The Relationship among Ethanol, Sugar and Oil Prices in Brazil: Cointegration Analysis with Structural Breaks

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Abstract

Ethanol has gradually gain momentum in the world's energy market in recent decades with Brazil the largest producers. The issue of price linkage among ethanol, sugar and oil is particular interesting and important in the context of Brazilian sugarcane sector. By accounting for the possible structural breaks in the data, we investigate the price linkage of the three commodities and discover that prices are not cointegrated in the first sub-periods but cointegrated in the second sub-period. Also oil price demonstrates weakly exogenous to the prices of the other two commodities; sugar prices appears to drive the ethanol price in the first sub-periods while in the second sub-period, they influence one another.

Key words: Biofuel, Break Points, Cointegration, Ethanol, Oil, Sugarcane, Price

Introduction

The recent decade has seen a strong growth in the consumption and production of biofuels. Biofuels provide alternative energy source to fossil fuels, which has an important economic ramifications especially for developing countries in the face of high and volatile oil prices. Also, production and consumption of biofuels is an important strategy to reduce the greenhouse gas emissions and contain global warming. Further, the development of biofuels meets the social expectation of multifunctional agriculture: agriculture needs to supply the society with not only traditional food and fibers but also additional goods and services including biofuel (Jordan and Warner 2010).

Ethanol is one important type of biofuels. Ethanol is consumed either as an additive to gasoline or directly as fuel and ethanol can be made from various agricultural food and feedstock. United States and Brazil have long been the major producers and consumers of ethanol, contributing to more than 85% of the world's total consumption and production since the 2000[1]. One primary difference between the ethanol industries in the two countries is that while most U.S. ethanol is produced from corn, Brazilian ethanol is largely based on sugarcane.

There are strong linkages among U.S. agricultural sector, ethanol sector and oil market. That a large proportion of U.S. corn production[2] is used to make ethanol creates a strong linkage between the ethanol market and the grain market. This generates the well-known debate of food or fuel. On the other hand, the mandatory blending of ethanol to gasoline

[1] Observed from International Energy Statistics from U.S. Energy Information Administration. Retrieved from http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm on Dec. 15, 2014.
[2] Observed from U.S. Bioenergy Statistics, USDA/ERS. Since 2000, an increasing proportion of corn harvested in United States is used for ethanol production, and in recent years, the proportion has reached up to 40% on average annually.

generates the linkage between the biofuel and oil market. Under the Energy Independence and Security Act of 2007, 36 billion gallons of renewable fuel need to be blended into transportation fuel by 2022. In the literature many studies henceforth focus on the price relations among ethanol, corn and oil markets in the U.S. context, which reflects the important roles U.S. plays in the global agricultural and energy markets. Saghaian (2010) raises the question of whether volatility on oil market would spread to the agricultural commodity market through the biofuel mandate. With a directed graph theory modelling approach, he finds mixed evidence of causality from oil market to commodity market. Serra, et al. (2011) applies a smooth transition vector error correction model to study the price relationships among ethanol, corn, oil and gasoline and concludes that long-run relationships exist among the four prices.

However, studies isolating the U.S. market from the global context can only lead to partial understanding of the price relations of the related commodities. It needs to be pointed out that the development of the sugarcane industry can have a large bearing not only on the ethanol market in both Brazil and United States but also the global sugar market. First, Brazil has long been the largest producer and exporter of ethanol and Brazilian sugarcane-based ethanol can be more efficiently produced than the U.S. corn based ethanol (Zhang, et al. 2007). Second, the U.S. congress has eliminated the heavy tariff on imported ethanol and subsidy to domestic producer in United States (Kish 2012). The opening of the U.S. ethanol market could render Brazilian ethanol more significant influence on the U.S. biofuel market. Third, because ethanol and sugar are joint products from the Brazilian sugarcane industry and Brazil has the dominant role in the world market of both commodities, it is straightforward to conclude that the two commodity markets could have strong impacts on each other. Therefore, including the Brazilian ethanol and sugar industry under investigation substantially extends the ongoing research of agricultural and energy markets.

