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Cointegration and nonlinear causality among ethanol-related prices: evidence from Brazil

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Abstract

The objective of this study was to investigate the causal relationships among crude oil, ethanol and sugar prices in the context of Brazil. In doing so, we consider the application of ARDL bound tests to examine whether these variables comove in the long run. Besides, we employ a recently developed nonlinear symmetric and asymmetric test for noncausality which assists us to explore the short-run 'lead-lag' associations among the price indexes under review. The results of the ARDL bound test indicate that cointegration exists only when the ethanol price is used as the dependent variable. This finding suggests that oil and sugar prices lead the Brazilian ethanol prices in the long run. Moreover, the results of nonlinear causality test also confirm the existence of a short-term unidirectional causality running from sugar to ethanol market. We also document that the impact of sugar prices on ethanol prices appears to be positive indicating that rising sugar prices will cause a growth in the ethanol prices. Our findings further demonstrate that sugar prices are not affected by the fluctuations in ethanol price. The results carry important implications for policymakers.

Keywords: ARDL bound tests, Brazil, ethanol market, nonlinear causality, oil price, sugar price

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Introduction

An ongoing concern in the agricultural sector is whether rising biofuel prices could lead to a rapid upward shift in the level of important food prices. Such apprehension is not irrational, as ethanol, which is currently the world's leading biofuel, is mainly produced from food crops. More specifically, in the United States, which has recently surpassed Brazil to become the largest producing and exporting nation for ethanol in the world, corn is primarily used to generate ethanol. According to the US Food and Agriculture Organization (FAO), approximately 36% of the total corn production has been utilized to generate ethanol in 2014. This amount is not tiny, considering the fact that corn is an important staple food product in the United States. Moreover, for the production of ethanol in Brazil, sugarcane remains the main feedstock. In 2014, Brazil becomes the world's largest producer and consumer of sugarcane ethanol as a transportation fuel. Accordingly, the substantial growth in ethanol demand has raised concerns about the impact of ethanol on the price level of agricultural commodities (Bentivoglio *et al.*, 2016).

In recent times, investigating the dynamics of ethanol prices has received enormous attention in the literature due to a significant global expansion of ethanol market

during the last few years. In 2007, for instance, the worldwide production of ethanol amounts to 13 123 million gallons, while such quantity has reached 25 583 million gallons in 2016. These figures hence confirm that the overall production of ethanol has become doubled during the last decade. Although the production of this important biofuel has increased universally, the international ethanol market is predominantly led by the United States and Brazil. In 2016, the United States and the Brazilian markets account for 58% and 27% of the worldwide ethanol production, respectively. A summary of the global ethanol production for the period 2007 to 2016 is exhibited in Table 1.

Previous studies argue that rising oil prices and implementation of energy security-related policies are the main factors behind such significant increase in global ethanol production. The empirical work of Chiu *et al.* (2016) contends that biofuels have been brought into the energy market as a substitute in order to moderate the amount of carbon emissions released into the atmosphere as well as to prevent energy prices from rising. Besides, Vedenov *et al.* (2006) argue that highly volatile crude oil prices reduce crude oil competitiveness and represent a further incentive to adopt alternative energy sources. In addition, Wang *et al.* (2012) report that ethanol produced from sugarcane has reduction rates between 40% and 62% in GHG (greenhouse gas) emissions compared to gasoline. It hence appears that growth in the production of ethanol helps to reduce

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Table 1 World fuel ethanol production by country or region (million gallons)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
United States	6521	9309	10 938	13 298	13 948	13 300	13 300	14 300	14 806	15 379
Brazil	5019	6472	6578	6922	5573	5577	6267	6190	7093	7295
Europe	570	734	1 040	1209	1168	1179	1371	1445	1387	1377
China	486	502	542	542	555	555	696	635	813	845
Canada	211	238	291	357	462	449	523	510	436	436
Rest of World	315	389	914	985	698	752	1272	1490	1147	1301
World	13 123	17 644	20 303	23 311	22 404	21 812	23 429	24 570	25 682	26 583

Source: Renewable Fuels Association.

the dependence on crude oil and GHG emissions. It is also important to note that the introduction of biofuel seems reducing the prices of crude oil as well. A study by the Renewable Fuels Association (2013) claims that crude oil prices would be approximately 15–40 a barrel higher in the absence of bioethanol production additives. While finding the reason behind this interesting issue, Marzoughi & Kennedy (2012) argue that price impact of bioethanol use can be observed as a positive shock to the gasoline supply.

