LISBOA SCHOOL OF ECONOMICS & MANAGEMENT

MASTER IN

FINANCE

MASTER´S FINAL WORK

DISSERTATION

DRIVERS OF AGRICULTURAL FUTURE COMMODITY PRICES: A COINTEGRATION ANALYSIS

JOÃO FILIPE MELO DE ALMEIDA FIGUEIREDO

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ORIENTATION:

PROFESSOR PIERRE JOSEPH MARIA HOONHOUT

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Abstract

This dissertation aims to study the effects of changes in the prices of future contracts on Brent Crude Oil and US Dollar Index in the price of several agricultural future contract prices (Cocoa, Cotton, Coffee, Sugar, Soybean, Wheat and Corn).

These futures outrights are traded on ICE (Intercontinental Exchange, Inc.) and have a remarkable liquidity. Weekly data was used from March 2013 to March 2015 with a total of 105 observations. The prices were collected from the Quandl futures database and are settlement prices from the front outrights. The Back-Adjusted method was chosen to perform the roll over.

We started by studying the correlation between US Dollar Index and Brent Crude Oil prices. Confirming the conclusions of other studies, we found a negative correlation between the prices of Brent Crude Oil and the US Dollar Index. The Granger Causality test gave us enough statistical evidence to conclude that a variation in Brent Crude Oil prices indeed cause an impact on the US Dollar Index.

By applying Johansen`s cointegration test we indeed found cointegrating vectors between Brent Crude Oil, the US Dollar Index and each one of the studied agricultural commodities. The next step was to build vector error correction models. Although some of them proved not to be rock solid, we manage to establish a link among the variables, namely in the case of Soybean, which produce remarkable results and may, in fact, be treated as a benchmark for traders of future contracts.

Keywords: Cointegration, Future Contracts, agricultural commodities, Brent Crude Oil, US Dollar Index

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1.Introduction

Trading is believed to have taken place throughout much of the recorded history of human kind and it is an important asset of our economy. Speculation played a key role in the development of financial markets and trading platforms.

From stocks to bonds, futures and options nowadays it is possible to trade hundreds of thousands of different financial products. With the flourishing of organized clearing houses and the generalization of electronic trading the financial markets have now more liquidity than ever and are at every person´s reach.

Having this context as starting point, this dissertation aims to test the presence of cointegrating relations between the prices of future contracts in Brent Crude Oil, US Dollar Index and agricultural commodities.

Exchange rates are known for their direct impact on the export and import of goods and services and, thus, are expected to influence the price of these trading commodities.

At the same time, the use of chemical and petroleum derived inputs has increased in agriculture over time. It is therefore expected that energy, namely the price of Crude Oil, to have an important impact in commodity production.

Working as a futures trader for OSTC Portugal, I find this topic deeply interesting and useful both in theoretical and practical framework.

The number of future contracts traded on exchanges worldwide is increasing every year and dozens of millions of contracts change hands every trading day.

According to FIA (Futures Industry Association), more than 12,1 billion future contracts were traded worldwide in 2014 alone. Agricultural commodities have also being flourishing in 2014, showing a volume increase of more than 15% from approximately 1,2 billion contracts traded in 2013 to 1,4 billion in 2014.

Many prior studies were conducted to test these relations between Crude Oil prices and agricultural commodities prices (Nazlioglu (2012)), between the US Dollar strength and agricultural commodities prices (Abbot et al. (2008)) and between the three variables (Harri et al (2009)) over a significantly long period of time using weekly or monthly data.

Trading future contracts is a highly leveraged investment. The initial margin required to enter into a new futures contract is usually lower than 10% of the futures contract.

This may bring a big profit (or loss) to an investor for a small market movement. In fact, many futures traders enter in a position to make 1 or 2 ticks (minimum amount prices of future contracts can move).

Therefore, this study will focus on a short-run analysis with weekly observations, which may lead to novel conclusions and serve as a benchmark for practical purposes.

2. Literature Review

Is there any relationship between exchange rates and Crude Oil prices and commodities prices? This subject has been studied by different authors in the last years. The purpose of their studies is mainly related to a practical need: to find a comprehensive model that explains past prices and predicts future prices of those commodities.

In fact, the fluctuation of Crude Oil prices (by far the most traded commodity) and the volatility of some agricultural commodities (corn, wheat, soybean, for example) and also the exchange rate (mainly the US Dollar exchange rate, in comparison with other currencies, euro, yen, Australian dollar) tend to be correlated. How do they influence each other?

Novotni (2012) studied the relationship between the nominal effective exchange rate of the US Dollar and the Brent Crude Oil price, examining monthly data from January 1982 to September 2010. He modeled the Brent Crude Oil price as a function of some explanatory variables: nominal effective exchange rate of US Dollar, the industrial production of the OCDE countries and oil inventories of United States. He concluded that, in the period between 2005 and 2010, Brent Crude Oil price and the exchange rate were related in an inverse way: decreasing the nominal effective exchange rate of the Dollar of 1% implies an increase in the Brent Crude Oil price of 2,1%. Before 2005 the correlation between those two variables was very weak or even inexistent.

One explanation for the inverse relation between Brent Crude Oil price and the effective exchange rate of the US Dollar may be the fact that commodities are traded in US Dollar, so depreciation in US Dollar implies the compensatory rise of the commodities price.

Natalenov et al (2013) studied the relationship between Crude Oil, corn and ethanol during a particularly turbulent period between 2006 and the end of 2011.

Their first conclusion was that, considering the whole period of time, there was no correlation between these three variables. Then the period of time was divided in two sub periods, the first from March 2005 to July 2008, and the second period of time from August 2008 to the end of 2011. At the same time, they decided to look for a bi-variate relation between two variables, instead of looking for cointegrated relations between the prices of the three mentioned commodities.

They came to the conclusion that, between 2008 and 2011, the Brent Crude Oil price and corn, and the Brent Crude Oil price and ethanol, were linearly related, with changes of the Brent Crude Oil price implying changes, with the same signal but with different amplitude, on the corn and the ethanol prices.

Natalenov referred to some factors that may have contributed to the complex relation between those three commodities prices: The Energy Policy Act of 2005, Crude Oil price level surpassing the threshold of 75 USD/barrel and the 2008 financial crises.

Nazlioglu (2012) analysed the price transmission from the world oil prices to the key agricultural commodity prices by employing weekly data from 1994 to 2010. Using Granger causality test, Nazlioglu found empirical evidence of a nonlinear causal linkage between Oil and the agricultural commodity prices for corn, soybean and wheat.

Another study on this topic was put forth by Campiche et al. (2007). This research examined the co-variability between Crude Oil prices and corn, sugar, sorghum, soybeans, soybeans oil and palm oil prices during the period 2003-2007. Johansen cointegration tests revealed no cointegrating relationships during 2003-2005, but a positive cointegration of corn prices and soybean prices with oil prices during the 2006-2007 time periods.

Abbot et al. (2008) highlights the strong and important link between the US Dollar Index and commodity prices. Most commodities are priced in US Dollars, but are purchased in the local currency. When the dollar strength falls there is a link with rising commodity prices.

A similar approach is used by Murphy (1999). By graphically illustrating a similar path between gold prices and the US Dollar Index from April 1995 to October 1996, it states that a rising Dollar normally has a depressing effect on most commodity prices.