Current studies on the Brazilian sugarcane industry seems to be scarce. Balcombe and Rapsomanikis (2008) studies the nexus of sugar-ethanol-oil nexus in Brazil with a nonlinear vector error correction model and finds that sugar and ethanol prices adjust nonlinearly to the oil price while sugar and ethanol prices adjust to one another in an linear manner. This paper also aims to discover the price linkage of the three commodities in Brazil. The main contribution is that we explicitly account for the possible break points and different linkages of the price series of the three commodities because of a series of events in these markets happened in or around 2008. For example, global sugar price began to rise since 2008, oil price plummeted in the second half of 2008 and ethanol production decrease initiated in the economic crisis (Angelo 2012).

The remainder of the paper is arranged as follows. In section 2, a brief introduction of the Brazilian sugarcane industry is offered. Then follows the description of the data. Econometric methodology, including the stationarity test with breaking points, vector autoregressive (VAR) model and vector error correction (VECM) model. Empirical results and corresponding implications are discussed. The last section concludes and point out some limitations of this paper.

Brazilian Sugarcane Industry

Brazil has a long history of producing ethanol from sugarcane which is facilitated by its tropical natural environment. However, the commercial use of sugarcane for ethanol production did not begin until the first oil crisis in the 1970s. In order to reduce the dependence on imported oil, the Brazilian launched the National Alcohol Program to promote ethanol production and made it mandatory to blend oil with ethanol at a fixed ratio (FAO 2006; Valdes 2011). Initially, the production and export of ethanol was highly regulated. However, in the 1990s, the market was gradually deregulated and currently the government does not directly control the ethanol sector but still maintains the mandatory blending ratio of ethanol to gasoline (FAO 2006).

The joint product nature of ethanol and sugar from sugarcane creates a unique linkage between the biofuel market and the agricultural commodity market in Brazil. Since the production of ethanol and sugar competes for the same raw material and total acreage for sugarcane production is fixed, at least in the short run, it is straightforward that an increase in the price of one commodity would divert away resources from the production of the other commodity, increasing its marginal cost of production (Martines-Filho, et al. 2006). And this contributes to the price rise of this commodity. Thus, prices of the two commodities are expected to move in the same direction. Until 2008, due to the high demand for ethanol domestically and the low price of sugar in the international market, ethanol production is favored over that of sugar (Valdes 2011).

The price linkage between ethanol and oil is somewhat more complex because ethanol and oil are both complements and substitutes in Brazil. On one hand, the mandatory blend ratio indicate the complementary nature of the two commodities. On the other hand, however, the ethanol was introduced as a substitute for oil so that the country can be less affected by the global oil price. Also, the popularity of the flex-fuel cars which can run entirely on hydrous ethanol adds further support to the substitution between the two commodities. Furthermore, the similar moving trends of the ethanol and oil prices (Figure 1) might suggest that these two commodities are more substitute than complement goods to each other.

Since the ethanol market is closely linked to the sugar market and oil market, it is quite likely the change in the sugar or oil market will substantially affect the ethanol market. The hike of sugar price in the international market beginning in 2008 diverted sugarcane from ethanol production to sugar production, reducing the supply of ethanol in the domestic market. This reduction was also facilitated by several factors around 2008. For example, the underinvestment in the ethanol production infrastructure due to the economic crisis and bad harvests of sugarcane in these years (Angelo 2012). The demand, however, was pushed up by the mandatory blend ratio and the popularity of flex-fuel cars. This resulted high ethanol price, even incentivizing consumers to substitute oil for ethanol.

Overall, the Brazilian ethanol and sugar market seem to experience drastic change around the year of 2008 and we thus hypothesize that the price relations and price transmission process of the three commodities in Brazil might differ across different periods. Although it can be expected that the oil price may show certain degree of exogeneity due to its large share in total fuel consumption (Rapsomanikis, et al. 2006), there is no a priori knowledge about the direction of price transmission between ethanol and sugar, and thus we leave this open as an empirical question.

