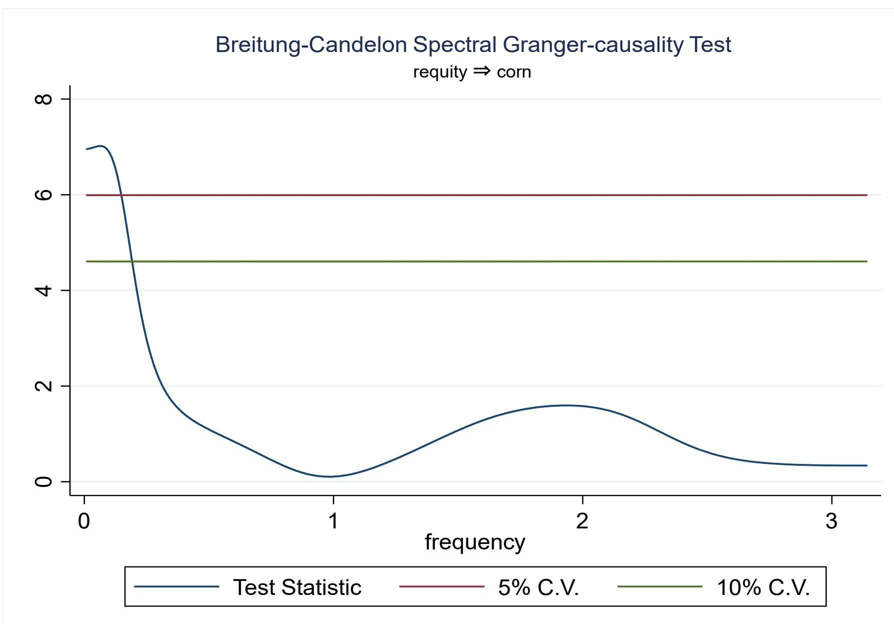


Figure 5: Granger causality from requity to corn.

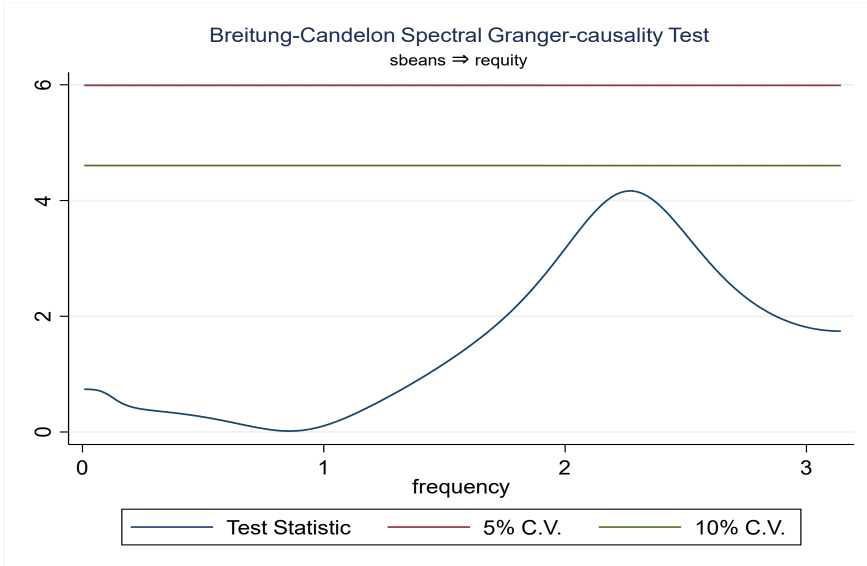


Figure 6: Granger causality from sbeans to requity.

