

THE IMPACT OF BRAZIL ON GLOBAL GRAIN DYNAMICS: A STUDY ON CROSS-  
MARKET VOLATILITY SPILLOVERS

BY

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THESIS

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## **ABSTRACT**

We will investigate the evolution of the relationship between Brazilian and Global grain markets. Through a three step approach, we will test the series for cointegration, proceed with the adequate modeling (VAR or VECM) and use the residuals of these models to estimate a BEKK GARCH and relative volatility spillovers across two time periods, before and after Brazil started double-cropping. Our results indicate no significant cointegration between corn and soybeans markets before Brazil started double-cropping and significant cointegration after, for both markets. Volatility spillovers dynamics also changes, from no spillovers to spillovers from and to Brazil on corn, and from the US spilling over Brazil to Brazil spilling over to the US on soybeans. Our results are important because they show that the importance of Brazil to global grain price formation is substantial and risk managers must be aware of it in order to perform well.

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*To my mom, Deborah, my dad, Eduardo, and my brother, Leonardo.*

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# CHAPTER 1

## INTRODUCTION

Over the past 15 years Brazil's farm sector went through several structural changes. The biggest being the development of more adapted soybean and corn varieties, allowing farmers to double-crop in the same year. Farmers in Brazil are able now to grow soybeans and then corn on the same land. That fact by itself almost doubled production for these crops.

As Brazil's production increased, so did its importance in global grain dynamics. Brazil jumped from a negligible exporter in corn to being the second largest exporter and is now the largest soybean producer and exporter in the world. While global grain price discovery has historically been located primarily in the Chicago Mercantile Exchange (CME) futures contracts as first described by Garbade and Silber (1983), grain handlers are more and more looking to Brazil for fundamental price information.

In this paper, we analyze how double-cropping changed Brazilian grain price relations with global prices. Our methodology incorporates the seasonal nature of volatility spillovers between Brazilian and US markets. Through a three step approach, we define if markets were cointegrated or not and proceed to estimate the existence and magnitude of volatility spillovers between Brazilian prices and US (Global) prices in each season in recent history.

The first step involves defining whether or not the series are cointegrated. Using Johansen's cointegration test as in Johansen (1988), we will test the series divided in two periods, pre (2004-2009) and post (2010-2019) to account for the rise of double-cropping in Brazil. The results obtained in step one will be used on step two, as they will define which type we use to model the series.

The second step consists of using either a Vector Autoregressive (VAR) or Vector-Error Correction Model (VECM). If the series are not cointegrated, we proceed with a VAR. If they are not cointegrated we proceed with a VECM. From this step, we will use the residuals obtained to run a BEKK GARCH.

The third step consists of estimating a BEKK GARCH and extracting the target coefficients to calculate the volatility spillovers. The target coefficients are the ones that bring the isolated cross-market effects from one market to the other, on that market conditional volatility equation. This measure will allow us to describe the magnitude and type of spillover present. It is also important because it will allow us to see if there is any seasonality in the spillovers.

By calculating a daily spillover ratio, we show that there has been a structural change in spillover directions. For soybeans in the pre-safrinha period the US volatility spills over to Brazil, after safrinha Brazil volatility spills over to the US, mainly during the first 6 months of the year. On the other hand, for corn, there were no volatility spillovers before the safrinha, and on the post safrinha period there is spillage in both directions between U.S. and Brazil.

## **CHAPTER 2**

### **BACKGROUND**

#### ***2.1 GLOBAL GRAIN PRODUCTION***

Global grain consumption per capita significantly grew from 2000-2017. Estimates from the USDA shows that soybeans and corn consumption increased 64% and 42%, respectively. Taking into consideration that the world population jumped from around 5 billion to 6.5 billion, demand for corn and soybeans has never been higher.

The United States, China, and Brazil are giants in corn production, representing approximately 60% of total production. However, China used to be a big exporter in the early 2000s, but is now a net importer of corn, due to its growth in demand over the past 20 years. That change in China's dynamic, moving from net exporter to importer, created a gap in supply that was filled mainly by two things: a global trend in increasing yields and Brazil entering world markets and becoming the second largest exporter of the grain.

When it comes to soybeans, the three biggest producers are Brazil, the United States, and Argentina, with the three countries representing close to 80% of total production. On the demand side, China accounts for more than 60% of global imports. Asia as a continent accounts for 80%. The big shift in soybeans is that, on a 10-year span, Brazil surpassed the US as the largest producer and exporter of soybeans. Brazil, therefore, was one of the main countries responsible for the growth in production that kept global corn and soybean supply on pace with global demand.

## 2.2 BRAZILIAN PRODUCTION

As noticed above, the rise of Brazilian production was fundamental to keeping global demands sated. Without the country's significant growth in production, it is unlikely that grain production would have been able to keep up with rising demand. The "discovery" of the *Cerrado* region (or Center-West) as a viable location for area expansion in the early '70s and its subsequent development were fundamental factors allowing the transformation in production cycles that the country saw in the early/mid-2000's. Figure 1 highlights the Cerrado region, in light green. It accounts for the states of Goiás, Mato Grosso and Mato Grosso do Sul, leading states in grain production in Brazil.