Data

Weekly data of Brazilian prices of ethanol, sugar and oil are used ranging from week 21 in 2003 to week 35 in 2014 with a total of 587 observations. We choose this period for study due to data availability and comparability. As discussed above, considerable changes have happened in both the Brazilian sugarcane market and world oil market. Particularly, the surge of sugar prices accompanied by oil price fluctuation in 2008 has substantially changed the development of the price series. An initial visual examination in Fig 1 suggests that there may be a shift in the mean of the price series; after the beginning of first week of 2009, all of the three prices seem to jump to a higher level. This could give the first indication of a structural change in the price linkage among the three commodities.

The source of the data is Center for Advanced Studies on Applied Economics (CEPEA) in the University of Sao Paulo. There are two types of ethanol, anhydrous and hydrous, both of which can be used as fuel ethanol. Their price difference is small and stable. We perform simple average of these two weekly price series, convert the unit to dollars per gallon and make logarithm transformation. The sugar price, in dollars per kilogram, is a daily series and is converted to weekly series through simple average. Crude oil prices come from U.S. Energy Information Administration (EIA). Two weekly crude oil prices have been quoted: the Cushing, OKWTI spot price FOB and the Brent Spot price FOB. Similar as the treatment of ethanol prices, these two oil prices are also averaged. Logarithm transformation is further performed on sugar and oil series so that the estimated coefficients have elasticity interpretations.

Empirical Methodology

Johansen cointegration analysis and the vector error correction model (VECM) have been the major methodology in the recent price cointegration and transmission literature. Before applying the cointegration analysis, the stationarity properties of the variables under investigation need to be studied. This section briefly discusses the econometric procedures in the following analysis: Perron and Vogelsang (1992) unit root test with structural breaks and Johansen (1995) cointegration analysis. Some extensions of the linear VECM have also been discussed to justify our research method.

Unit Root Test with Structural Break

Cointegration analysis conventionally starts with the testing of unit root in the series under investigation. While an industry of unit root tests have been proposed with the advancement of time series techniques, Dickey and Fuller (1979) test (ADF) is widely used in the applied studies. It does not, however, accounts for the structural breaks which are common in the long-span time series and the standard unit root tests are biased towards non-rejection if there exists a structural break in a stationary time series (Perron 1990). As discussed before, we expect the existence of structural breaks in the price series under investigation, and thus we follow the unit root test of Perron and Vogelsang (1992) which specifically accounts for a shift in the mean in both null and alternative hypothesis.

For a price series p_t, Perron test postulates the following non-stationary mean shifting data generating process:

$$p_t = \mu + \delta_1 DTVB_t + p_{t-1} + \epsilon_t \quad (1)$$

where $DTVB_t = 1$ in $T_b + 1$ and 0 otherwise, and T_b is the shifting time. Under the alternative hypothesis, however, p_t is the trend stationary with a shift in the mean level which takes the form of:

$$p_t = \mu + \beta t + \delta_2 DVU_t + \epsilon_t \tag{2}$$

where DVU_t =1 if $t > T_b$ and 0 otherwise. Hence, before the breaking point, p_t is stationary with a mean of μ while after the breaking point, p_t is also stationary but with a mean of μ+δ_2.

Depending on whether the shift in mean happen abruptly or gradually, there are two ways to model this process: the additive outlier (AO) model and the innovational outlier (IO) model. For commodity prices, it is not likely that a shift in the mean would be completed instantly and therefore we postulate that the IO model would be more suitable to test the stationarity of the price series. Two specification issues need to be addressed in the IO model are the selection of breaking points and the number of lags of the differenced price terms. Perron and Vogelsang (1992) proposes to choose T_b within the entire sample period to maximize the t statistic of the structural change term. Conditioning on T_b, the number of lags is chosen through an joint significance F test of the lagged price differenced terms. With the application of this procedure, we can discover not only whether there is a mean shift in the price series but also the stationarity of the series given the presence of the structural break.