Harri et al (2009) studied the relationship between the exchange rate (measured as a trade weight average of the US dollar value against other major currencies), Crude Oil price and some other commodities (mainly corn, cotton and soybeans) prices. By using overlapping time periods taken from monthly data, between January 2000 and September 2008, they found a cointegration relationship: oil prices are linked to corn, cotton and soybeans, but not to wheat.

They also found that the exchange rates, crude oil and corn prices are correlated, and that exchange rates influence the linkage of the commodities prices over time.

Rosa et al (2012) have studied the relationship between some agricultural commodities and crude oil prices, trying to test the hypothesis that the increased volatility in agricultural prices is caused by the exogenous crude oil prices. They used data between January 1999 and May 2012, and this study compared the prices of corn, wheat and soybean (whose choice is justified because they are the most traded agricultural commodities used on feedstock, food and fuel) with the crude oil price.

The authors concluded for a strong non-linear linkage between crude oil and corn prices, explained by the increased use of corn in the production of ethanol. The volatility of the crude oil price causes some volatility on corn and soybean prices, too, because of their energy and industrial use. The case of wheat prices is different: an increase in consumption leads to the decrease in wheat stocks, which is responsible for the large increase in wheat prices, during that period of time.

Zhang (2013) used Granger causality test to test the hypothesis that changes on the price of crude oil causes the change in the US dollar exchange rate, and not vice-versa. Golub (2013) explains that effect saying that when the oil price rises, it increases the income of oil exporting countries and those countries use the higher income to purchase more US dollars, which causes its appreciation. Using monthly data between January 2003 and June 2010, Zhang finds no evidence of significant cointegration between the two mentioned variables, but that evidence appears when allowing for two structural breaks in the past: November 1986 and February 2005 (these two dates are related with important changes in the oil market). He finally concludes that there is a stable relationship between the price of Crude Oil and the value of the US dollar exchange rate, but that relationship has been subject to structural breaks over time.

3. The Data

The data used in this study is the Quandl Future prices database and comprises of weekly data (Tuesday) from the first trading Tuesday of March 2013 until the first trading Tuesday of March 2015 with a total of 105 observations per product.

The variables used are futures in Brent Crude Oil, US Dollar Index, Corn, Soybean, Wheat, Cocoa, Coffee C, Cotton and Sugar No.11.

The US Dollar Index is a measure of the value of the US Dollar relative to a basket of foreign currencies. It is calculated as a weighted geometric mean of Dollar´s value against Euro, Japanese Yen, Pound Sterling, Canadian Dollar, Swedish Krona and Swiss Franc. In the future markets, one contract is traded as 1000$ x Index Value.

All the prices collected are settlement prices, which is a trade weighted average of the number of lots traded at each price over a certain period of time, shortly before the close of the market. This price is used to determine the profit or loss for the day in order to update margin requirements.

All these future prices are from the Intercontinental Exchange (ICE), a leading network of exchanges and clearing houses for financial and commodity markets, which operates completely as an electronic exchange.

One important aspect that we face when dealing with future contracts is the expiring nature of the product.

Futures are not continuous contracts such as stocks. Each specific contract has a starting trading day and an expiring day. For this reason, it is essential to use a roll method between contracts to create a continuous future contract which can later be used for back testing.

Stringing subsequent price series together creates a discontinuous time series since the expiring of a contract and the passage to the next front-month may carry significant price gaps.

Therefore, the roll method used in this study is the Back-Adjusted method. The gap between two contracts is measured, and then added or subtracted to all values in the prior contracts.

This method is one of the most commonly used for this purpose, being also used by CQG Trader, a leading high-performance market data and electronic trading application used by future traders worldwide.

This work has been made of attempts and reformulations depending on the results and difficulties, which were found throughout the process. However, it was carried out the usual approach in this type of work: the sources and the data to be used were selected; the next step was to verify whether the data presented some kind of correlation (a look on the plot of the data is useful to this purpose) and run some tests concerning that correlation. The third step was to find a model that could express the evolution in time of the variables which were to be studied in order to fit the purpose of this analysis: try to understand in what sense agricultural commodities prices are related with the exchange rate and the Brent Crude Oil price.

The statistical software used to conduct this research was EViews. We´ve choose EViews because it is commonly used in statistical works and provides all kind of tests, models and tools that should be necessary.

4. Methodology

This section discusses theoretical principles used in this work.

4.1. Stationary and non-stationary time series

Gujarati (2011) refers that “a time series is said to be stationary if its mean and variance are constant over time and the value of the covariance between the two periods depends only on the distance or gap or lag between the two time periods and not the actual time at which the covariance is computed” . However, many time series, more exactly typically financial time series, often display some kind of systematic upward or downward movement through time and, as a consequence, are not stationary.

Stationary and non-stationary time series demand different approaches, otherwise forecast studies will predict, most probably, inconsistent conclusions and unrealistic or divergent results. A time series with a trend is one of the most usual examples of non-stationary time series.

Figure 1 illustrates a stationary and a non-stationary time series.

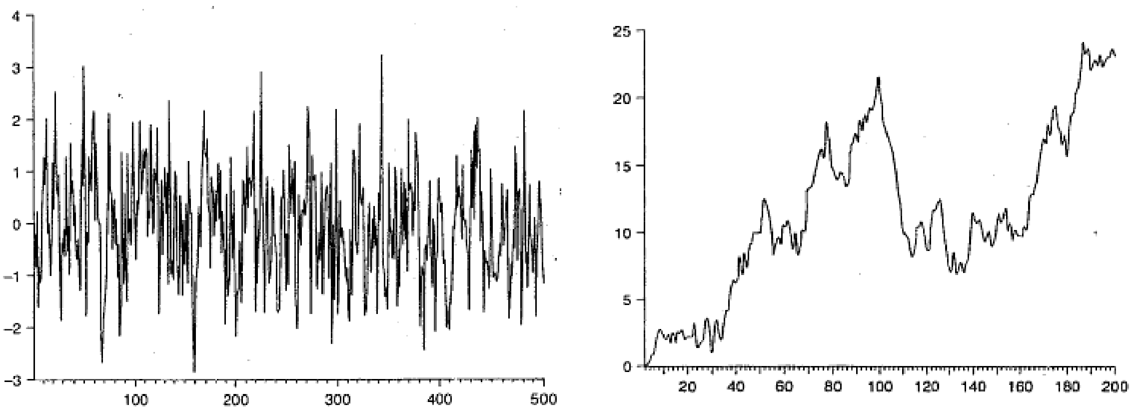

FIGURE 1: stationary time series and non-stationary time series, respectively (Asteriou, 2007)

If the series has a deterministic long-run trend it may be possible to transform it into stationarity, by considering the deviations from the trend. If the trend is stochastic, transformation into stationarity requires first-differencing.

Only rarely is differencing more than once necessary to obtain stationary time series.

4.2. Augmented Dickey-Fuller (ADF) test

To test the stationarity of a time series we usually use the reference test or the Augmented Dickey-Fuller test.

Dickey and Fuller proposed three alternative regression equations, based on a simple AR(1) model, that can be used for testing for the presence of unit root as synonymous of non-stationarity.

These equations are:

$$\Delta y_t = \delta y_{t-1} + u_t \quad (1)$$

$$\Delta y_t = \alpha + \delta y_{t-1} + u_t \quad (2)$$

$$\Delta y_t = \alpha + \gamma t + \delta y_{t-1} + u_t \quad (3)$$

Where (3) includes a time trend and a constant and (2) only includes a constant.