Considering the economic significance of the linkage between biofuel and food prices, several empirical studies have assessed the connection between ethanol and its feedstock prices. One strand of literature finds a significant long-run link between ethanol and food prices. Serra *et al.* (2011a), for instance, show that in case of Brazil, an increase in crude oil price levels increases ethanol prices, which in turn causes sugar price levels to grow. Another study by Serra *et al.* (2011b) reveals that the US ethanol prices are driven by both crude oil and corn prices. In addition, the authors document a significant association between corn and energy markets which occurs mainly through the ethanol market and contributes to explaining the strong increases in corn prices during the ethanol boom in the second half of the 2000s. Employing a nonparametric correction to time series estimations, Serra (2011) finds a long-run linkage between ethanol and sugarcane prices. The study further unfolds that crude oil and sugarcane prices lead ethanol prices and not vice versa. While analyzing the correlations between a wide array of food and fuel commodity prices in the United States and European Union (EU) over the period 2003 to 2008, Kristoufek *et al.* (2012) show that food and fuel prices tend to comove with biofuels connecting these markets. Besides, Trujillo-Barrera *et al.* (2012) demonstrate that volatility is significantly transmitted from the corn to the ethanol market, but not the other way around. Gardebroek & Hernandez (2013) also report a unidirectional volatility spillover from corn to ethanol markets. A recent study by Kristoufek *et al.* (2016) suggests that the long-run

relationship between prices of ethanol and corn appears to be positive, strong and stable in time. The study also reveals that while prices of feedstock lead the prices of ethanol, this does not hold for the opposite trend. More recently, Chiu *et al.* (2016) investigate the connections among crude oil, corn and ethanol prices over the period from January 1986 to August 2015 using a vector autoregressive model and vector error correction model. The authors show that while corn prices are driven by ethanol prices, the prices of corn do not affect the ethanol prices until 2005. The study further reports a unidirectional causality running from crude oil prices to ethanol prices throughout the sample period.

However, another line of literature fails to find any significant long-term link between fuel and agricultural commodity prices. For example, Zhang *et al.* (2009) study the volatility linkage between fuel and food commodity prices using cointegration, vector error corrections and multivariate GARCH models. The authors show that ethanol, oil and corn prices do not move together in the long run. Furthermore, Zhang *et al.* (2010) explore the long-run cointegration of ethanol and sugar prices simultaneously with their multivariate short-run interactions. Results indicate no direct long-run price relations between fuel and agricultural commodity prices, and limited if any direct short-run relationships.

It is quite evident from the existing literature that the relationship between ethanol and its feedstock prices is somewhat complex and hence, there is no specific consensus on the association between these two variables. For example, Serra & Zilberman (2013) identify 51 different studies that investigate biofuel-related prices. Out of these studies, which are published over the period 2006–2012, 20 support an existence of the link between biofuels or energy prices and feedstock prices, 13 do not support it, and 18 focus on different topics (Kristoufek *et al.*, 2016).

Our study aimed to join this discussion by further analyzing the biofuel–food nexus in one of the most developed ethanol markets using recently introduced

methodologies. To be specific, we examine whether there is any kind of long-run and short-run causal relationships between ethanol and sugar prices in Brazilian perspective. Since earlier studies (Serra *et al.*, 2011a; Chiu *et al.*, 2016 and others) document that crude oil market plays a vital role in both ethanol and its feedstock prices, we also consider WTI (West Texas Intermediate) oil prices in our analysis. Methodologically, we employ the ARDL bound tests to assess whether the variables under study are cointegrated in the long run. In addition, we consider the application of a nonlinear symmetric and asymmetric test for noncausality, proposed by Kyrtsou & Labys (2006) and Varsakelis & Kyrtsou (2008), with a view to investigating the short-run 'lead-lag' relations among the price indexes considered.