**Figure 1 - Map of Brazil and Cerrado**

Source: Associação Brasileira de Desenvolvimento Sustentável (ABIDES)

Due to its location the area receives plentiful rainfall through the growing season. This and the government's effort to develop corn and soybeans cultivars better adjusted to the region's climate has resulted in dramatic increases in yields in the region, almost doubling over the past 10 years.

The development of this region as a big producer of grain is key for the surge of Brazil as a top grain producer and exporter. The importance of this region is even bigger since the early 2000's when researchers and farmers discovered the possibility of double cropping corn after soybeans in the same growing year. This effectively doubled the available area for planting (as now farmers could grow both grains on the same space). Double cropping is only possible because the Cerrado region receives plentiful rainfall.

As Figure 2 shows, there is plenty of available water in the soil until the end of May. That means that, on average, a farmer in that region should be able to have enough water for a crop to develop until that period.

Poxoréo/MT | Maximum Retentive Capacity | AWC = 125 mm

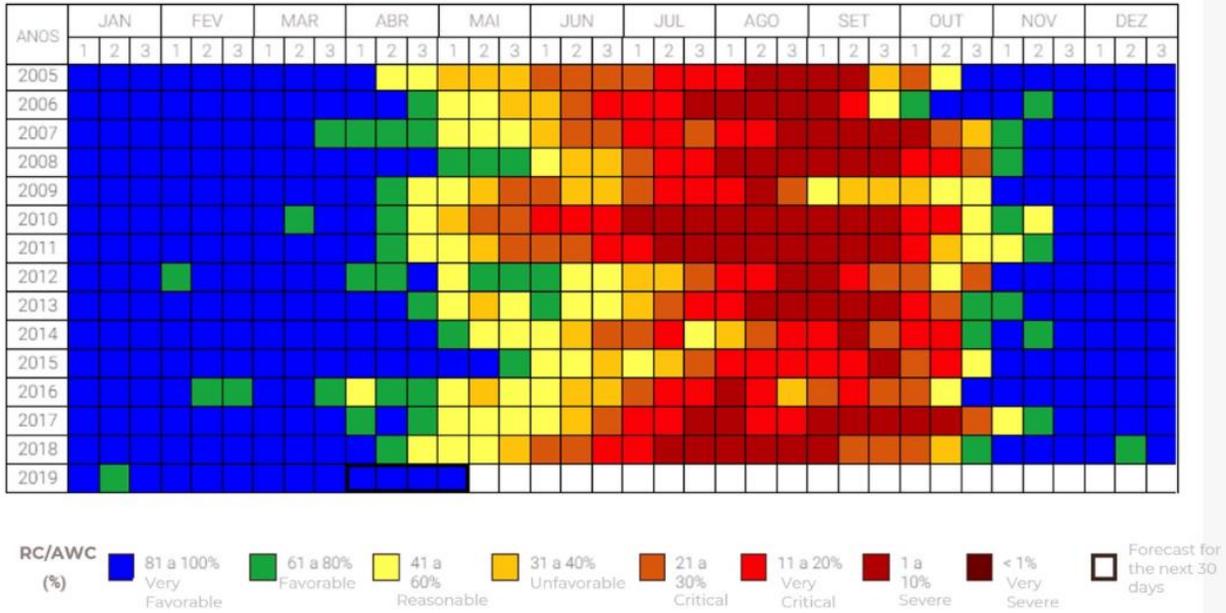


Figure 2- Available Water on Soil

Source: Agrymet (2019)

With an average cycle of 120 days for soybeans and 150 days for corn, 270 day total, farmers started planting soybeans as early as possible, usually starting in October, and planting corn right after harvesting beans. This allows the same area to be used for both crops, increasing production for both. Figure 3 illustrates soybeans and corn planting and harvesting months.

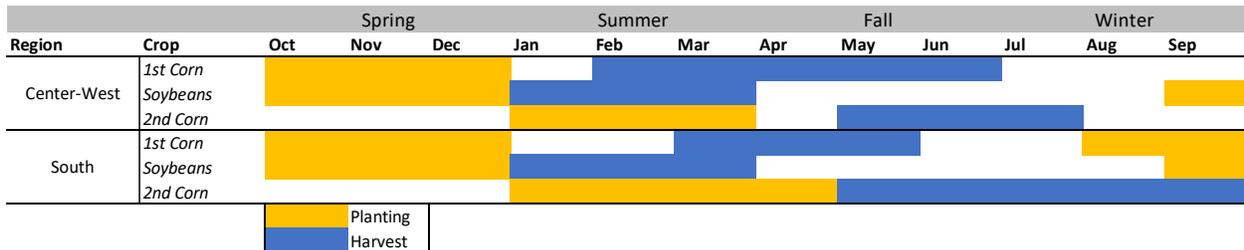


Figure 3- Crop Calendar

Source: Conab (2019) – built by the author

One important factor is that, if the farmer chooses to plant Corn as a first crop, he loses the opportunity to double-crop, as corn takes longer to mature when compared to beans (30 day difference). This feature existent in Brazil pushed the country to the top exporters list in both commodities, increasing yields and area planted.