DF test is a t-test, but not a conventional one, so we must use non standard critical values which were first calculated by Dickey and Fuller, and later by other authors.

Dickey and Fuller extended their test procedure including extra lagged terms of the dependent variable. This allows for the testing of unit roots in autoregressive processes that are of order higher than one, The three possible equations of the test are the same but now they all include the additional term $\sum_{i=1}^{p} \beta_i.\Delta y_{t-i}$. So we have the Augmented Dickey-Fuller test, with the null hypotheses defined as Ho: there is a unit root.

This test may be used with all the variables and, when non-stationarity is observed, it may be used again to test their first differences, second differences, and so on.

We say that a variable is integrated of order 1, or simply $I(1)$ when the series is non-stationary in level but his first differences are stationary.

4.3. Cointegration

If we have two or more non-stationary time series, that become stationary when differenced, such that some linear combination of those series is stationary, then we say that they are cointegrated. That means that those series show some kind of long-run relationship.

In other words, we say that two $I(1)$ time series x_t and y_t are cointegrated, if there is a β such that $z_t = y_t - \beta.x_t$ is stationary.

Figure 2 illustrates the situation: x_t and y_t are non-stationary, but in long-run they are moving together. So we may find a relation between those two series, and define a third one which is stationary.

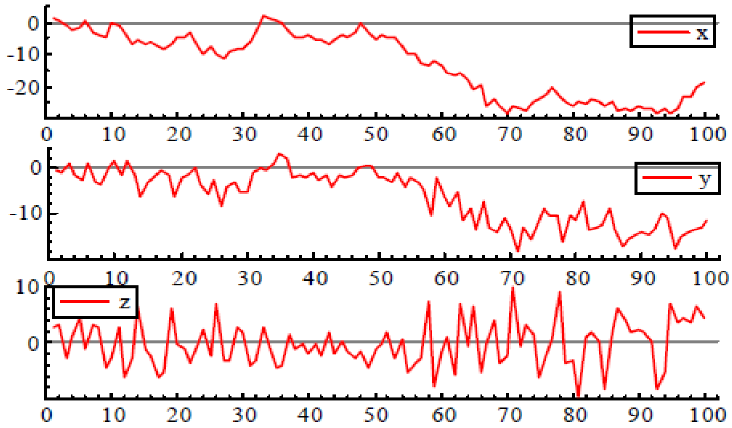

FIGURE 2: Example of cointegrated time series, Bação (2000)

In this example, if we suppose that z_t is approached by $x_t - 2.y_t$, for instance, then $(1,-2)$ will be a cointegrating vector between the variables x_t and y_t. More generally, the cointegrating vector is a $(k,-2k)$ vector $(k \neq 0)$.

4.4. Johansen test

To test the existence of cointegration between the variables, we may use, at least, one of three kind of tests: the Engle-Granger cointegration test developed by Engle and Granger (1987), the Philips-Ouliaris reference test, presented by these authors, or most recently the Johansen cointegration test, presented by Johansen and Juselius in 1990.

The main advantage of the Johansen test, regarding the others tests, consists in the determination of the number of cointegrating vectors that exists among the studied variables, when these variables are cointegrated, and provides estimates of all cointegrating vectors.

As Dwyer (2014) refers, the Johansen test can be seen as a multivariate generalization of the ADF test because it is the study of linear combination of variables for unit roots. It must be noticed that if there are n variables, each with unit roots, there are $n-1$ possible cointegrating vectors, and if there are n variables and n cointegrating vectors, then we may conclude that the variables do not have unit roots.

Johansen proposes two different tests: the trace test and the $\lambda_{\max}$ test.

The trace test is based on the log-likelihood ratio $\ln[L_{\max}(r)/L_{\max}(k)]$ and is conducted sequentially for $r = k-1,...,1,0$. This test tests the null hypothesis that the cointegration rank is equal to r against the alternative hypothesis that the cointegration rank is equal to k.

Asteriou (2007) refers four steps in Johansen test approach: step 1: test the order of integration of all variables; step 2: set the appropriate lag length of the model. This may be done using some criteria that we will see next; step 3: choose the appropriate model that correlates the variables; step 4: determine the rank of Π or the number of cointegrating vectors, using $\lambda_{\max}$ test or trace test.

4.5. Granger causality test.

We may test the possibility of statistical precedence between them: which one causes the other one movement? We may test it in both directions, using the Granger causality test.

Given two sets of time series data, x_t and y_t, we may create two models to test which of them better fits to predict y_t: one model only with past values of y_t and the other model with past values of y_t and x_t.

The residual sum of squares errors is compared and a test is used to determine which model is more adequate to explain the future values of y_t. The null hypothesis is: H_0: $\alpha_i = 0$ for each i, with α_i the coefficient of the variable x_t, in the model, against H_a: $\alpha_i \neq 0$ for at least one of the α_i coefficients. We may execute this test using different values of lags.

4.6. Akaike Information Criterion

We must compare the goodness of fit data-models, to decide the number of lags must be used in the model. We may use some criteria provided by R or EViews software, for instance: the Akaike Information Criterion (AIC), the Finite Prediction Error (FPE), the Schwarz Baysean Criterion (SBC) and the Hannan and Quin Criterion (HQC).

Ideally the chosen model should be the one which minimizes all these criteria. However, sometimes the results are contradictory, and in the analysis of time series the statistic most commonly used is AIC. It is defined by:

$$AIC = \left(\frac{RSS}{n}\right) \times e^{\frac{2k}{n}} \qquad (4)$$

where we must recall that $RSS = \sum_{t=1}^{n} \hat{u}_t^2$ and $\hat{u}_t$ represents the difference between the actual y_t and the fitted values predicted by the regression equation.

4.7. VAR (Vector Autoregressive) model, VEC (Vector Error Correction) model

We may model a time series data using some models. The simplest one is the autoregressive of order one model AR(1), which is given by:

$$y_t = \alpha . y_{t-1} + u_t \qquad (5)$$

Where $|\alpha| < 1$ and u_t is a Gaussian error term. This model assumes that the actual value of y_t is determined by its own value in the precedent period.

The model becomes more complex when we have more than one time series, with the actual values of each one influenced not only by its own past values, but also by the past values of all the others variables. In this case we can use a VAR model.

Pfaff (2006) defines a Vector Autoregressive model as a set of k endogenous variables written in the form:

$$y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + u_u . \qquad (6)$$

In this equation, A_i is the ($k \times k$) matrix of coefficients and u_t is a k-dimensional lagged process of order p, with $E(u_t) = 0$.

More clearly, considering two variables, we may write it in the following way:

$$y_t = A_1 x_t + \sum_{j=1}^{p} B_j y_{t-j} + \sum_{j=1}^{p} C_j x_{t-j} + u_{1t} \qquad (7)$$

$$x_t = A_2 y_t + \sum_{j=1}^{p} D_j x_{t-j} + \sum_{j=1}^{p} E_j y_{t-j} + u_{2t} \qquad (8)$$

where we assume that u_{1t} and u_{2t} are uncorrelated white-noise error terms, called impulses or shocks.

In this form we may see that y_t and x_t are affected not only by their past values, but each variable is affected, too, by the other variable past and current values.