Cointegration Analysis

Johansen cointegration analysis starts with a vector auto regressive (VAR) model:

$$P_t = \mu + \Pi_1 P_{t-1} + \Pi_2 P_{t-2} + \cdots + \Pi_k P_{t-k} + \varepsilon_t \tag{3}$$

where P_t is a $r \times 1$ vector with its elements the price series under investigation at time t. μ is the $r \times 1$ intercept vector and Π are $r \times r$ matrices of parameters of lagged prices, both of which need to be estimated. ε_t is the error vector. k, representing the number of lags of the prices, is usually selected by various information criterion.

If all series are integrated to the order of one, by subtracting P_{t-1} on both sides of (3) and rearranging terms, the following equation can be obtained:

$$\Delta P_t = \mu + \Pi P_{t-1} + \Gamma_1 \Delta P_{t-1} + \Gamma_2 \Delta P_{t-2} + \cdots + \Gamma_k \Delta P_{t-k} + \varepsilon_t \tag{4}$$

where $\Pi = \Pi_1 + \Pi_2 + \cdots + \Pi_k - I$ and $\Gamma_k = -\sum_{j=k+1}^{p} \Pi_j$.

Since P_t is I(1) vector, and ΔP_t should be I(0) vector. The only term on the right hand side in (4) which could possibly be I(1) is ΠP_{t-1} and if the cointegration relations exist, they must be contained in ΠP_{t-1}. Johansen developed trace test and maximum eigenvalue test based on the eigenvalue of Π to determine the number of cointegration relations.

If the cointegration relations do exist, a typical VECM is conventionally estimated:

$$\Delta P_t = \mu + \alpha\beta' P_{t-1} + \Gamma_1 \Delta P_{t-1} + \Gamma_2 \Delta P_{t-2} + \cdots + \Gamma_k \Delta P_{t-k} + \varepsilon_t \tag{5}$$

where Π in equation (4) can be decomposed into $\alpha\beta'$. β is the cointegration vector, indicating the long run relationship between the prices, and thus $\beta' P_{t-1}$ is the disequilibrium error which shows the deviation of the price relationship from the long-run equilibrium. α characterizes the percentage of disequilibrium error that would be corrected in each period and is referred to as adjustment speed.

Johansen test with linear VECM described above have some strong assumptions and theoretical advancements have been made to relax those assumptions. First, it is assumed that the cointegration vector does not change during the period under investigation. However, fundamental factors such as demand and supply may change over time and the policy environment can also shift. Both factors could lead to the change in the long-run equilibrium in the market, resulting price relationships varying across time. Johansen, et al. (2000) proposed an approach to model the price relations with the presence of structural breaks in the deterministic trend of the cointegration vector. A recent application of this model is Esposti and Listorti (2013). They recognize that the wheat and corn price bubbles and subsequent importing policy adjustments in Italy could result structural breaks in long-run price relations among several Italian domestic market and the international market; they thus applies this methodology to study cointegration of these series.

Another important assumption of both the linear VECM and VECM with structural break is that the price adjustment towards long-run equilibrium stays constant. Nevertheless, many price adjustment process is asymmetric with different speed for price increase and price decrease. Hansen and Seo (2002) extended the linear VECM to threshold VECM (TVECM) with different adjustment towards equilibrium depending on the magnitude of the disequilibrium error from the previous period. TVECM is popular in literature of spatial price transmission considering transportation cost and vertical price transmission with monopoly or monopsony on the market. Meyer and von Cramon-Taubadel (2004) offer a good survey on this line of literature. However, TVECM assumes the cointegration relations among prices stay constant.