The main contribution of this article is its further investigation of the associations between ethanol and agricultural commodity prices. Although previous empirical studies evidence that causal relationships exist between ethanol and its feedstock prices, assessing such links using nonlinear causality tests is greatly ignored. To fill this gap, we investigate the direction of causality between fuel and food prices by employing nonlinear symmetric and asymmetric causality tests. The advantage of using the asymmetric nonlinear causality test is that it can verify whether the direction of changes in the considered price indexes has a significant effect on their causal associations (Ajmi *et al.*, 2013). Investigating the link between ethanol and its feedstock prices using newly developed methodology could carry significant implications given that the application of more sophisticated models may reveal additional evidence on the biofuel–food nexus. Previous researchers (e.g., Kristoufek *et al.*, 2012) also document that the use of less adequate methods might fail to capture the dynamics of the linkage between ethanol and food prices. Our study thus contributes to the existing literature through the application of the stylish models, which will further allow us to examine the stability of the dependencies between the variables under study. Moreover, investigating the price dynamics of Brazilian ethanol market does not receive much attention in the existing literature. The previous studies are mainly focused on the US market. The present work therefore aimed to extend this scarce literature.

The rest of the article is structured as follows: Section Materials and methods refers to the data considered in our empirical analysis. Section Results outlines the ARDL bound tests and nonlinear symmetric and asymmetric test for noncausality. The empirical findings are discussed in Section Discussion. Section Conclusions concludes our study.

Materials and methods

Data description

In our empirical analysis, we consider weekly prices of Brazilian hydrous ethanol (USD per liter), and sugar (USD per 50 kg bag), which are sourced from the Centre for Advanced Studies on Applied Economics. In addition, the weekly data on WTI oil price are collected from Thomson Reuters DataStream. The sample period runs from May 2003 to December 2016, yielding a total of 668 weekly observations.

Table 2 reports the descriptive statistics of different commodity indexes used. Panel A shows the results for the levels, while Panel B does the same for differenced series. One striking finding of Panel A is that the ethanol prices follow a normal distribution as the Jarque–Bera test accepts the null hypothesis of normality. The skewness and kurtosis properties further support this outcome. While considering the differenced series (see Panel B), the normality assumption is rejected in each case. Moreover, both panels confirm that oil market is more volatile than other markets as evidenced by the corresponding standard deviations. The findings of Panel B also indicate that only sugar market exhibits positive skewness. In addition, all the indices have kurtosis higher than three implying that each index has a leptokurtic distribution with asymmetric tails.

Table 3 exhibits Pearson correlation coefficients between the energy and sugar markets. The findings demonstrate significantly positive contemporaneous correlations between the price indexes under study implying that the expected changes in fuel and food prices seem to move in the same direction over the sample period. Such associations suggest the existence of close linkages among these commodity series. Furthermore, the highest correlation is observed between ethanol and sugar, which is not surprising at all, as sugarcane remains the main feedstock for producing ethanol in Brazil.

Table 2 Descriptive statistics

	Ethanol	Sugar	Crude oil
Panel (A): Levels			
Mean	0.4377	21.0082	71.0079
Standard deviation	0.1499	9.1658	24.9947
Skewness	0.1806	0.7398	0.2020
Kurtosis	2.9313	3.0665	2.2185
Jarque–Bera test	3.7670	61.1637***	21.5768***
Panel (B): 1st difference			
Mean	0.0005	0.0271	0.0359
Standard deviation	0.0205	0.8395	3.4668
Skewness	−1.0151	0.7375	−0.5674
Kurtosis	17.6001	17.3051	7.1661
Jarque–Bera test	6047.74***	5756.24***	518.95***

This table presents the descriptive statistics of weekly closing values of WTI crude oil, Brazilian sugar and ethanol markets from May 2003 to December 2016. The data consist of 668 weekly observations. Panel (A) reports the results for the levels, while Panel (B) does the same for differenced series. *** indicates statistical significance at 1% level.

ARDL bound tests

The application of ARDL bound tests is beneficial in several aspects. First, all the testing equations are allowed to have different lags. Second, it can be employed regardless of whether the underlying variables are stationary, that is, I(0); integrated of order one, that is I(1); or fractionally integrated (Bouri *et al.*, 2017). Finally, the method does not suffer from the spurious regression (Liu *et al.*, 2013). It is important to note that this test has prerequisite that series under investigation should not be integrated of order 2 or higher.

