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## **Price Linkages in the Brazilian Sugarcane-Ethanol Industry in the Post-2008 Financial and Economic Crisis**

Bo Chen and Sayed Saghaian

The Brazilian sugarcane-ethanol industry has undergone substantial changes after the 2008 financial and economic crisis. The industry has seen a large decrease in production and policy changes concerning gasoline, the main substitute for ethanol. In this context, price linkages of commodities in this industry, including Brazilian ethanol, gasoline, and sugar prices, international crude oil prices, and prices of U.S. ethanol are investigated. The results indicate Brazilian ethanol and sugar, oil, and U.S. ethanol prices form a long-run relationship. Moreover, Brazilian ethanol prices respond to price shocks in other commodity markets and adjust to correct the disequilibrium error induced by those shocks, maintaining the long-run relationship. Corresponding industry and policy implications are also discussed.

**Key words:** 2008 financial-economic crisis, Brazil, ethanol, price transmission, policy

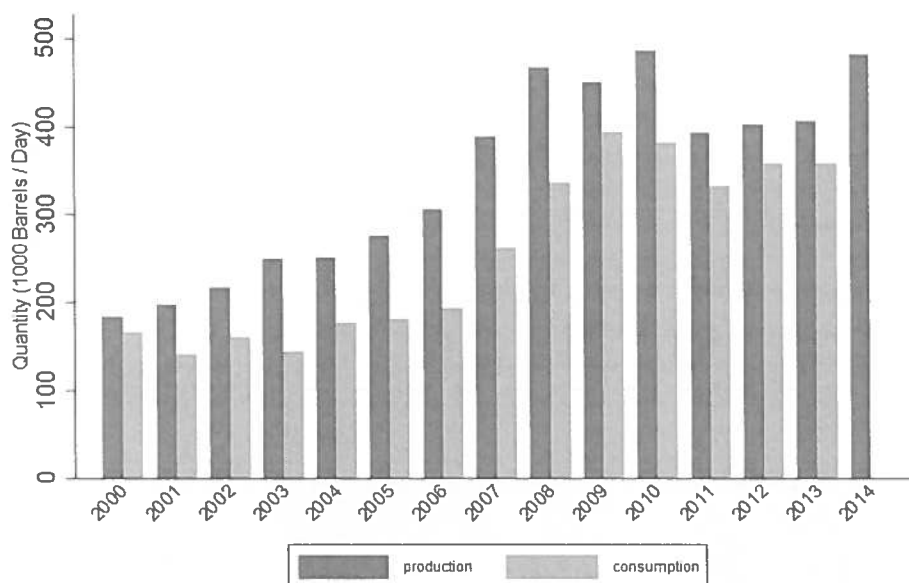
The last few decades have seen substantial expansion of the biofuel industry as an effective strategy to combat high oil prices and climate change around the world. Among the many types of biofuels, ethanol has taken the leading role. According to the International Energy Statistics from U.S. Energy Information Administration (EIA), daily production and consumption levels reached nearly 900,000 barrels per day by 2012. Ethanol production and consumption are primarily concentrated in the United States and Brazil. These two countries have contributed more than 85% of the global ethanol production and consumption since 2000.

During the past decade, and particularly with the 2008 financial and economic crisis, we have seen dramatic changes not only in the Brazilian sugarcane-ethanol industry, but also in the general macroeconomics and trade policy environments. The purpose of this article is to investigate the price linkages of Brazilian ethanol and related commodities in the post financial-economic crisis era. The objective is to investigate whether the prices of Brazilian ethanol, sugar, gasoline, international crude oil, and prices of U.S. ethanol as a competitor, are cointegrated and have a long-run relationship. We also examine the direction and magnitude of transmission among these prices after the 2008 financial and economic crisis.

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The Brazilian ethanol industry started during the oil crisis in the 1970s to reduce oil import costs. Ethanol production, consumption, export, and pricing were highly regulated and subsidized before the 1997 market liberalization the government put in place as a measure to address production shortages and demand management problems in the early 1990s (Food and Agriculture Organization (FAO), 2006). The Brazilian ethanol industry has benefited substantially from the country's long history as the world's leading sugar producer and exporter. In 2004-5, Brazil was the world's largest sugarcane, sugar, and ethanol producer (Martines-Filho, Burnquist, and Vian, 2006). In 2008-9, ethanol production peaked at a historical high of 27,526 cubic meters. However, since then, the industry has experienced a dramatic crisis, and production has not continued with an upward trend. Production dropped sharply in the 2009-10 harvest year, and did not return to the pre-crisis level until 2013-14 (Figure 1).