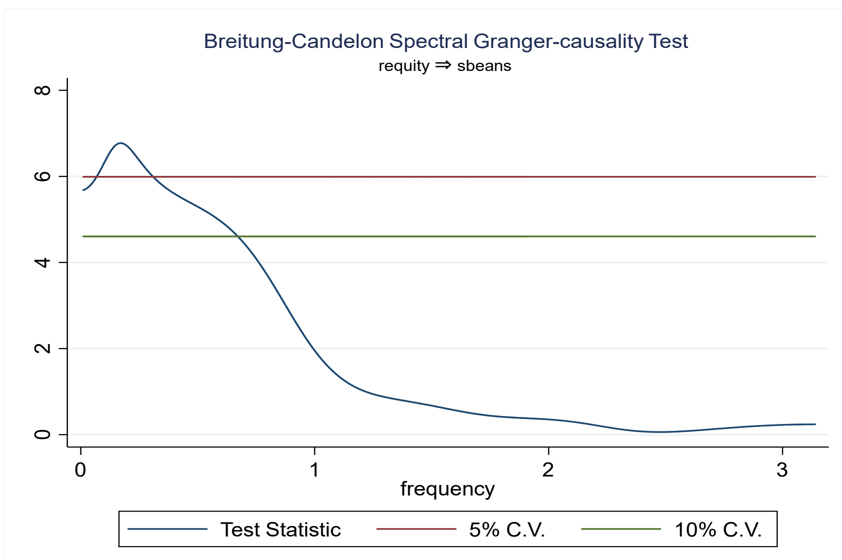


Figure 7: Granger causality from requity to sbeans.

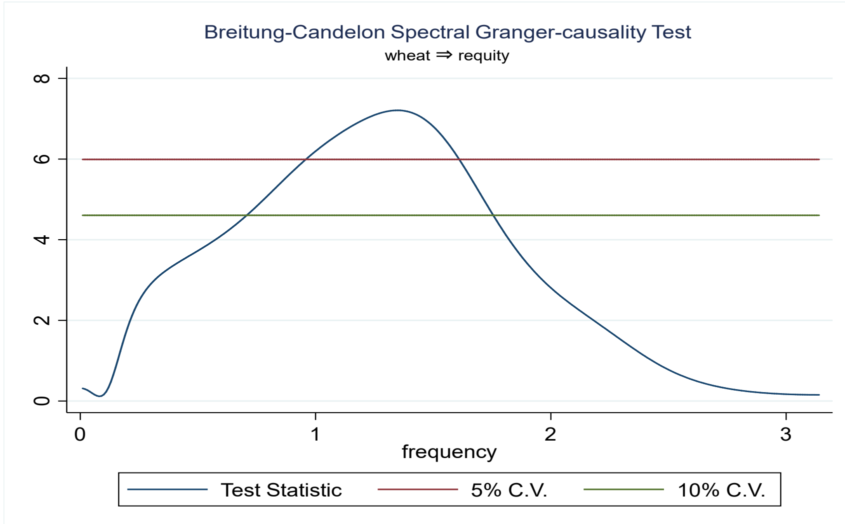


Figure 8: Granger causality from wheat to requity.

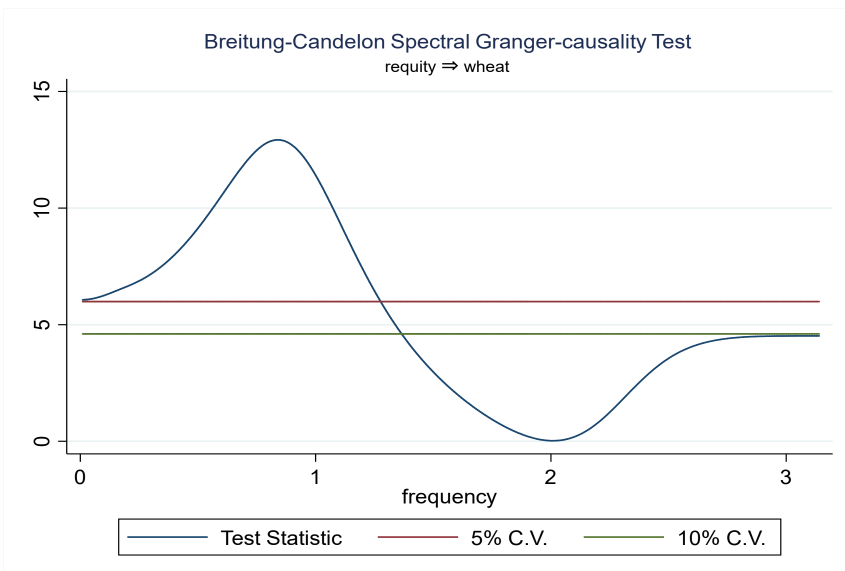


Figure 9: Granger causality from requity to wheat.