In this study, we construct the following unrestricted ARDL regressions without any time trend component:

$$\begin{aligned} \Delta Oil_t = & \omega_1 + \sum_{i=1}^n \alpha_{1,i} \Delta Oil_{t-i} + \sum_{i=1}^n \beta_{1,i} \Delta Ethanol_{t-i} \\ & + \sum_{i=1}^n \gamma_{1,i} \Delta Sugar_{t-i} + a_1 Oil_{t-1} + b_1 Ethanol_{t-1} \\ & + c_1 Sugar_{t-1} + \varepsilon_{1t} \end{aligned} \tag{1}$$

$$\begin{aligned} \Delta Ethanol_t = & \omega_2 + \sum_{i=1}^n \alpha_{2,i} \Delta Oil_{t-i} + \sum_{i=1}^n \beta_{2,i} \Delta Ethanol_{t-i} \\ & + \sum_{i=1}^n \gamma_{2,i} \Delta Sugar_{t-i} + a_2 Oil_{t-1} + b_2 Ethanol_{t-1} \\ & + c_2 Sugar_{t-1} + \varepsilon_{2t} \end{aligned} \tag{2}$$

$$\begin{aligned} \Delta Sugar_t = & \omega_3 + \sum_{i=1}^n \alpha_{3,i} \Delta Oil_{t-i} + \sum_{i=1}^n \beta_{3,i} \Delta Ethanol_{t-i} \\ & + \sum_{i=1}^n \gamma_{3,i} \Delta Sugar_{t-i} + a_3 Oil_{t-1} + b_3 Ethanol_{t-1} \\ & + c_3 Sugar_{t-1} + \varepsilon_{3t} \end{aligned} \tag{3}$$

where D denotes the first difference operator. In order to verify whether cointegrating relationship exists among the volatility indexes, it suffices to test $H_0: a = b = c = 0$. The general F-statistics are further calculated and compared with two different sets of critical values provided by Pesaran *et al.* (2001). One of these sets is used as the upper-bound for purely I(1) series, while the other is used as the lower-bound for purely I(0) series.

Table 3 Correlation coefficients

	Ethanol	Sugar	Crude oil
Panel (A): Levels			
Ethanol	1.0000	21.0082	71.0079
Sugar	0.3718	1.0000	24.9947
Crude Oil	0.1806	0.7398	1.0000
Panel (B): 1st difference			
Ethanol	1.0000	0.8594	0.6446
Sugar	0.8594	1.0000	0.4651
Crude Oil	0.6446	0.4651	1.0000

This table shows the Pearson correlation coefficients among WTI crude oil, Brazilian sugar and ethanol markets. The sample period ranges from May 2003 to December 2016 yielding a total of 668 weekly observations. Panel (A) reports the results for the levels, while Panel (B) does the same for differenced series.

Cointegration is present only if the computed F-statistic exceeds the upper-bound critical value.

Kyrtsov–Labys nonlinear symmetric and asymmetric noncausality test

One of the most popular methods to assess the lead–lag associations among different variables is the Granger’s linear test for noncausality (Granger, 1969). Later, Hiemstra & Jones (1994) also propose a nonlinear version of this test which, however, lacks power in large samples (Diks & Panchenko, 2006). In this research, we consider the application of an extended version of nonlinear Granger causality test, developed by Kyrtsov & Labys (2006) and Varsakelis & Kyrtsov (2008), by replacing the vector autoregression (VAR) structure of the Granger test with a Mackey Glass model to capture the nonlinear connections among the price indexes under study. This test is advantageous, as it does not suffer from power limitations with large samples (Jain & Biswal, 2016 and Bouri *et al.*, 2017).

For a bivariate case with two variables X_t and Y_t , the model used in our empirical investigations assumes the following form:

$$X_t = \theta_{11} \frac{X_{t-\delta_1}}{1 + X_{t-\delta_1}^{c_1}} - \gamma_{11} X_{t-1} + \theta_{12} \frac{Y_{t-\delta_2}}{1 + Y_{t-\delta_2}^{c_2}} - \gamma_{12} Y_{t-1} + v_t$$

$$Y_t = \theta_{21} \frac{X_{t-\delta_1}}{1 + X_{t-\delta_1}^{c_1}} - \gamma_{21} X_{t-1} + \theta_{22} \frac{Y_{t-\delta_2}}{1 + Y_{t-\delta_2}^{c_2}} - \gamma_{22} Y_{t-1} + \mu_t$$

where, θ_{ij} and γ_{ij} refer to the parameters to be estimated and the residuals are normally distributed. Each δ_i denotes integer delays, and each c_i is a constant to be determined prior to estimation by maximizing the likelihood of the model. In our analysis, majority of the models have maximum likelihood, using a delay of one and a constant exponent of two. Only in case of the ethanol market, we choose a delay of two.