Source: For 2000 to 2012, the data comes from U.S. Energy Information Administration (EIA). For 2013 and 2014, data is from Brazil Sugarcane Industry Association. The consumption in 2014 is missing from both sources.

**Figure 1. Production and Consumption of Fuel Ethanol in Brazil**

The decrease in production is partially attributed to the global financial crisis of 2008, which led to decreased investments in this sector (Angelo, 2012). A second important factor contributing to the production decrease is the relatively higher sugar prices. Due to the fact that both sugar and ethanol are produced from sugarcane, the relative prices of

these two commodities determine whether sugarcane is devoted to ethanol or sugar production. Prior to 2008, this relationship favored ethanol over sugar (Valdes, 2011). However, as shown in Figure 2, sugar prices moved higher after 2009, and more sugarcane was consequently moved into sugar production, resulting in a decrease in ethanol production. The immediate consequence of the ethanol production decrease was an increase in ethanol prices (Figure 2).

Moreover, the popularity of the flex-fuel vehicles on Brazilian roads has been a major driving factor behind demand for ethanol. Flex-fuel vehicles can take any mix of pure gasoline and pure ethanol, helping to establish ethanol as an independent fuel and making it easier for consumers to substitute between these two fuel types (de Freitas and Kaneko, 2011). As a result, the high ethanol prices coupled with the substitutability of ethanol for gasoline incentivized consumption of gasoline and reduced demand for ethanol.

Another effect of the production decrease concerns Brazilian ethanol trade. Until 2008, Brazil was the largest exporter of ethanol, supplying 62% of ethanol traded in world markets. However, the United States replaced Brazil as the largest ethanol exporter in 2009 (Valdes, 2011) and, along with the decline in exports was the sharp increase in imports in order to meet the domestic demand, with a majority of the imports coming from the United States. More importantly, in 2010, the Brazilian government ended its 20% import tariffs on ethanol and, immediately following, the United States also eliminated its \$0.54/gallon tariff on imported ethanol (Kish, 2012; Valdes, 2011). The reduction of tariff barriers is beneficial to ethanol trade. This is also conducive in creating a strong linkage between ethanol prices in the two countries.

Furthermore, gasoline and ethanol price relationships have not been solely driven by market factors. Government policies have also played substantial roles, affecting consumption and prices of both commodities. In 2011, the Brazilian government devised a policy to cap gasoline prices in order to keep domestic inflation under control, which provided additional incentives for substitution of ethanol for gasoline (Angelo, 2012). This incentive was further strengthened in 2012 by the expiration of the Contribuição e Intervenção no Domínio Econômico (CIDE) fuel tax on gasoline. The Brazilian ethanol market is currently relatively free of government intervention, though the government still manages the aggregate demand by adjusting the mandatory blending ratio of hydrous ethanol into gasoline.

The remainder of the paper is arranged as follows: The next section presents a brief discussion of the related literature. Section 3 describes the dataset used in this study. Section 4 presents the empirical model and estimation results. Section 5 discusses the implication of the results for the relevant industries and concludes.

### **A Brief Literature Review**

The literature is rich in this area. One of the well-known arguments in the literature is food verses fuel. The logic behind this argument is straightforward: since the production of food and ethanol competes for agricultural resources, a surge in demand for ethanol attracts resources into ethanol and away from food production, reducing food supply and driving up prices. This argument received much attention during the 2007 global food crisis when 25% of corn stocks in the United States, the predominant exporter of corn worldwide, was used to produce ethanol in that year (Headey and Fan, 2008).

The biofuel research extends far beyond the food verses fuel debate. Serra and Zilberman (2013) give an extensive review of this ever-growing literature on the price linkages of biofuel and other agricultural commodities. Since ethanol is primarily made from corn in the United States, corn is the focus in the U.S. context and the studies on U.S. ethanol generally include corn price analysis. However, sugarcane is the major input and the focus in the Brazilian biofuel industry, and sugar prices are included in the studies on Brazilian ethanol.