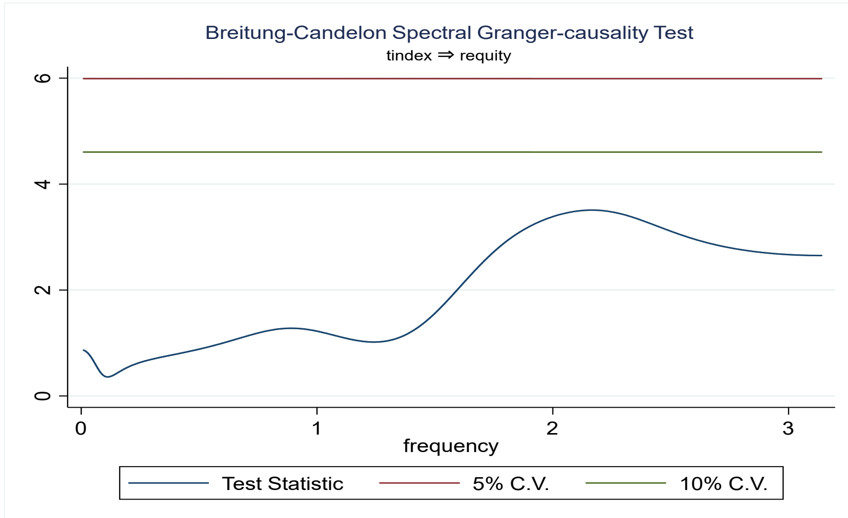


Figure 10: Granger causality from tindex to requity.

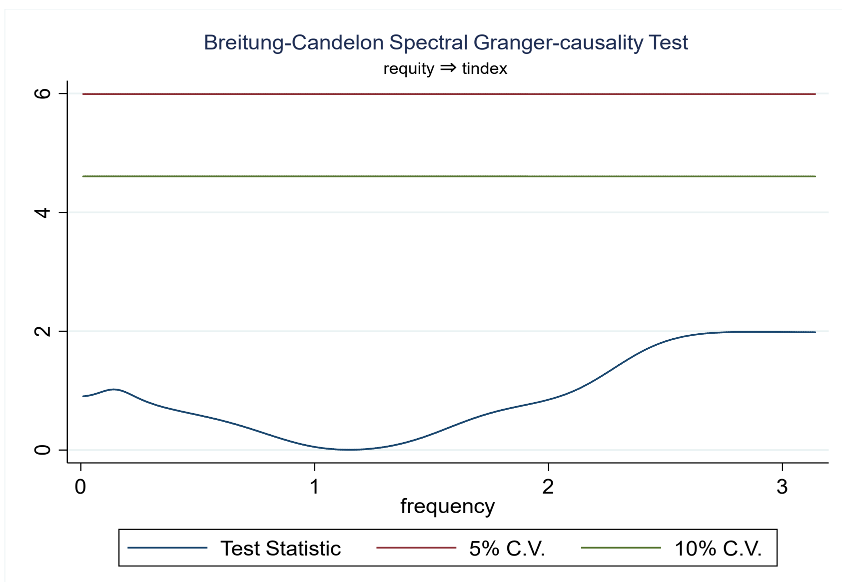


Figure 11: Granger causality from requity to tindex.