The test consists of two steps: In the first step, the unconstrained model is estimated using ordinary least squares (OLS) method. To test for Y causing X , in the second step a constrained model with ‘ $\theta_{12} = 0$ ’ is estimated. The Kyrtsov–Labys test statistic can be derived from the sum of squared residuals of the constrained and unconstrained models, and it follows an F distribution. If the test statistic is higher than the critical value, we can reject the null hypothesis of Y not causing X . The test statistic is as follows:

$$T = \frac{(S_R - S_{UR})/n_R}{S_{UR}/(N - n_{free} - 1)} \sim F_{n_R, (N - n_{free} - 1)}$$

where, n_{free} defines the number of free parameters in the model, $n_R - 1$ indicates the number of parameters set to zero while testing the constrained model, and S_R and S_{UR} denote the sum of squared residuals in the restricted and unrestricted equations.

Our study examines symmetric and asymmetric causal relationships. The symmetric causal relationship indicates the direction of causality among the variables but fails to indicate the type or size of effect. In this study, the asymmetric test is defined to assess the effect of positive or negative changes in

the causal variable on the dependent variable. An increase (or decrease) in the causal variable might cause an increase (or decrease) in the dependent variable, which the asymmetric test will assist us to measure. To test whether nonnegative returns in series Y cause series X , an observation (X_i, Y_i) is included for regression only if $Y_{t-\delta 2} \geq 0$. The test is then performed in a similar way as defined before. Testing the reverse causality adopts the same procedure with the order of the series reversed (Bouri *et al.*, 2017).

Moreover, Varsakelis & Kyrtsov (2008) document that asymmetric causality testing tends to improve the common symmetric causality test. The test provides further insights into the impact of the causal variable on the dependent variable.

Results

Findings of ARDL bound tests

The results of different unit root tests are presented in Table 4. Panel A shows the results for price index (levels), and Panel B displays the same for the differenced series. We employ three distinct unit root tests: ADF, PP and KPSS tests. The null hypothesis of both ADF and PP tests reveals that the data are nonstationary, while that of KPSS test assumes stationarity. Although we have mixed unit root results when observing the findings of Panel (A), after differencing, all the series become stationary. Thus, none of these series is integrated of order 2.

Next, the findings of the ARDL bound tests are exhibited in Table 5. Before analyzing these results, it is essential to mention that in order to select the appropriate lag structure, the model producing the lowest Akaike information criterion (AIC) has been adopted in our analysis. As discussed in Section 3.1, one advantage

Table 4 Unit root test results

	ADF	PP	KPSS
Panel (A): Levels			
Ethanol	-2.6169*	-2.3413	1.6216***
Sugar	-2.2348	-2.0247	1.1129***
Crude oil	-2.1102	-2.4437	0.6695
Panel (B): 1st difference			
Ethanol	-18.7360***	-18.0679***	0.0365
Sugar	-12.3508***	-16.5978***	0.0587
Crude oil	-25.6829***	-26.1145***	0.1249

This table presents the results from three unit root tests for the weekly closing values of WTI crude oil, Brazilian sugar and ethanol markets from May 2003 to December 2016. These tests include ADF (Augmented Dickey Fuller), PP (Phillips and Perron) and KPSS (Kwiatkowski-Phillips-Schmidt-Shin). *** and * indicate statistical significance at 1% and 10% levels, respectively.

of using ARDL procedure is that all the testing equations are allowed to have different lags. That is, when the three different series are chosen as the dependent variables in three models, the lag structure of the model could change (Bouri *et al.*, 2017). Once the suitable lags have been selected, we test for the autocorrelation among the residuals to verify whether the selected model is correctly fitted.