In the Brazilian context, Balcombe and Rapsomanikis (2008), with a Bayesian methodology and data spanning from 2000 to 2006, found Granger causal relationships in prices from oil to sugar to ethanol. In this study, an increase in oil prices triggers expectation for further oil price increases and stimulates a higher inventory demand for ethanol, leading to higher sugar prices, while a decrease in oil prices eases the demand for ethanol, resulting in downward adjustments in sugar prices. Moreover, ethanol production costs affect the price differential between ethanol and oil, and only when their price differential passes a threshold and the oil price is substantially higher than the ethanol price does the ethanol price adjust to the oil price.

Capitani (2014) goes beyond the oil-sugar-ethanol linkages and studies the price relationships between these three commodities with an array of other agricultural commodity prices in Brazil, including soybeans, corn, wheat, rice, and cassava prices from 2004 to 2014. However, he finds insignificant impact of prices of sugarcane, ethanol, oil, and exchange rates on the other commodity prices considered in the study.

In the United States, favorable government policies have also greatly benefited the ethanol industry. As early as 1978 in the Energy Tax Act, import of ethanol was taxed, and tax exemptions were made for the sale of gasoline mixed with at least 10% alcohol (McDonald, 1979). The Renewable Fuel Standards (RFS) in 2007 mandated high blending requirements for renewable fuel by 2022. With these policies, the U.S. government aims to support the ethanol industry, reduce pollution and reliance on foreign oil, and create jobs domestically.

Serra et al. (2011) employed a nonlinear time series method to study the price relationships among U.S. ethanol, corn, oil, and gasoline prices from 1990 to 2008. Their

results showed cointegration relationships among the four commodity prices and, more noteworthy, showed an increase in energy prices contributed to the increase in corn prices via the ethanol link. Saghaian (2010) studied the oil-ethanol-corn linkages with U.S. data from 1996 to 2008 with a directed graph theory modeling approach. He found strong correlation among the prices, but the evidence for causation from the energy sector to agricultural commodity markets was inconclusive.

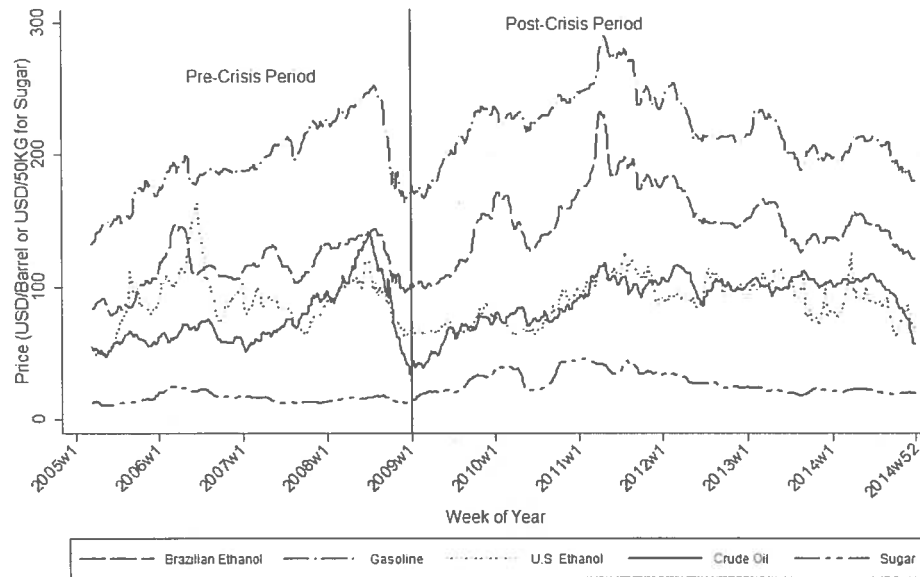
### Data Description

Weekly prices of Brazilian hydrous ethanol, sugar, gasoline, and crude oil prices in the international markets and U.S. ethanol prices are chosen for this study. The data range is from 2005 to 2014. The Brazilian ethanol and gasoline prices are from the Brazilian National Agency of Petroleum, Natural Gas, and Biofuels. The units were converted to U.S. dollars per barrel for both commodities. The exchange rates are the PTAX Dollar Exchange Rate from the Central Bank of Brazil. The sugar prices are obtained from the Center for Advanced Studies on Applied Economics (CEPEA) of the University of San Paulo. The unit is in dollars per 50 Kg and the original daily data is converted to weekly data by averaging over one week's price.