In order to take account of both the possible change in the cointegration vector and adjustment vector, we follow Mohanty and Langley (2003) by first dividing the entire sampling periods into sub-periods based on the break points derived from the Perron test discussed above. In each sub-period, we continue to study cointegration relations among prices; if cointegration is found, then linear VECM is further estimated to study the price cointegration and price transmission, otherwise, a VAR is estimated instead to study the short-run price dynamics.

Results and Discussion

Table 1 shows the result of the Perron Unit root tests on both the level and first difference of weekly prices of ethanol, sugar and oil. All price levels of the three commodities are not stationary even after accounting for a shift in the means. Also the coefficients of the mean shift variable are significant, substantiating the mean shift hypothesis. The break points are week 17 in 2009 for ethanol, week 48 in 2008 for sugar and week 52 in 2008 for oil, all of which fall around 20. These results are consistent with our hypothesis of structural change during this time. It also needs to be noted that the ethanol price is the latest among the three to experience a breaking point, while the break points of sugar and oil happen around roughly the same time, it is indicative of causality from these two prices to the ethanol price. We further study the stationarity of the first differenced price series; all of the first differenced series turn out to be stationary and none of the mean shift coefficients are significant. Henceforth, the differenced series are integrated to the order of zero. This paves way for the subsequent cointegration analysis.

Since the three series have different but similar break points, to avoid dividing the period under investigation into multiple sub-periods with small number of observations in some sub-periods, we would unify the break points to week 1 of 2009 which falls among the three break points identified in the Perron tests. The results in the subsequent analysis, however, is robust to the specification of breaking points between week 48 in 2008, the earliest breaking point among the three commodities, to week 17 in 2009, the latest breaking point.

For the first sub-period, week 21 in 2003 to week 52 in 2008, the Johansen cointegration test in Table 2 shows non-rejection of 0 cointegration vector at 5% and thus no long-run relations of the three prices exist. The lack of cointegration relations during this sub-period indicates that the interaction among prices is limited to the short-run responses. A VAR model is thus estimated with the first differenced price series and its result is shown in the upper half of Table 3.

As is shown in this table, strong autocorrelation is present in each of the first differenced price series. Price change of one commodity is affected significantly by its change in the previous period. Also, ethanol price change is significantly affected by that of sugar whereas the reverse does not hold. This result is consistent with the break points from the Perron tests as we discussed above. Moreover, price change of oil strongly influences price change of ethanol and sugar without being influenced by the oil. The estimation result of VAR is further supported by the Granger Causality tests. Ethanol price is Grangerly caused by sugar prices and both ethanol and sugar prices are Grangerly caused by the oil price.

In the second sub-period ranging from week 1 in 2009 to week 35 in 2014, one cointegration relation is found among the prices of ethanol, sugar and oil through the Johansen cointegration test (see Table 4). A VECM is accordingly estimated to study the price interaction. As the result shown in Table 5, even though the adjustment coefficients are significant at conventional significance levels in all three price equations, oil price shows weakly exogeneity comparing with the ethanol and sugar prices, hence oil price is leading the formation of long run price relationships among the three prices. Moreover, ethanol price adjusts more rapidly to the long-run equilibrium than the other two commodities. In each period, 42.9% of the disequilibrium error is corrected for ethanol price whereas only 2.71% and 3.39 % are corrected for sugar and oil respectively. The cointegration vector reveals almost full pass through from oil price to ethanol price, indicating a strong price linkage: a 1% increase in oil price would eventually lead to 0.96% increase of ethanol price. An ADF test performed on the disequilibrium error rejects the null of unit root process in the disequilibrium error.

Conclusions

Brazil has been a major ethanol producer, exporter and consumer for decades. Also, ethanol production from sugarcane in Brazil is more sufficient than the corn-based ethanol in United States. Additionally, with the elimination of the subsidy for domestic ethanol producers and the tariff imposed on imported ethanol, the imported Brazilian ethanol could have a sizeable impact on the U.S. ethanol industry.