It is evident from the results of Table 5 that cointegration is present among the series only when the ethanol price index acts as the dependent variable, as the F -statistic in this case appears to be higher than the $I(1)$ bound critical value. This finding indicates a significant linkage between the price levels of Brazilian ethanol market and those of crude oil and sugar. However, cointegration is not detected when the crude oil and sugar prices are considered as dependent variables. Therefore, these two commodity markets mainly depend on their own specific or occasional market factors. More importantly, the findings confirm that sugar prices are not driven by the rise and fall in ethanol prices.

Our results are consistent with several earlier studies. Serra (2011), for example, suggests that ethanol and crude oil, as well as ethanol and sugar price levels, are linked in the long-run by equilibrium parity. To be specific, the author finds that ethanol prices increase with an increase in both crude oil and sugar prices. Kristoufek *et al.* (2016) also document that the long-term relationship between ethanol and its producing factors is positive, strong and stable in time. Additionally, the study reports that prices of the producing factors lead the prices of ethanol and not the other way around.

However, the findings of our work contradict the study by Serra *et al.* (2011a) who document a casual chain running from crude oil to ethanol and finally to the sugar market. In particular, the study shows that an increase in crude oil price levels increases ethanol prices, which in turn causes sugar price levels to grow. However, we do not find any evidence that crude oil or ethanol prices tend to impact the price of sugar market in the long run. The above finding is also supported by

Table 5 Results of ARDL bound tests

Dependent variable	F -statistic	Decision
Δ Ethanol	9.7635***	Long-run association exists.
Δ Sugar	2.9088	No association is found.
Δ Oil	3.3638	No association is found.

The critical F -statistic at the 1% level for model with all $I(1)$ series is 6.36. See Table CI(iii) with $k = 2$ on page 300 of Pesaran *et al.* (2001). *** indicates statistical significance at 1% level.

Bentivoglio *et al.* (2016) who also do not find any strong evidence that variations in ethanol prices impact the sugar price levels. The authors further show that an upsurge in sugar prices tends to cause an increase in the ethanol prices.

Findings of Kyrtsou–Labys tests

Table 6 reports the symmetric and asymmetric results from nonlinear Granger causality tests. Note that according to Diebolt & Kyrtsou (2006), when nonlinear causality is detected, there exists a strong possibility that a small variation in one variable can lead to an abnormal behavior of the others. We now discuss the findings of the symmetric version of the nonlinear causality tests. These outcomes indicate that a change in sugar prices causes a change in ethanol price, but the causality from the opposite direction does not appear to be significant. That is, we find a unidirectional causality running from sugar to ethanol market. Interestingly, this is the only significant finding we have reported from our empirical assessment. Hence, we do not find any evidence that ethanol price impacts its feedstock prices. In addition, both sugar as well as ethanol prices seem to get insulated from the influence of global oil price uncertainty. The results of our short-run analyses are thus consistent with the long-run investigations. In both cases, we find that fluctuations in sugar price tend to affect the levels of ethanol price. It is also noteworthy that sugar market has a positive influence on the ethanol market implying that an upsurge in the sugar prices would cause an upward shift in the ethanol prices. As mentioned earlier, this finding is not surprising, as ethanol in Brazil is mainly produced from sugarcane. Such positive associations between ethanol and sugar prices are also consistent with earlier studies (see, e.g., Serra, 2011; Serra *et al.*, 2011a and similar others).

Next, we proceed to the results of the asymmetric version of the Kyrtsou–Labys test. Observing the results of the asymmetric case, we document that findings of

the symmetric version of the nonlinear causality tests are further supported in the asymmetrical causality case. For example, like the symmetric tests, asymmetric tests also suggest that there is a significant unidirectional causality running from sugar to ethanol market. In particular, the causality runs from positive changes in sugar price to changes in ethanol price. That is, we do not find any significant result for negative changes in sugar price. This finding simply indicates that ethanol prices seem to react more to positive changes of sugar prices compared to the negative ones, which is logical given that rising sugar prices obviously cause an upsurge in the levels of ethanol price. In addition, the fact that negative changes in sugar prices do not lead ethanol price changes indicates that the information contained in negative food price shocks cannot significantly improve the ability to predict the biofuel price changes (Bildirici & Turkmen, 2015). We further note that when oil and ethanol or oil and sugar pair is considered, no causal connection appears to be statistically significant. This finding is also consistent with the symmetric case. On the whole, the results suggest ethanol prices are strongly affected by the variations in sugar price and such impact is positive suggesting that an increase in sugar price leads to an increase in the levels of ethanol price.