The U.S. ethanol price is from the Agricultural Marketing Resource Center and the unit is in U.S. dollars per barrel. Average price of the Cushing, OKWTI spot price FOB and the Brent Spot price FOB are chosen as the crude oil prices. The data source is the EIA. Prices for Brazilian ethanol and gasoline in week 25 and 26 of 2010 and U.S. ethanol in week 48 of 2009 were missing, and they were filled by simple averaging. Moreover, only prices transformed by natural logarithm are used in the subsequent empirical analysis so that the estimated coefficients can be interpreted as elasticities. Henceforth, if not specified as the original price, all prices are in their natural logarithm form in the next section.

Figure 2 plots the original price movements during the period under study. One notable feature lies in the possible structural changes in the second half of 2008 during which the global financial crisis broke out. All of the energy prices dropped substantially with the crude oil price experiencing the steepest descent. Moreover, before 2008, Brazilian ethanol and gasoline prices seemed to have an upward trend, while after 2009, the prices were adjusting around a higher level. Thus we tentatively characterize the structural change as a shift of the mean in these price series. In the following analysis, we will formally test for this mean shift. It also needs to be noted that Brazilian ethanol and gasoline prices show strong signs of co-movements, reflecting the substitution relationship between the two commodities. Furthermore, even in the post-crisis era, the prices of the two commodities have experienced other shocks besides supply and demand

dynamics of biofuel. One important factor is the fluctuation of the exchange rate of Brazilian real to U.S. dollar. Given the Brazilian policy of stabilizing the domestic gasoline price to contain inflation as discussed above, the post-crisis era has first seen an appreciation of Brazilian real to U.S. dollar and then a depreciation until the end of 2014. This contributes to the initial increase and then decrease of Brazilian ethanol and gasoline price denominated in U.S. dollars after 2009.



**Figure 2. Price of Brazilian Ethanol, Gasoline, Sugar, U.S. Ethanol, and International Crude Oil**

Another feature of interest concerns ethanol prices in the two countries. During the initial periods, the Brazilian and U.S. ethanol prices stayed close to each other, while after 2009, Brazilian ethanol prices were significantly higher than U.S. ethanol prices. The higher prices after the global financial meltdown well reflect the short supply and high demand for ethanol in the Brazilian markets, and it is consistent with the large Brazilian imports of U.S. ethanol.

### Empirical Model and Estimation Results

Johansen cointegration analysis has been widely used to study price relations and price transmission in various agricultural commodity markets (Johansen, 1995; Johansen and Juselius, 1990). Herein we employ this analytical framework to study the post-crisis price linkages of Brazilian ethanol, sugar, gasoline, and U.S ethanol. Our analysis begins with the investigation of the time series properties of the prices. First, the Perron and Vogelsang unit root test with mean shift (Perron and Vogelsang, 1992) is performed on all prices during the entire period to study the timing of the potential mean shift<sup>1</sup>. We use this timing ( $T_b$ ) to define the post-crisis era during which our following analysis is carried out. Subsequently, the Augmented Dickey Fuller (ADF) test (Dickey and Fuller, 1979) and KPSS test (Kwiatkowski et al., 1992) are used to test for the stationarity of the series in the post-crisis era; the two tests have different null hypotheses and their results can be confirmatory to one another. Then we apply the Johansen test to find the number of cointegration relationships among the prices. Based on the cointegration results, we estimate the vector error correction model (VECM) to quantitatively analyze the long-run price linkages and short-run price adjustments among these commodities.