5 Conclusion and policy suggestions

In the United States, energy sources from renewables is found to have grown by about 9.1% from 2008 to 2012 and subsequently experienced a robust growth of about 15% from 2012 to 2017 (International Renewable Energy Agency, 2018). Considering the significant level of agricultural activities in the United States, then there is a justification for the investigation of the regime dynamics of equities of the renewable energy sources along with the agricultural commodity prices vis-à-vis corn, soybean and wheat by employing the Markov switching model. While taking note of the importance of the three main agricultural commodities (corn, wheat and soybeans) to the agricultural sector of the United States, the current study further investigated the presence of speculative bubbles in the prices of these variables. Our study found a significantly negative impact of the corn price on the renewable energy equity in both regimes. Such impact is positive for soybean and wheat during the regime periods. Thus, this coincides with the result of Nazlioglu (2011). Expectedly, soybean has the highest share of RE source and the highest share of harvest export (Adämmer & Bohl, 2015). The unexpected result for corn could be associated with recent findings that opined the use of corn for food rather than energy because of inherent environmental cost. However, the study found partial explosive processes and collapse bubbles in the prices of renewable energy equity, corn, and wheat but not in soybeans prices. By providing robustness evidence to support the association between renewable energy equity and the aforementioned commodities, the Breitung and Candelon (2006) approach established Granger causality at varying frequencies. For instance, there is Granger causality evidence from corn to renewable equity in frequency (1.4, 2.1) and frequency (0.8, 2.4) at 5% and 10% statistically significant level respectively. The evidence of Granger causality from renewable energy equity to corn only exists before frequencies 0.1 and 0.15 at 5% and 10% statistically significant level respectively. Moreover, there is evidence of bidirectional Granger causality between renewable energy equity and wheat at frequency ranges while there is only unidirectional evidence of Granger causality from renewable energy equity to soybeans before frequencies 0.30 and 0.60 at 5% and 10% statistically significant level respectively.

5.1 Policy and future study

As a strategic policy redirection, the government and stakeholders could further deploy instrument that is geared toward a sustainable energy and agricultural framework. Considering the expansion of the global renewable energy market especially the aspects of agricultural-related energy, more concerted global effort should be geared toward addressing the global food insecurity potentially arising from trade tussle such as between the United States and China, regional and domestic tensions especially among the agrarian economies. A subsidy policy or tax incentive policy for the agricultural investors is an essential price control strategy that the United States government could consider. Hence, more agricultural investment should be further encouraged.

However, further study could focus on the response of different renewable equity indices, especially for agricultural products and related energy sources (Paschalidou, Tsatiris & Kitikidou, 2016). Additionally, a more recent and sophisticated methodologies such that are capable of detecting outliers and structural breaks (Pretis et al., 2018) could be utilized while also looking at the possibility of employing the returns and volatilities series of the variables in future studies.

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Appendix

Table A: Descriptive Statistics and Correlation

Statistics	REQUITY	CORN	SBEANS	TINDEX	WHEAT
Mean	10.195	4.442	11.423	103.122	5.552
Median	9.900	3.640	10.110	106.224	5.080
Maximum	18.200	8.490	17.900	119.228	9.140
Minimum	4.600	2.790	7.8400	89.597	3.260
Std. Dev.	2.607	1.512	2.507	9.341	1.378
Skewness	0.541	1.130	0.614	-0.064	0.672
Kurtosis	3.638	2.732	1.995	1.3440	2.326
Jarque-Bera	112.102*	368.228*	178.970*	195.964*	160.497*
Probability	0.000	0.000	0.000	0.000	0.000
Observations	1705 1705	1705 1705	1705	1705	1795

Correlation

Variables	REQUITY	CORN	SBEANS	TINDEX	WHEAT
REQUITY	6.791				
CORN	-1.379*	2.285			
SBEANS	-1.190*	3.319*	6.280146		
TINDEX	2.736*	-10.803*	-20.266*	87.211	
WHEAT	-0.778*	1.884*	3.100*	-10.923*	1.898

Note: The * represents the 1% statistically significant level.

Table B: BDS Non-linearity test

Variable	BDS Statistic	Standard Error	Probability
Requity	0.189*	0.002	0.000
Corn	0.200*	0.002	0.000
Sbeans	0.198*	0.001	0.000
Wheat	0.195*	0.001	0.000
Tindex	0.232*	0.001	0.000

Note: The * represents the 1% statistically significant level.