Discussion

Overall, our results indicate that ethanol prices in Brazil are highly sensitive to its sugar price shocks. In other words, variations in sugar prices lead the changes in ethanol prices. Such findings are not unexpected for several reasons. First, In Brazil, a significant amount of the total sugarcane production is utilized to generate ethanol. In 2005, for instance, more than half of the sugarcane output is used for producing this leading biofuel. Second, as sugarcane remains the main feedstock for the ethanol production in Brazil, fluctuations in its price levels inevitably affect the prices of ethanol. In fact, about

Table 6 Results from the Kyrtsou–Labys nonlinear causality test

Relation	Symmetric <i>F</i> -statistic	Case Coefficient	Asymmetric <i>F</i> -statistic	Case (P) Coefficient	Asymmetric <i>F</i> -statistic	Case (N) Coefficient
$\Delta\text{Sugar} \rightarrow \Delta\text{Ethanol}$	4.0064**	0.0068**	2.7454*	0.0076*	1.0611	0.0055
$\Delta\text{Ethanol} \rightarrow \Delta\text{Sugar}$	0.0005	3.1751	1.2638	0.8439	0.4725	0.0327
$\Delta\text{Oil} \rightarrow \Delta\text{Ethanol}$	0.2635	0.0006	1.5840	0.0046	0.5272	−0.0024
$\Delta\text{Oil} \rightarrow \Delta\text{Sugar}$	2.9334	0.1689	0.0033	0.0082	0.0095	0.0139

** and * indicate that the coefficient is significant at the 5% and 10% levels, respectively. P Case indicates a causality test with positive changes in the causal variable, whereas N Case indicates a causality test with negative changes in the causal variable. We do not report the results of the relations $-\Delta\text{Ethanol} \rightarrow \Delta\text{Oil}$ and $\Delta\text{Sugar} \rightarrow \Delta\text{Oil}$, as our main interests lie in the links reported in the table. However, we do not find any evidence that sugar or ethanol causes any variations in the crude oil market. The results are available from the author.

60% of the total cost of producing ethanol is spent on the feedstock costs (Bentivoglio *et al.*, 2016). Finally, the production of ethanol has considerably increased in recent years to reduce the carbon and such emissions. Consequently, the growth in the ethanol demand has raised the production of sugarcane as well. The budget allocated for the sugarcane production has therefore shifted upward which, in turn, could lift the prices of ethanol.

One interesting outcome of our empirical analysis is that sugar prices in Brazil do not respond to the changes in international oil price. One could expect that the agricultural market in Brazil has adopted some effective measures to minimize the impact of oil price uncertainty. A more logical explanation is that the introduction of ethanol fuel greatly reduces the country's dependency on fossil fuel. We now discuss how the increased usage of ethanol lessens the cost of oil dependency in case of food markets. A common belief is that variations in oil price substantially affect the agriculture sector due to the transportation costs. According to the Key World Energy Statistics published by the Energy Information Administration (EIA) in 2014, the transport sector accounts for 63.7% of global oil consumption. From 1973 to 2012, the sector has increased its oil consumption from 1022 to 2326 million tons of oil equivalent (mtoe) on an annual basis; that is, it has more than doubled its demand. As the transportation cost plays a major role in determining the prices of food commodities, oil market has an indirect effect on the agriculture sector. As we mentioned earlier, Brazil is currently the world's largest producer and consumer of sugarcane ethanol as a transportation fuel. In fact, Brazil has replaced almost 42 percent of its gasoline needs with sugarcane ethanol – making gasoline the alternative fuel in the country (see the website 'sugarcane.org' for more information). Brazil has thus achieved a greater energy security by making ethanol a major part of its energy mix. As a result, the impact of global oil price fluctuations on the country's agriculture sector is markedly reduced.