Table 1 shows the result of the Perron and Vogelsang test. All prices are nonstationary, and four of them have a shift in the mean of the price series. More importantly, the timing of the mean shift for sugar and crude oil prices coincides with the observed structural change at the end of 2008 in Figure 2. The break point for Brazilian ethanol is also around this time even though there is a 24-week lag. Therefore, the existence of a structural change in the Brazilian sugar-ethanol industry can be established. In order to simplify our analysis, we unify the slightly differing break points to week 1 in 2009 and base our further analysis on periods after 2009 according to our research aim of investigating the post-crisis price linkage. Stationarity test results for prices after 2009 are reported in Table 2. The two tests confirm that the level of prices of Brazilian ethanol, gasoline, U.S. ethanol, and crude oil are not stationary, while after first differencing all of the series become stationary. Thus, these series are  $I(1)$  processes. The ADF test fails to reject non-stationarity of the sugar price level, while the KPSS test fails to reject the stationarity of the sugar price level, even though both tests indicate the first difference of the sugar price is stationary; the potential of analyzing a mixture of  $I(0)$  and  $I(1)$  series does not invalidate Johansen cointegration procedure (In and Inder, 1997).

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<sup>1</sup> This timing is often referred to as “break point” in the literature.



**Table 1. Perron and Vogelsang Unit Root Test with Mean Shift**

	(p - 1)	$\delta$	$T_b$
Brazilian Ethanol	-0.02460 (-3.804)	0.00716 (2.699)	2009w24
Sugar	-0.01428 (-3.422)	0.00834 (2.651)	2008w48
Gasoline	-0.02001 (-3.141)	0.00221 (1.236)	2008w48
U.S. Ethanol	-0.03954 (-3.354)	-0.01740 (-2.415)	2006w24
Crude Oil	-0.02651 (-4.087)	0.00732 (2.098)	2008w51

Note:  $T$  statistics in parenthesis.  $p$  is the coefficient of the price series with one lag, and like the ADF test, a test of  $p$  against 1 is used to determine the stationarity of the series.  $p$  does not have a standard  $t$  distribution and thus 5% critical value is -4.270.  $\delta$  is the coefficient of the plus variable (Clemente, Montañes, and Reyes, 1998) and  $T_b$  is determined by a search over the entire sample which maximize the  $t$  statistic for testing  $\delta=0$  (Perron and Vogelsang, 1992). A test of  $\delta$  against 0 tests the existence of a structural change.

**Table 2. Stationarity Tests of the Prices of Brazilian Ethanol, Sugar, Gasoline, U.S. Ethanol and Crude Oil**

	Level		First Difference	
	ADF	KPSS	ADF	KPSS
Brazilian Ethanol	-2.05	0.443	-10.747	0.047
Sugar	-3.461	0.4	-8.051	0.0843
Gasoline	-2.33	0.442	-13.885	0.0694
U.S. Ethanol	-2.474	0.427	-19.795	0.0364
Crude Oil	-1.797	0.462	-16.6	0.0947

Note: Both tests test for trend stationarity. For the ADF test, 1%, 5% and 10% critical values are -3.988, -3.428 and -3.130 respectively. The lag is chosen based on Hannan-Quinn Information Criterion (HQIC). For the KPSS test, 1%, 5% and 10% critical values are 0.216, 0.146 and 0.119 respectively. Autocovariances are weighted by Bartlett Kernel and lag is chosen according to Newey and West (1994).

### Johansen Cointegration Test

The Johansen cointegration test starts with the vector autoregressive (VAR) model:

$$(1) \quad P_t = \mu + \Pi_1 P_{t-1} + \dots + \Pi_k P_{t-k} + \phi D_t + \varepsilon_t$$

where  $P_t$  is a  $4 \times 1$  vector with its elements being the price series under investigation, namely, the prices of Brazilian ethanol, sugar, gasoline, and U.S. ethanol.  $D_t$  is a stationary, weak exogenous variable. The international crude oil price is an important

factor affecting both the biofuel and sugarcane industries whereas, due to their relatively smaller size and importance, it is unlikely that prices of these commodities would substantially affect crude oil prices in the long run. Hence, we include the crude oil price as a weak exogenous variable in the model.  $D_t$  is thus specified as the first difference of crude oil price.  $\mu$  is the  $4 \times 1$  intercept vector and  $\Pi$ s are  $4 \times 4$  matrices of parameters of lagged prices. Since we cannot observe a clear trend in the price series, we restrict  $\mu$  to be 0 for all prices.  $\varepsilon_t$  is the error vector and is assumed to follow multinomial normal distribution.  $k$  is the number of lags of the prices, which is usually determined by various information criteria. Equation (1) can be rewritten in the error correction form as:

$$(2) \quad \Delta P_t = \mu + \Gamma_1 \Delta P_{t-1} + \cdots + \Gamma_{k-1} \Delta P_{t-k+1} + \Pi P_{t-1} + \phi D_t + \varepsilon_t$$

where  $\Gamma_j = -I + \Pi_1 + \cdots + \Pi_j$  for  $j=1, \dots, k-1$  and  $\Pi = -I + \Pi_1 + \cdots + \Pi_k$ . If all of the price series are  $I(1)$  processes, the differential vectors in (2) and  $\Pi P_{t-k}$  should be stationary. Thus,  $\Pi$  contains the long-run relationship among these prices.  $r$  is denoted as the rank of  $\Pi$ .

When  $r = 0$ ,  $\Pi$  is a zero matrix. That is, no linear combination of the prices is stationary and no long-run relationship exists among the prices. When  $r = n$ , the price series are stationary, and a VAR model is sufficient to model the prices. When  $0 < r < p$ , there are  $r$  combinations of prices that are stationary, and thus there exist  $r$  long-run relationships among the prices. To obtain  $r$ , Johansen and Juselius (1990) suggest ordering the eigenvalues of  $\Pi$  from highest to the lowest and using a trace test, which is based on the likelihood ratio to sequentially test whether the eigenvalues are statistically different from zero. The number of cointegration relationships equals the number of positive eigenvalues in  $\Pi$ .

The trace test results are sensitive to the specification of the constant and the trend in the model. We implement the trace test with two specifications: unrestricted constant which allows a linear trend in the data, and restricted constant which does not allow for linear trends. The results of the test are shown in Table 3. As shown, in both models the null hypothesis of  $r = 0$  is rejected, but  $r = 1$  cannot be rejected. Thus, there is one long-run relationship among the price series. Since we cannot find a clear trend in the level of the series, we chose the restricted constant specification for the subsequent analysis.

**Table 3. Johansen Cointegration Test**

r	Eigenvalue	Restricted Constant		Unrestricted Constant	
		Trace statistic	5% Critical Value	Trace statistic	5% Critical Value
1	0.111	75.485	63.561	75.393	73.128
2	0.063	39.09	42.602	39.029	50.075
3	0.043	18.825	25.568	18.801	30.912
4	0.017	5.314	12.282	5.31	4.966

### Normalization and Restriction Tests

When  $0 < r < p$ ,  $\Pi$  can be decomposed into  $\Pi = \alpha\beta'$  where  $\beta$  is the cointegration vector reflecting the long-run relationships among the prices, while  $\alpha$  is the adjustment vector showing the speeds of adjustment of each price series to a deviation from the long run. However, it is important to note that decomposition of  $\Pi$  into  $\Pi = \alpha\beta'$  is not unique. In fact, given  $4 \times 4$  invertible matrix  $H$ ,  $\Pi = \alpha\beta' = \alpha HH^{-1}\beta' = (\alpha H)(\beta H^{-1})'$  and, henceforth, there are numerous estimates of  $\alpha$  and  $\beta$ . This raises the identification of the model.

One way to identify  $\beta$  is to normalize the eigenvector of  $\Pi$  corresponding to the positive eigenvalues by  $\hat{\beta}'S_{11}\hat{\beta} = I$  and continue to normalize each vector on its first element (Johansen, 1995). From the above analysis, we get  $r = 1$  and thus, there is only one  $\hat{\beta} = (1, -0.337, -0.198, -0.245, -0.282)$ ; the elements of the vector are Brazilian ethanol, sugar, gasoline, U.S. ethanol and crude oil, respectively. Since we have only one cointegration vector, this normalization has already uniquely identified the model.

However, two issues remain: First, there might be some variables in the cointegration vector that are not significantly different from zero; this is also referred to as the exclusion restriction. Second, we are also interested in finding out whether there is a complete pass-through of price transmission among the prices and we need to restrict some of the variables in the cointegration vector to be equal. To test for the validity of these restrictions on  $\hat{\beta}$ , Johansen (1995) proposed a likelihood ratio (LR) test. The LR test statistic follows a  $\chi^2$  distribution.