Moreover, due to the joint production of ethanol and sugar from sugarcane in Brazil and the dominant role of the Brazilian sugar in the international market, a comprehensive understanding of world's sugar market is impossible without taking the Brazilian sugarcane into the scope.

Our main conclusions are that the structural break of the Brazilian sugarcane industry in 2008 changes the relationships among the prices of the ethanol, sugar and oil. Before the break, the price adjustments are mainly short-term whereas prices form into a long-run relationship after the break. Oil price, as expected, influences the prices of the other two commodities due to its important role in the global economy. International sugar prices significantly affects the ethanol price in Brazil.

The main limitation of this research lies in the data. There seems to be a lack of data on the proportion of the hydrous and anhydrous ethanol, the simple average may not accurately reflect the ethanol price in Brazil. Also we only consider the fuel ethanol despite that most ethanol is indeed used as fuel in Brazil. Since it has not been long since the elimination of U.S. producer subsidy and tariff on imported ethanol, to what extent the Brazilian ethanol can affect the U.S. ethanol market and how the ethanol markets in Brazil and United States is integrated deserved further research.

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Figures

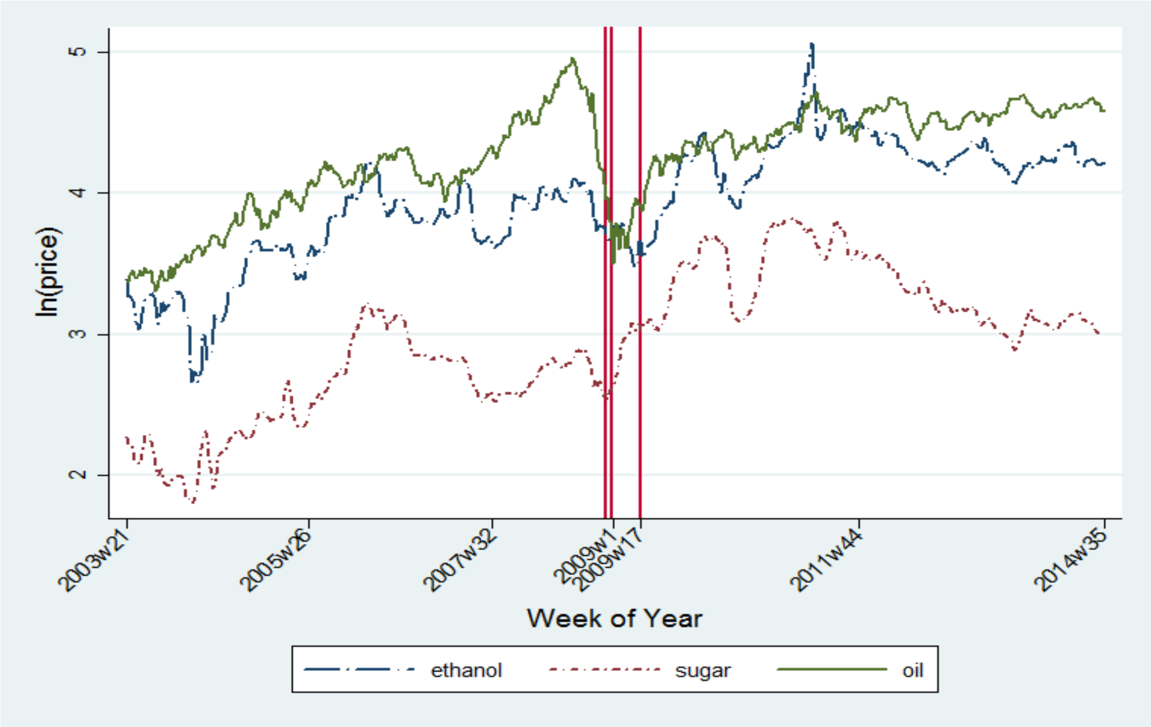

Figure 1 Price Movement of ethanol, sugar and oil in Brazil

Tables

Table 1.Perron Unit Root Test Results

	ethanol	Δethanol	sugar	Δsugar	oil	Δoil
du1	0.0136 (2.914)	0.0075 (0.942)	0.0076 (2.288)	-0.0022 (-0.960)	0.0098 (2.610)	0.0028 (0.864)
rho - 1	-0.0213 (-3.834)	-0.7362 (-7.381)	-0.0105 (-3.059)	-0.4903 (-11.375)	-0.0195 (-3.720)	-0.7246 (-7.268)
Optimal Break Point	2009w17	2004w6	2008w48	2010w18	2008w52	2008w52