Although the number of lagged values of each variable can be different, we usually use the same number (p) of lagged terms in each equation

A VAR model can be reformulated as an error correction model considering the following relation:

$$\Delta y_t = \Pi y_{t-p} + \Gamma_1 \Delta y_{t-1} + ... + \Gamma_{p-1} y_{t-p+1} + u_t \ , \qquad (9)$$

With $\Pi = \alpha.\beta^{'}$. The matrix α is the loading matrix (includes the speed of adjustment to equilibrium coefficients) and the coefficients of the long-run relationships are contained in $\beta^{'}$, and the Γ_i matrices measure the effect of transitory impacts.

The $(k \times k)$ $\Pi^{'}$matrix contains the error correction terms. The dimensions of α and β are k and r, respectively, and r is the number of long-run relationships between the variables y_t do exist.

The general case of VECM including all the options is:

$$\Delta y_t = \alpha \begin{bmatrix} \beta \\ \mu_1 \\ \delta_1 \end{bmatrix} . \ [\, y_{t-1} \quad 1 \quad t \,] + \Gamma_1 \Delta y_{t-1} + ... + \Gamma_{k-1} y_{t-k-1} + \mu_2 + \delta_2 t + u_t \qquad (10)$$

where the terms represent: μ_1: intercept in the cointegrated equation (CE), δ_1: trend in CE; μ_2: intercept in VAR; δ_2 : trend in VAR. EViews provide us with five distinct models depending on the existence of intercept and trend in CE or in VAR; the model with trend in CE and in VAR is only theoretical (non realistic) so, in practice, it is rarely adopted.

In VECM model, the rank (or trace) of matrix $\Pi^{'}$has the following lecture, concerning with the cointegration of the variables: if $r = 0$ there is no cointegration (we can't use VECM, only VAR in first differences); if $0 < r < k$ there are r cointegrating vectors (we can use VECM); if $r = k$ all the variables are already stationary, so we may use VAR on level data.

5. Empirical results

A regard over the plot of the time series data may pronounce the existence of temporal correlation amongst the variables (Figure 10). Some of them are expected to be correlated (Corn and Brent, for instance, according to some literature) but the nature of this study, mainly focused on short-run prices, may produce unexpected results.

Figure 3 shows the plot of Brent Crude Oil and the US Dollar Index during the studied period. It is not clear the existence of cointegration; in fact, cointegration, seen as a long-run relationship, may not be seen in a two years time period, with weekly observations.

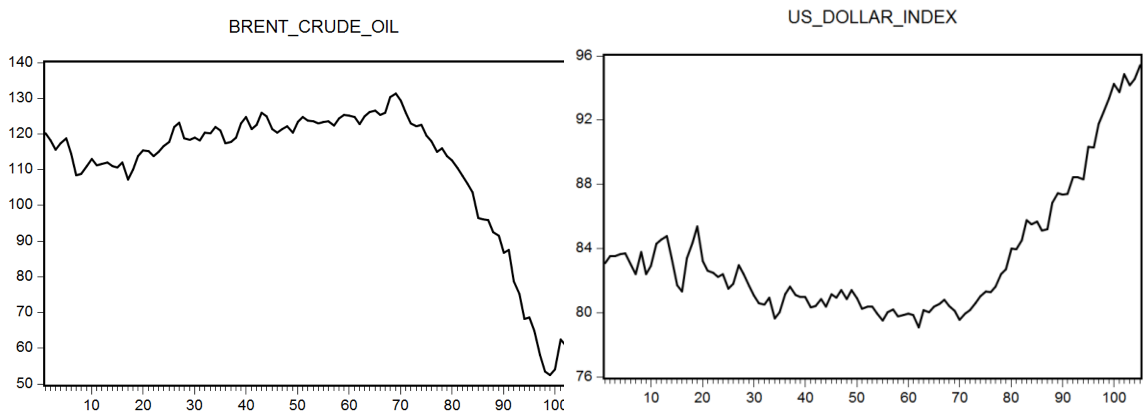

FIGURE 3: Plot of Brent Crude oil and US Dollar Index.

As it was mentioned before, it is necessary a preliminary study of stationarity of the variables. This study may begin by the observation of the plot of the time series and, next, by the application of the ADF test. To run this test we may begin fitting a model, chosen among the three options (none, intercept or trend) and a regard over the plot may be an important step. In order to avoid spurious regression problem, we will begin searching for unit roots using the ADF test with the options and compare the results with the ADF critical values, provided by EViews (Table I)

TABLE I

Critical values to ADF test, taken from Hamilton (1994) and Dickey and Fuller(1981)

Significance level	**1%**	**5%**	**10%**
Model			
Constant	-3,500	-2,892	-2,583
Constant and trend	-4,059	-3,454	-3,153
None	-2,588	-1,944	-1,615

The Augmented Dickey-Fuller test is preceded by the determination of the optimal number of lags, and that was made using the Akaike Information Criterion.

The results of the t-test are contained in tables II and III, with reference to the fitted model and the number of lags.

TABLE II

Augmented Dickey-Fuller test (results in level)

Unit-root tests at level **Commodities**	**Constant (Lags)**	**Constant and trend (Lags)**	**None (Lags)**
USD Index	1,535 (1)	1,465 (4)	1,703 (1)
Brent Crude Oil	-1,735 (8)	-0,012 (1)	-0,835 (5)
Sugar	-0,581 (1)	-3,240 (1)	-1,646 (1)
Coffee	-1,362 (1)	-1,235 (1)	-0,485 (1)
Cocoa	-2,004 (2)	-2,773 (1)	1,356 (2)
Cotton	-1,227 (1)	-2,268 (1)	-1,444 (1)
Corn	-1,547 (1)	-2,207 (4)	-1,394 (1)
Soybean	-2,050 (1)	-1,743 (1)	0,331 (1)
Wheat	-0,725 (1)	-2,654 (1)	-1,632 (1)

TABLE III

Augmented Dickey-Fuller test (results in first differences)

Unit-root tests at first differences

Commodities (Lags)		None
USD Index	(3)	-7,266
Brent	(4)	-2,651
Sugar	(1)	-11,334
Coffee	(1)	-8,113
Cocoa	(1)	-8,554
Cotton	(1)	-10,481
Corn	(1)	-10,287
Soybean	(2)	-6,308
Wheat	(1)	-9,303

Comparing the values obtained, in Table II and III, with the critical values, in Table I, it is easy to conclude that all the variables are non stationary in level, at a statistical significance level of 5%, which is the usually adopted level. This is a no surprising result, after the regard of the plots of the studied variables. Figure 3 reveals the beginning of a particular turbulence period in the US Dollar Index and in Brent Crude Oil prices (October 2014- March 2015) and most of the agricultural commodities suffer the consequences of such volatility.

Next, the same test was run to the first differences of all the variables. In this case it was not necessary to test with the three models, because all the plots showed the values distributed more or less along the zero line, as we can see in Figure 4, with the graph of the Brent Crude Oil first differences.

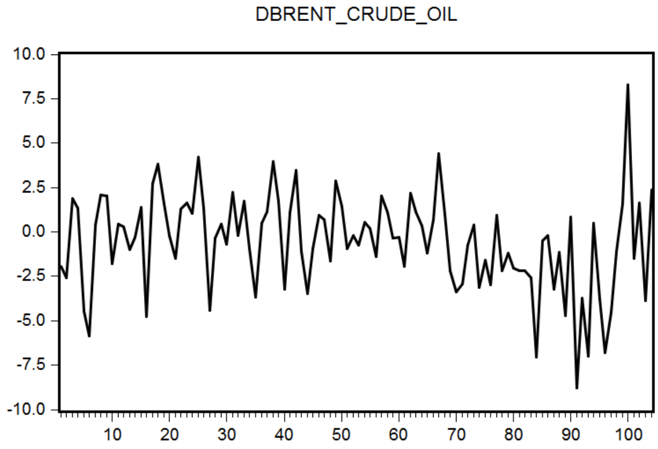

FIGURE 4: Graph of ΔBrent (Brent Crude Oil first differences)

In the case of the ADF test applied to the first differences, all coefficients are statistically significant at a 1% or lower level, which means that all the variables are integrated of order one: $I(1)$.