The tests results of these restrictions are shown in Table 4. As shown, we reject that the gasoline price is in the cointegration vector with other price series, but fail to reject that Brazilian ethanol, sugar, U.S. ethanol, and crude oil prices form a long-run relationship. By excluding gasoline prices from the cointegration, we continue to put complete pass-through restrictions on the price pairs of Brazilian ethanol and sugar,

Brazilian ethanol, and U.S. ethanol, and Brazilian ethanol and crude oil prices. All of the complete pass-through restrictions are rejected, indicating no complete pass-through during the price transmission process.

**Table 4. LR Tests on the Cointegration Vector**

Null hypothesis	LR statistics	p value
$\beta_1 = 0$	12.665	0
$\beta_2 = 0$	10.62	0.001
$\beta_3 = 0$	0.427	0.514
$\beta_4 = 0$	5.869	0.015
$\beta_5 = 0$	10.668	0.001
$\beta_1 + \beta_2 = 0, \beta_3 = 0$	19.903	0
$\beta_1 + \beta_4 = 0, \beta_3 = 0$	15.13	0.001
$\beta_1 + \beta_5 = 0, \beta_3 = 0$	17.938	0

#### Vector Error Correction Model Estimation

Based on the previous restrictions, we only exclude gasoline prices from the cointegration vector and estimate the vector error correction model. The results are shown in Table 5. First, Brazilian ethanol, sugar, U.S. ethanol, and crude oil prices are shown to be cointegrated and have a long-run relationship. If the prices of sugar, U.S. ethanol, and crude oil increase by 1%, the ethanol price will increase by 0.407%, 0.264% and 0.309%, respectively, in the long run. This result highlights the importance of sugar prices in the price formation of ethanol. Moreover, the international macroeconomic environment and competition from the U.S. ethanol sector also have substantial impacts on the Brazilian ethanol prices through prices of crude oil and U.S. ethanol.

The linear combination of the prices by  $\beta$  indicates the deviation from the long-run equilibrium, while  $\alpha$  indicates how fast a price is adjusting to the deviation. The common  $t$ -test on each element of  $\alpha$  is the weak exogenous test, showing whether a price adjusts significantly to deviation from the long-run equilibrium. In our analysis, only the Brazilian ethanol price is adjusting significantly to the deviation of long-run equilibrium and, if there are shocks to sugar, U.S. ethanol, or crude oil price, the Brazilian ethanol price adjusts itself to maintain the long-run cointegration. For each week, a 4.8% deviation from the long-run equilibrium would be eliminated. Additionally, even though the gasoline price does not form a long-run relationship with the other prices, it does

significantly affect the Brazilian ethanol price in the short run. The crude oil price also affects all other prices in the short run.

Table 5. Vector Error Correction Model (VECM) Results

	Brazilian Ethanol	Sugar	Gasoline	U.S. Ethanol
$ECT_{t-1}$	-0.048 (-3.187)	0.028 -1.381	-0.016 (-1.183)	0.098 -1.945
$\Delta EtOH_{t-1}$	0.779 -9.523	0.071 -0.635	0.097 -1.338	0.522 -1.908
$\Delta Sugar_{t-1}$	0.091 -2.596	0.815 -16.996	0.043 -1.375	0.066 -0.56
$\Delta Gas_{t-1}$	-0.659 (-6.265)	0.043 -1.375	0.061 -0.65	-0.827 (-2.353)
$\Delta USEtOH_{t-1}$	0.003 -0.199	0.066 -0.56	0.013 -0.871	-0.129 (-2.308)
$\Delta Oil_{t-1}$	0.155 -5.418	0.077 -1.975	0.149 -5.864	0.401 -4.196
$\Delta Oil_{t-2}$	-0.06 (-2.048)	0.018 (-2.048)	-0.042 (-1.626)	0.023 -0.237
$\beta$	$EtOH_{t-1} - 0.407 Sugar_{t-1} - 0.264 USEtOH_{t-1} - 0.309 Oil_{t-1} - 1.098$			

Note: Standard error in parentheses.