Note: The null hypothesis is that series is non-stationary with a single mean shift. du1 represents the coefficient of mean shift variable and its corresponding optimal break point is shown in the last row while rho-1 is the coefficient of the lagged dependent variable. Number in the parenthesis is the t statistic; du1 has standard t distribution while rho – 1 does not. 5% critical value for this sample size is -4.270.

Table 2.Johansen Cointegration Test Results: 2003w21-2008w52

Null Hypothesis	Trace Statistics	5% Critical Value	Eigen Value
r=0	15.3088	29.68	0.0344
r≤1	5.1253	15.41	0.0098
r≤2	2.2559	3.76	0.0077

Table 3. VAR Estimation Result: 2003w21-2008w52

	VAR Estimation		
	Δethanol	Δsugar	Δoil
constant	0.4761	0.023	0.1044
	(0.0615)	(0.0431)	(0.0595)
l. Δethanol	-0.1705**	0.0148	-0.0051
	(0.0613)	(0.0429)	(0.0592)
l2. Δethanol	-0.0627**	0.5784	0.1347
	(0.0909)	(0.0637)	(0.0878)
l. Δsugar	0.2217	-0.0304**	-0.1448
	(0.0904)	(0.0633)	(0.0874)
l2. Δsugar	-0.0393**	-0.0851	0.2059
	(0.0611)	(0.0428)	(0.0591)
l. Δoil	0.2425	0.1126**	0.0621*
	(0.0608)	(0.0426)	(0.0588)
l2. Δoil	0.0005**	0.0006**	0.0003
	(0.0024)	(0.0017)	(0.0023)
	Granger Causality Test		
Exclude:			
ethanol	-	.64313	3.4929
sugar	6.6522*	-	3.2969
oil	15.932**	9.1862**	-
both	23.88**	9.8368*	10.166*

Notes: ** denotes estimator significant at 5% and * significant at 1%
The lag of VAR model is chosen by HQIC.

Table 4.Johansen Cointegration Test Results: 2009w1-2014w35

Null Hypothesis	Trace Statistics	5% Critical Value	Eigen Value
r=0	65.1731*	29.68	0.1747
r≤1	8.5303	15.41	0.0217
r≤2	2.0627	3.76	0.0070

Table 5. VECM estimation result: 2009w1-2014w35

VEC Estimation			
	Δethanol	Δsugar	Δoil
Adjustment Coefficient α	-0.429**	0.0271**	0.0339*
	(0.0151)	(0.0099)	(0.1656)
constant	0. 0017	0.0002	0. 0021
	(0.0021)	(0.0014)	(0.0023)
l. Δethanol	0.4742**	-0.0271	0.0309
	(0.05527)	(0.0099)	(0.0608)
l. Δsugar	0.0369	0.06257**	0.0204**
	(0.0735)	(0.0482)	(0.0809)
l. Δoil	-0.0760	-0.0449	0.0688
	(0.0518)	(0.0339)	(0.0569)
Cointegration Vector β			
ethanol – 0.9587 oil – 0.5410 sugar + 1.8418			
(0.1138) (0.0885)			
ADF Test on Disequilibrium Error			
-3.382 **			

Notes: ** denotes estimator significant at 5% and * significant at 1%
Numbers in parenthesis are standard errors. The lag of VECM is chosen by HQIC.