The findings of our empirical work offer significant provisions for new research as well. For example, the information content of crude oil volatility index (OVX), published by Chicago board of Options Exchange, could be utilized for the prediction of biofuel and food market volatilities. Earlier studies (Liu *et al.*, 2013; Dutta, 2017) argue that OVX reveals more information than do the traditional oil prices and hence, OVX could be considered as a robust indicator of oil market uncertainty. Therefore, including the oil volatility index in the empirical models could provide more important evidence on the relationship between biofuel and its feedstock prices. Moreover, consistent with previous studies (Zilberman *et al.*, 2013; Bentivoglio *et al.*, 2016; Kristoufek *et al.*, 2016), we cannot claim that biofuels have no effects on the price levels of food commodity, albeit

our findings suggest so. The results might be sensitive to the time period considered, or it could also be the case that more sophisticated models should be applied to capture the impacts of ethanol on sugar prices. Zilberman *et al.* (2013), for example, argue that their results showing a little impact of ethanol price on food price do not necessarily imply that the introduction of biofuel has minimal effects on the price of food but that the analysis of the relationship between food and fuel prices cannot fully capture the impact of biofuel on food prices. In addition, Kristoufek *et al.* (2016) contend that even though the long-term relationship seems to be rather stable in time, the short-term and medium-term dynamics progress quite freely and react to an actual market situation. In order to solve this issue, the authors recommend the use of more adequate approaches that could encompass long-run equilibrium relationship between variables with impulses coming from the producing factors to ethanol. In addition, such models should allow for time-varying parameters of the short-run dynamics as well. Therefore, further research should be carried out utilizing newly developed models which could provide more insights into the relationships between ethanol and its allied markets.

Conclusions

Rising crude oil prices and inception of different energy security-related policies have caused the ethanol market to expand. Being one of the leading ethanol producers, Brazil remains extremely successful in reducing emissions of CO₂ and the dependency on fossil fuel. Compared to gasoline, sugarcane ethanol cuts carbon dioxide emissions by 90 percent on average. This amount is, in fact, higher than any other liquid biofuel produced today at commercial scale. As ethanol in Brazil is mainly produced from sugarcane, one concern in the agriculture sector could be whether the huge growth in ethanol demand would raise the prices of food commodities. Accordingly, a growing number of studies try to examine the ethanol–sugar nexus. However, the result of the existing literature is rather mixed and hence the underlying link merits further investigation. Besides, the current literature mainly concentrates on the US ethanol and food markets, while much less attention has been paid to the Brazilian markets.

In order to extend this scarce literature and shed further light on the fuel–food linkage, the present study aimed to investigate the causal relationships among oil, ethanol and sugar prices in the context of Brazil. Methodologically, we consider the application of ARDL bound tests to assess whether these variables move together in the long run. In addition, we make use of a

recently developed nonlinear symmetric and asymmetric test for noncausality which allows us to gauge the short-run 'lead-lag' relations among the price indexes used. The results of the ARDL bound test reveal that cointegration exists only when the ethanol price is employed as the dependent variable. This finding suggests that oil and sugar prices lead the Brazilian ethanol prices in the long run. Moreover, the results of nonlinear causality test also confirm the existence of a short-term unidirectional causality running from sugar to ethanol market. We also report that sugar prices impact ethanol prices in a positive manner suggesting that rising oil prices will cause an increase in the ethanol prices. The results further demonstrate that sugar prices are not affected by the fluctuations in ethanol or crude oil price.

Our findings carry important implications for policymakers. For example, the results provide evidence that sugar prices are not affected by the variations in global crude oil price and hence agriculture policies should be independent and policymakers should take into account the detachment of fossil fuel and agriculture policies. Moreover, the results of our empirical investigation also indicate that rise and fall in ethanol price would not have any significant impact on the sugar price levels in the long run. Therefore, rising ethanol prices do not seem to encourage an increase in food prices during the time period used. Thus, the concerns regarding Brazilian ethanol markets bringing higher and more volatile food prices appear to be inconsistent with the results reported in our analysis (Serra, 2011). Furthermore, the effects of sugar price on the levels of ethanol price have been supported by our empirical evidence. This finding is established by both short-run and long-run analyses. It therefore appears that uncertainty in sugar market will continue to transmit to the ethanol market in near future. It is thus important to adopt effective measures to manage the price volatility on sugar market. One such strategy could be promoting better market monitoring systems by introducing sugar futures market (Gardebroek & Hernandez, 2013). A developed and improved futures market could then limit the sugar price risk more efficiently and further make the allied markets (such as biofuel markets) more stable.

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