Following the purpose of this study, next we will see if there is evidence of correlation in time among some variables. First we will test for correlation between Brent Crude Oil prices and the US Dollar Index as some previous studies (mentioned in the literature review) have done, in a larger temporal window. Then it will be studied the relationships among the US Dollar Index, Brent Crude Oil prices and each one of the agricultural commodities.

5.1. Relationship between Brent Crude Oil prices and the US Dollar Index

We can determine if Brent Crude Oil prices and the US Dollar Index are cointegrated using Johansen cointegration tests. Both tests (trace test and maximum eigenvalue test) reveal the presence of one cointegrating vector which describes the long run relationship between the two variables. The test output is in Table IV.

TABLE IV

Johansen Cointegration Test output

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend
Series: Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.198007	23.69765	15.49471	0.0023
At most 1	0.011607	1.190843	3.841466	0.2752

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.
None	0.198007	22.50681	14.26460	0.0020
At most 1	0.011607	1.190843	3.841466	0.2752

Granger causality test was used to study the relationship between Brent Crude Oil prices and the US Dollar Index, with the optimal number of lags equal to 5 (Table XII). Table V shows that, in the period of time between March 2013 and March 2015, a change in Brent Crude Oil price indeed causes an impact in the US Dollar Index, but not the vice-versa.

TABLE V

Granger Causality Test output

Null Hypothesis	Obs	F-Statistic	Prob.
ΔUS Dollar Index does not Granger Cause ΔBrent Crude Oil	99	0.64575	0.6654
ΔBrent Crude Oil does not Granger Cause ΔUS Dollar Index		4.42994	0.0012

Now it will be used the Vector Error Correction Model. Asteriou (2007) refers some reasons why this is a very useful model: it measures the correction from disequilibrium of the previous period, which has a very good economic implication; it is formulated in first differences which typically eliminate trends from the variables involved and resolves the problem of spurious regression; the disequilibrium error term is a stationary variable, so there is some adjustment process which prevents the errors in the long-run relationship becoming larger and larger.

There are five different models, depending on the existence of intercept or trend in VAR and also the existence of intercept or trend (linear or quadratic) in the cointegrating equation. Software EViews provide us with the information of the best model to use (Table XIII). We use the same lag length previously determined. The result is displayed on Table VI.

TABLE VI

Vector Error Correction Model

	USD Index	Brent Crude Oil	Constant
$\hat{\beta}$	1.0000	0.2138 (0.0104)	-106.7981

	$\hat{\alpha}$	$\Delta USDIndex_{t-1}$	$\Delta USDIndex_{t-2}$	$\Delta Brent_{t-1}$	$\Delta Brent_{t-2}$	C
ΔUSD Index	-0.347** (0.074)	0.078 (0.095)	0.007 (0.093)	0.017 (0.028)	0.010 (0.029)	0.123* (0.070)

** Denotes significance at the 5% level

* Denotes significance at the 10% level R-squared 0.237203

The long run relationship between the variables can be read in the cointegrating equation: $USDollar\_Index \approx 106{,}7981 - 0{,}213789 \times Brent\_Crude\_Oil$

We can conclude that the error correction term (-0.347140), which describes the speed of adjustment to equilibrium, is highly significant.

The model is based in the assumption that residuals follow a white noise process or, in other words, we need to check if the residuals are normally distributed, with zero mean, with no serial correlation, and show no arch effect.

Table VII and Figure 5 report the results of the tests.

TABLE VII

VECM – Residual Diagnostics

(Breusch-Godfrey Serial Correlation LM Test and ARCH Test)

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.488573	Prob. F(4,92)	0.7441
Obs*R-squared	2.121646	Prob.Chi-Square(4)	0.7134

Heteroskedasticity Test: ARCH

F-statistic	1.270542	Prob. F(4,92)	0.2872
Obs*R-squared	5.077912	Prob.Chi-Square(4)	0.2794

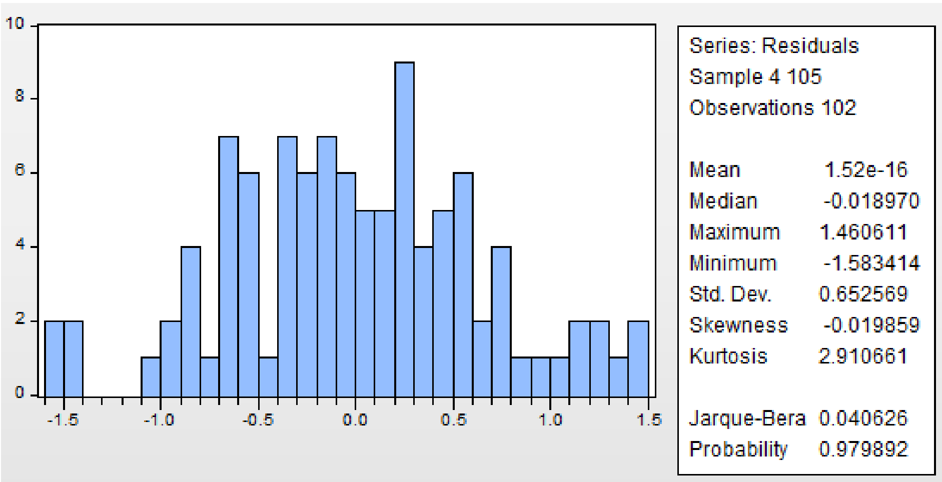

FIGURE 5 – Jarque-Bera residual test

The null hypothesis of no serial correlation is not rejected by the Breusch-Godfrey LM test, at a 5% significance level. The null hypothesis of no heteroskedasticity is also not rejected in the ARCH test for the same significance level. The Jarque-Bera test provides statistical evidence that the residuals follow a normal distribution.

Figure 6 shows the impulse response of US Dollar Index to a one unit shock in Brent Crude Oil price.

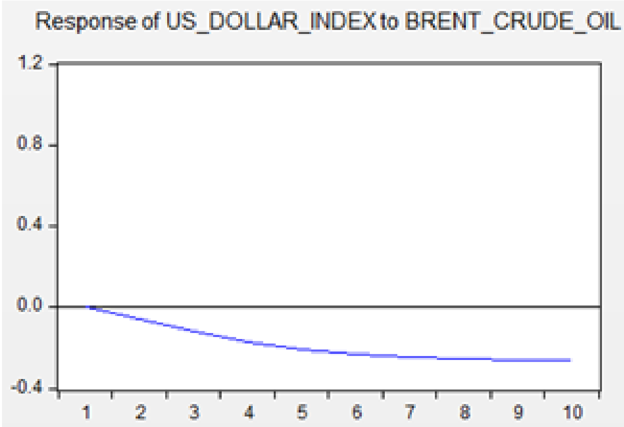

FIGURE 6: Response of US Dollar Index to a shock in Brent Crude Oil price

As stated by some authors mentioned previously in the literature review, an increase in Brent Crude Oil price implies a decrease in US Dollar Index.