### Conclusions and Recommendations

The post-2008 financial-economic crisis years have seen substantial changes in ethanol, gasoline, and sugar markets, coupled with changes in industrial and trade policies. Under these market conditions and policy changes, and given the impacts of these policies in favor of gasoline consumption and also gasoline and ethanol substitutability, the purpose of this study was to investigate the long-run relationships and price transmissions among Brazilian ethanol, gasoline, and sugar, international oil, and U.S. ethanol prices in the 2008 post-crisis era.

Johansen cointegration analysis was applied to study the price relationships among those five variables for the period after the 2008 financial and economic crisis, and cointegration was found among Brazilian ethanol and sugar, U.S. ethanol, and crude oil prices. The results indicate these four price series form a long-run relationship, and Brazilian ethanol price adjusts to changes in other prices to restore the long-run relationship. However, the Brazilian ethanol price does not have a significant impact on the other prices in the long run.

These results point to the significant role of imported U.S. ethanol and international crude oil prices in the formation of ethanol prices in the Brazilian ethanol industry. In order for domestic Brazilian ethanol to gain and maintain a competitive advantage over imported U.S. ethanol or the international crude oil, it is crucial for the industry to maintain an efficient production level so the domestic ethanol price can be competitive. The 2008 economic and financial crisis contributed to the production shocks in the following years and further served to lead to high prices of ethanol, making it difficult to compete with imported ethanol or crude oil. However, government policies affected its relative competitiveness through the taxation on imports, impacting its consumption relative to U.S. ethanol or crude oil.

These results are consistent with those of Balcombe and Rapsomanikis (2008) in pointing out that the Brazilian ethanol price is also influenced by sugar prices in the long run, but the direction of the price impact is only one way from sugar to ethanol. Since sugar and ethanol are joint products from sugarcane, the industry can adjust production of these commodities depending on their relative prices. When the sugar price is increasing, more sugarcane can be devoted to producing sugar, while more ethanol can be produced if its price is rising. This production process highlights the importance of market analysis and price prediction of sugar and its impact on ethanol price discovery. It follows naturally for the ethanol industry to monitor sugar prices closely. This is also of special importance for Brazil, the largest sugar producer worldwide. Its sugar price has a profound impact on international sugar prices.

Furthermore, even though the government sets the mandatory blending ratio of ethanol into gasoline, the demand for ethanol is still elastic. This is partially contributed by the popularity of the flex-fuel vehicles which makes switching between the two fuels virtually costless. When ethanol prices are relatively higher than gasoline prices, consumers substitute gasoline for ethanol. Thus, the demand of ethanol is critically dependent on the relative prices of ethanol and gasoline. In this regard, to produce efficiently and keep prices low, it is key to render ethanol competitiveness with gasoline. Also, the price advantage brought by an efficient production process is important for this sector when facing increasing competition from the U.S. ethanol industry. Hence, this industry must make strategic decisions to investment and increase research and development expenditures to stay competitive.

Additionally, Brazilian policies might have well contributed to the failure of finding a long-run relationship in this research between ethanol and gasoline. As discussed, the expiration of the CIDE tax and the government policy of stabilizing gasoline prices in order to control inflation kept gasoline prices artificially low, giving gasoline an advantage over ethanol. Thus, energy policies which aim to promote the biofuel industry, and also achieve other macroeconomic goals such as controlling inflation, are important

tasks faced by Brazilian policymakers. For the sugarcane-ethanol industry, a thorough understanding of the policy environment and the market conditions in which the industry operates are essential for industry leaders and policy makers to determine the right strategic production and marketing decisions.

Lastly, the limitations of this research are several: First, there was no differentiation between hydrous ethanol and anhydrous ethanol since their prices are highly correlated. However, hydrous ethanol is largely a substitute for gasoline while anhydrous ethanol is a complementary good for gasoline. Analyzing the differential relationships between these two types of ethanol and gasoline could yield new insights into the ethanol-gasoline price linkages. Also, this research does not aim to directly and specifically evaluate the welfare impacts of Brazilian government policies on consumers and the ethanol industry. Further research in this area can enrich the understanding and evaluation of the policy environment.

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