5.2. Relationship between Brent Crude Oil price, the US Dollar Index and agricultural commodities prices

Do Brent Crude Oil prices, US Dollar Index and the price of agricultural commodities go together in the long-run or, in other words, do they reveal a long-term relationship, in spite of its non-stationary behavior in level? To ask this question we run the Johansen test, using, each time, one of the agricultural commodities with the pair Brent Crude Oil-US Dollar Index.

Johansen' tests for cointegration were preceded by the determination of the optimal lag length and the optimal model to use, chosen among the five models of VECM. The results of the Johansen's trace test for cointegration are reported in Table VIII and the complete results of trace tests are in Tables XV to XXI.

TABLE VIII

Johansen's trace test
(Brent Crude Oil price, US Dollar Index and each agricultural commodity)

Model 2			
	5%*	Coffee	Cotton
r=2	9,16	2,44	3,36
r=1	20,26	16,00	16,14
r=0	35,19	40,32	42,60

Model 4						
	5% *	Cocoa	Sugar	Soybean	Wheat	Corn
r=2	12,52	6,96	5,36	9,55	7,30	5,38
r=1	25,87	20,70	17,64	21,71	15,56	13,54
r=0	42,92	46,74	53,44	64,80	46,98	46,10

*Critical Values

In all cases, the trace statistic indicates a cointegration rank of r = 1, given a 5% significance level. So we can conclude that there is one cointegrating vector between Brent Crude Oil price, US Dollar Index and each one of the other commodities, which reflects the long-run relationship among those three variables.

The next step is to create VEC models which allow us to quantify the short and long-run correlations. Lag 2 was determined by Akaike Information Criteria as being the optimal lag length to use in all the models. $\Delta \text{Commodity}_{t-1}$ and $\Delta \text{Commodity}_{t-2}$ represent lag 1 and lag 2 of the dependent variable, respectively.

The cointegrating vectors $\hat{\beta}$, normalized to the agricultural commodity, are in Table IX.

The adjustment coefficients $\hat{\alpha}$ and the equations that represent the short run relationship among the variables are in Table X.

TABLE IX

Cointegrating vectors

$\hat{\beta}$	Constant	Commodity	US Dollar Index	Brent Crude oil	Trend
Cocoa	12207.47	1.000	-127.6530 (36.8839)	-34.36732 (7.39895)	-10.70105 (1.22290)
Coffee	9210.009 (2503.12)	1.000	-86.57769 (23.9792)	-19.18729 (4.68806)	_________
Corn	-7387.775	1.000	64.11351 (13.1064)	13.61524 (2.64058)	1.519943 (0.43788)
Cotton	-1870.454 (475.569)	1.000	16.78613 (4.55197)	3.546154 (0.89343)	_________
Soybean	-10986.18	1.000	100.1568 (15.3828)	16.52378 (3.09833)	-3.620924 (0.52539)
Sugar	-126.9625	1.000	1.002407 (0.18435)	0.189250 (0.03707)	0.067956 (0.00624)
Wheat	-9080.601	1.000	77.70909 (12.5673)	16.09136 (2.52800)	2.823107 (0.42412)

Standard errors are in parentheses

TABLE X

Short Run Parameter Estimates

Variable/Equation	ΔCocoa	ΔCoffee	ΔCorn	ΔCotton	ΔSoybean	ΔSugar	ΔWheat
$\hat{\alpha}$	-0.178**	-0.009	-0.062**	-0.008	-0.129**	-0.149**	-0.019
	(0.049)	(0.008)	(0.025)	(0.013)	(0.040)	(0.058)	(0.034)
Constant	10.642	_____	-1.867	_____	4.128	-0.046	-2.808
	(7.759)		(1.628)		(3.584)	(0.058)	(2.079)
ΔCommodity.$_{t-1}$	-0.085	0.190*	-0.040	-0.042	0.042	0.058	0.058
	(0.096)	(0.103)	(0.100)	(0.101)	(0.098)	(0.105)	(0.105)
ΔCommodity$_{t-2}$	-0.122	-0.018	-0.022	-0.080	0.145	0.004	0.029
	(0.096)	(0.105)	(0.099)	(0.105)	(0.098)	(0.105)	(0.506)
ΔUSD_Index$_{t-1}$	-2.126	0.040	3.121	0.094	12.062**	-0.027	-2.171
	(10.591)	(1.185)	(2.179)	(0.354)	(4.834)	(0.075)	(2.894)
ΔUSD_Index$_{t-2}$	-7.809	1.197	2.664	-0.222	8.879*	-0.023	1.743
	(10.276)	(1.150)	(2.157)	(0.342)	(4.777)	(0.073)	(2.807)
ΔBrentC.Oil $_{t-1}$	-5.360*	0.221	0.740	0.050	2.722*	0.028	0.800
	(3.038)	(0.359)	(0.656)	(0.107)	(1.519)	(0.024)	(0.848)
ΔBrentC.Oil $_{t-2}$	2.296	-0.084	0.843	-0.037	4.530**	0.041*	-0.424
	(3.136)	(0.367)	(0.673)	(0.108)	(1.552)	(0.023)	(0.884)

** Denotes significance at the 5% level
* Denotes significance at the 10% level

Some conclusions can be taken about the significance of the model:

All coefficients of Δwheat and Δcotton model are not statistically significant at a 10% level. Therefore, both models must be read with extremely caution.

In Δcocoa, Δcorn, Δsoybean and Δsugar models, the adjustment coefficient alpha ($\hat{\alpha}$) is significant at a 5% or lower level. The higher values of that coefficient in ΔCocoa, Δsugar and Δsoybean reflects a higher speed of adjustment to equilibrium than in ΔCorn. ΔSoybean is the model with the most statistically significant coefficients.

As it was previously referred, this model is based in the assumption that residuals follow a white noise process. So we need to check if the residuals are normally distributed, with zero mean, with no serial correlation, and show no arch effect.

Table XI reports the results of these tests.

TABLE XI

Tests and Residual Diagnostics

	R^2	Skewness	Kurtosis	Jarque-Bera (Probability)	B-G LM test	ARCH
ΔCocoa	0.2159	0.0203	4.2301	6.4382 (0.0520)	0.9196	0.2732
ΔCoffee	0.0733	0.5944	3.9215	9.6145 (0.0082)	0.6717	0.0040
ΔCorn	0.0783	-0.8222	9.1864	174.1448 (0.0000)	0.0000	0.0000
ΔCotton	0.0070	-0.1260	3.1025	0.3145 (0.8545)	1.0000	0.1801
ΔSoybean	0.1573	-0.1108	2.6373	0.7679 (0.6812)	0.8769	0.0658
ΔSugar	0.1038	0.3894	3.3500	3.0978 (0.2124)	0.4897	0.1328
ΔWheat	0.0354	-0.0714	3.0029	0.086748 (0.9576)	0.0974	0.0529

According to the tests, we can't reject the null hypotheses that ΔCorn and ΔCoffee models exhibit heterokedasticity in residuals for a 5% significance level. ΔCorn fails too in LM test and Jarque-Bera test, so we can't reject the null hypotheses of a non normal distribution of the residuals and the existence of no serial correlation. ΔCoffee fails too in Jarque-Bera test. According to the results contained in Tables X and XI, we pursuit with the study of Soybean, Cocoa and Sugar models as being the best fitted models obtained in this study.

The relatively low values of R squared were already expected due to the small number of the explanatory variables. We may not forget that we are dealing with futures prices on agricultural commodities, which are highly dependent on weather conditions. Natural disasters or periods of dry in the main export countries causes extremely volatility in prices which are not a direct cause of changes in the Brent Crude Oil prices and the US Dollar Index.

Figures 7, 8 and 9 show respectively the impulse response of Soybean, Cocoa and Sugar to a one unit shock in US Dollar Index and Brent Crude Oil prices.

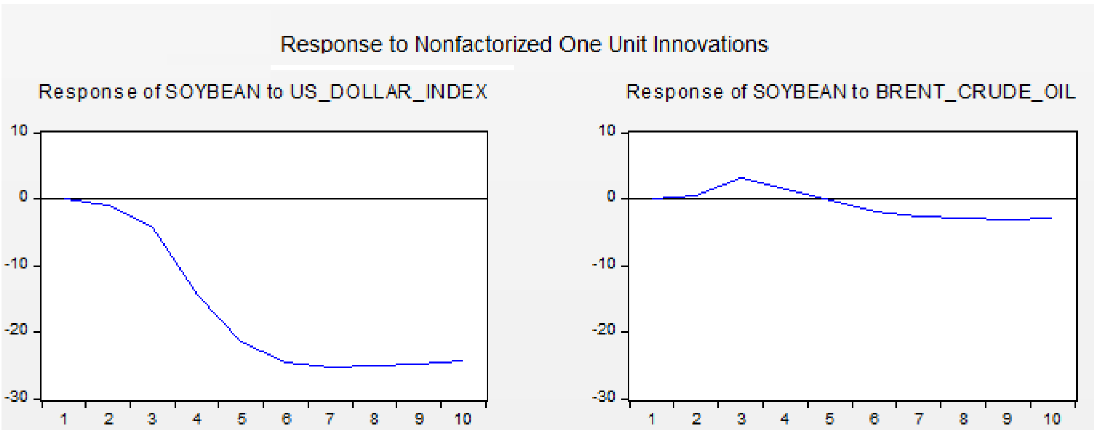

FIGURE 7: Response of Soybean prices to a shock in US Dollar Index and in Brent Crude Oil price

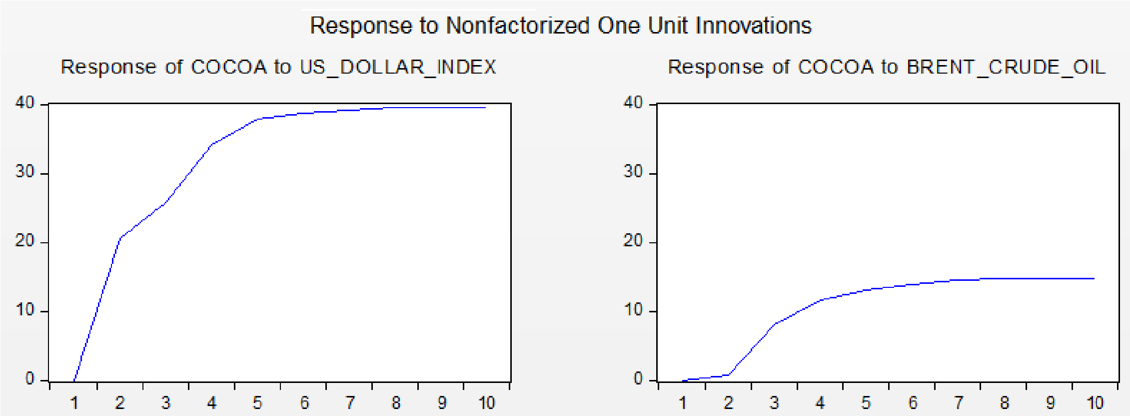

FIGURE 8: Response of Cocoa prices to a shock in US Dollar Index and in Brent Crude Oil price

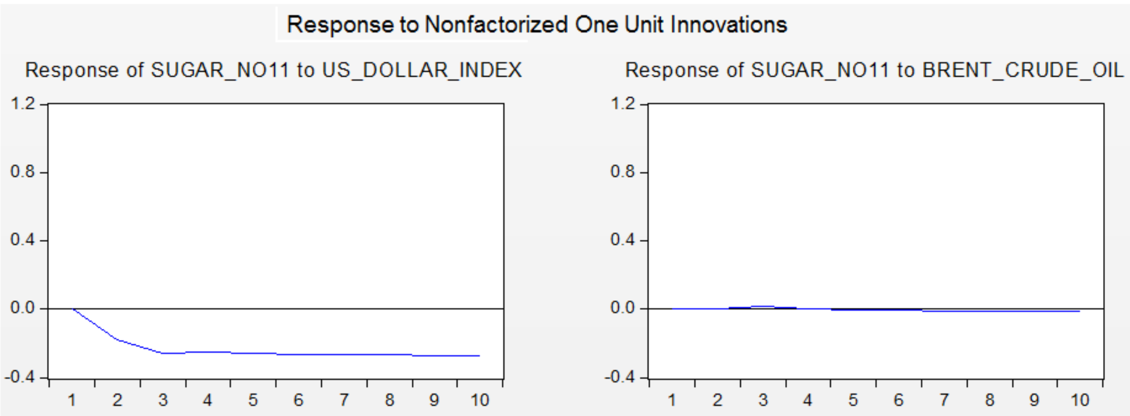

FIGURE 9: Response of Sugar prices to a shock in US Dollar Index and in Brent Crude Oil price

We verify that Sugar and Soybean respond positively to an increase of one unit in US Dollar Index and sugar tends to decrease its price. The response of Soybean to a unit shock in US Dollar Index has two distinguished periods: first Soybean price increases and then (around period t+5) decreases to lower values than the pre-shock level. In the other hand, Sugar remains relatively stable to a unit shock in Brent Crude Oil price.

6. Summary and conclusions

With the recent unusual volatility in the prices of some agricultural commodities and the Brent Crude Oil plumbing being often blamed for that, this dissertation aimed to test the strength of this correlation and to what extent speculators can use it as a benchmark.

The dollar strength, being quantified as the US Dollar Index, was also used as an independent variable highlighting the possible direct impact that Forex markets can cause to these variables which are all quoted in US Dollars on ICE (Intercontinental Exchange, inc.).

First, we started by studying the correlation between the Brent Crude Oil prices and the US Dollar Index. We found a cointegrating vector between these two variables (which revealed the inverse relationship between them) and, applying the Granger Causality test, we found that a change in Brent Crude Oil prices causes a change in US Dollar Index.

A regard over the plot of both time series also highlights this relationship. The recent plunge of Brent Crude Oil prices due to Iran´s increasingly oil production after having its sanctions lifted, and the slowdown of China´s manufacturing were followed by an enormous spike in the US Dollar Index.

The next step was to study the cointegrating relations between Brent Crude Oil prices, the US Dollar Index and each one of the selected agricultural commodities.

Through the application of the ADF and Johansen trace tests we concluded that all variables are stationary of order one and there is one cointegrating vector between all the three variables.

Next, we built vector error correction models and conducted its analysis and the study of residuals.

Low statistical significance was found for all coefficients of Wheat and Cotton. A feature which may indicate the low dependence of petroleum based inputs in these crops and a stable demand and supply of these commodities independently of Forex markets.

For Cocoa, Soybean, Sugar and Corn we have statistically significant coefficients of adjustment (alpha). The low value of alpha for Corn indicates a slow retrace of this commodity to equilibrium after a shock. The ARCH test made for this variable also indicates that we can´t reject the hypothesis of heteroskedasticity in its residuals for a 5% significance level.

The Soybean model was the one with the most statistically significant coefficients. A feature certainly related with the increasingly use of Soybean in the production of biofuel.

On the other hand, one of the most unexpected conclusions of this dissertation was the lack of correlation between Corn prices and the prices of Brent Crude Oil.

The use of Corn for the production of ethanol, which can be used as a substitute for both crude oil and gasoline, would expectedly create a link between these variables as pointed out by Natalenov et al (2013).

Nevertheless, this type of research must be carefully interpreted, since correlations might appear in different periods of time as was already proven by different studies. One thing we can be sure: Brent Crude Oil and the strength of the US Dollar do play a role in the price variation of agricultural commodities which should not be forgotten by both, speculators and agricultural companies who wish to hedge their exposure.

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8. Appendix

Figure 10: Graphical representation of the variables

TABLE XII

Optimal Lag Length Selection

VAR Lag Order Selection Criteria
Endogenous Variables: ΔUS Dollar Index; ΔBrent Crude Oil
Exogenous variables. C
Sample: 1 104
Included observations: 96

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-334.6701	NA	3.812208	7.013961	7.067385*	7.035556*
1	-331.9596	5.251681	3.916159	7.040825	7.201097	7.105609
2	-329.5311	4.604002	4.047095	7.073565	7.340684	7.181539
3	-326.5349	5.555487	4.133983	7.094477	7.468444	7.245641
4	-321.0074	10.01864	4.006844	7.062653	7.543469	7.257007
5	-313.7193	12.90592*	3.744995	6.994152*	7.581816	7.231696
6	-312.6928	1.775068	3.989609	7.056099	7.750610	7.336832
7	-309.7278	5.003447	4.083971	7.077662	7.879021	7.401584
8	-305.1986	7.454203	4.048841	7.066638	7.974845	7.433750

* indicates the lag order selected by each criterion

LR: sequential modified LR test statistic (each test at a 5% level)

FPE: Final Prediction Error

AIC: Akaike Information Criterion

SC: Schwarz Information Criterion

HQ: Hannan-Quinn Information Criterion

Table XIII

Choosing appropriate model for VECM on Brent Crude Oil price and US Dollar Index, using AIC

Sample: 1 105
Included observations: 102
Series: Brent Crude Oil; US Dollar Index
Lags interval: 1 to 2

Selected Number of Cointegrating Relations by Model*

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No intercept No Trent	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	0	1	1	1	1
Max-Eig	0	1	1	1	1

* For a 0.05 critical level based on Mackinnon-Michelis (1999)

Information Criteria by Rank and Model

Data Trend:	None	None	Linear	Linear	Quadratic
Rank or No. of CEs	No intercept No Trent	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Log Likelihood by Rank (rows) and Model (columns)					
0	-355.4618	-355.4618	-354.1336	-354.1336	-348.6842
1	-352.1384	-343.9428	-342.8802	-342.7444	-339.0490
2	-351.7681	-342.2848	-342.2848	-339.0415	-339.0415
Akaike Information Criteria by Rank (rows) and Model (columns)					
0	7.126702	7.126702	7.139875	7.139875	7.072239
1	7.139968	6.998878	6.997651	7.014596	6.961744
2	7.211138	7.064408	7.064408	7.040029	7.040029
Schwarz Criteria by Rank (rows) and Model (columns)					
0	7.332582*	7.332582*	7.397225	7.397225	7.381060
1	7.448789	7.333434	7.357942	7.400621	7.373505
2	7.622899	7.527638	7.527638	7.554730	7.554730

TABLE XIV

Statistics from VECM (Brent Crude Oil – US Dollar Index)

Dependent Variable: ΔUS Dollar Index

Method: Least Squares (Gauss-Newton/ Marquardt steps)

Sample (adjusted): 4 105

Included observations: 102 after adjustments

ΔUS Dollar Index = C(1)*(US Dollar Index(-1) + 0.213789219932*Brent Crude Oil(-1) – 106.798130314) + C(2)*ΔUS Dollar Index(-1) + C(3)*ΔUS Dollar Index(-2) + C(4)*ΔBrent Crude Oil(-1) + C(5)*ΔBrent Crude Oil(-2) + C(6)

	Coefficient	Std. Error	t-statistic	Prob.
C(1)	-0.347140	0.074029	-4.689233	0.0000
C(2)	0.078188	0.095116	0.822025	0.4131
C(3)	0.007491	0.093250	0.080333	0.9361
C(4)	0.016668	0.028125	0.592639	0.5548
C(5)	0.010264	0.028999	0.353952	0.7242
C(6)	0.122964	0.069981	1.757100	0.0821

R-squared	0.237203	Mean dependent var	0.116725
Adjusted R-squared	0.197474	S.D. dependent var	0.747175
S.E. of regression	0.669348	Akaike Information Criterion	2.091996
Sum squared resid	43.01052	Schwarz criterion	2.246406
Log likelihood	-100.6918	Hannan-Quinn Criterion	2.154522
F-statistic	5.970516	Durbin-Watson stat	1.992487
Prob(F-statistic)	0.000075		

TABLE XV

Johansen Test Results - Corn, Brent Crude Oil, US Dollar Index

(model 4, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Corn; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.273253	46.10040	42.91525	0.0232
At most 1	0.076893	13.54438	25.87211	0.6949
At most 2	0.051409	5.383351	12.51798	0.5423

TABLE XVI

Johansen Test Results - Sugar, Brent Crude Oil, US Dollar Index

(model 4, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Sugar; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.296016	53.43801	42.91525	0.0033
At most 1	0.113410	17.63603	25.87211	0.3689
At most 2	0.051174	5.358021	12.51798	0.5458

TABLE XVII

Johansen Test Results - Coffee, Brent Crude Oil, US Dollar Index
(model 2, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Coffee; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.212152	40.32248	35.19275	0.0128
At most 1	0.124511	16.00060	20.26184	0.1744
At most 2	0.023613	2.437398	9.164546	0.6900

TABLE XVIII

Johansen Test Results - Cocoa, Brent Crude Oil, US Dollar Index
(model 4, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Cocoa; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.225293	46.74146	42.91525	0.0198
At most 1	0.126038	20.70391	25.87211	0.1923
At most 2	0.065983	6.962625	12.51798	0.3484

TABLE XIX

Johansen Test Results - Cotton, Brent Crude Oil, US Dollar Index (model 2, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Cotton; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.228542	42.60460	35.19275	0.0067
At most 1	0.117711	16.13835	20.26184	0.1680
At most 2	0.032446	3.364344	9.164546	0.5149

TABLE XX

Johansen Test Results - Soybean, Brent Crude Oil, US Dollar Index (model 4, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Soybean; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.344551	64.79799	42.91525	0.0001
At most 1	0.112419	21.70967	25.87211	0.1513
At most 2	0.089339	9.545603	12.51798	0.1493

TABLE XXI

Johansen Test Results - Wheat, Brent Crude Oil, US Dollar Index

(model 4, lags 2)

Included observations: 102 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: Wheat; Brent Crude Oil; US Dollar Index
Lags interval (first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.265074	46.97554	42.91525	0.0186
At most 1	0.077810	15.56100	25.87211	0.5282
At most 2	0.069055	7.298570	12.51798	0.3144