Another structural change that the second crop brought was a change in price responsiveness of Brazilian farmers. Before Brazil was able to double-crop, Brazilian farmers had a similar planting decision as US farmers. Corn and soybeans would act like perfect substitutes and, in order to maximize the utility of the land, farmers should select the most profitable crop in that year to plant.<sup>1</sup> Land allocation, then, would bring prices to equilibrium. That behavior kept Brazilian and US farmers with similar levels of price responsiveness, and, by default, similar reactions to price shocks.

However, Brazilian farmers that have the ability of double-cropping react differently. Instead of having to select which crop to plant, these farmers will almost without exception plant both. Considering that the only combination for double-cropping is Soybeans then Corn, farmers will plant soybeans and then corn, regardless of the price ratio between both. As we will show later, this smaller planting reaction to price shocks is important to understand the change in volatility transmission on global markets.

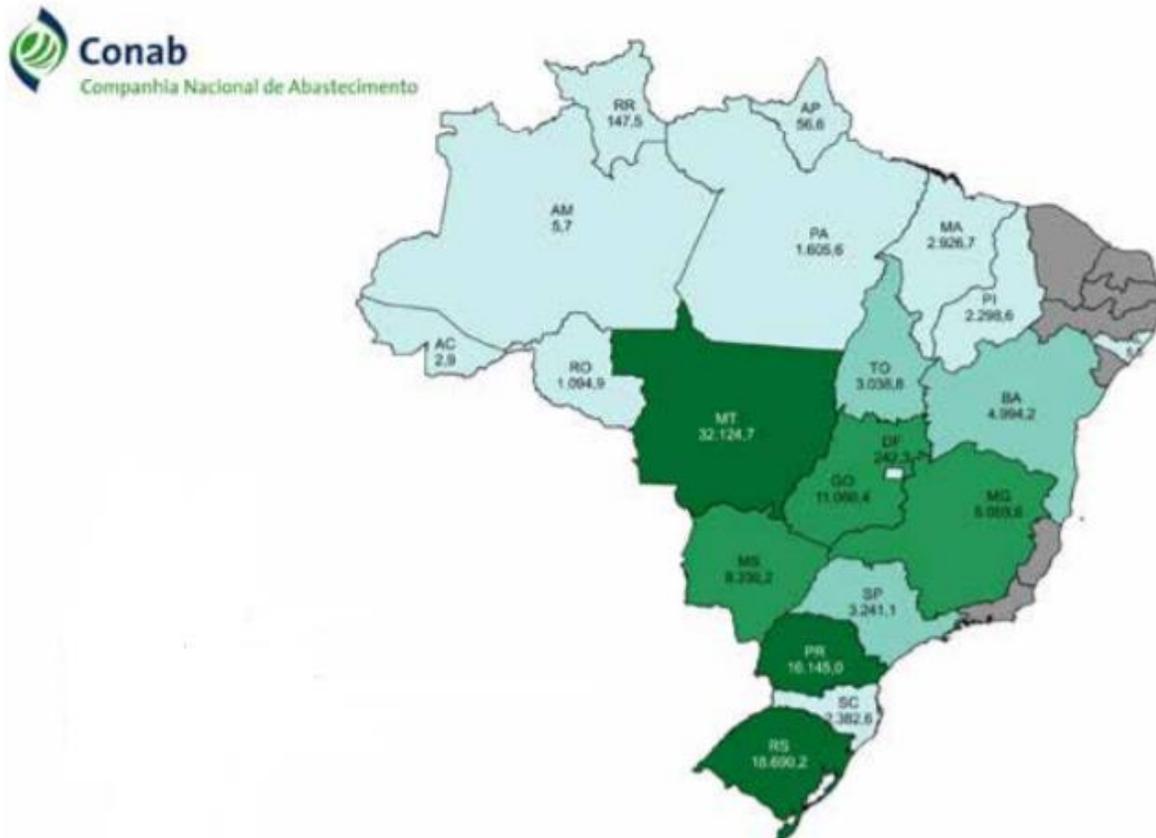
### **2.2.1 Soybeans**

Brazil is currently the largest soybeans producer in the world, recently passing the United States. Soybean production is spread out across the country, with the biggest producing states

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<sup>1</sup> We acknowledge that other factors affect a farmers decision on what to plant. However, several studies similar to Miao, Khanna and Huang (2015) point that price is the main driver.

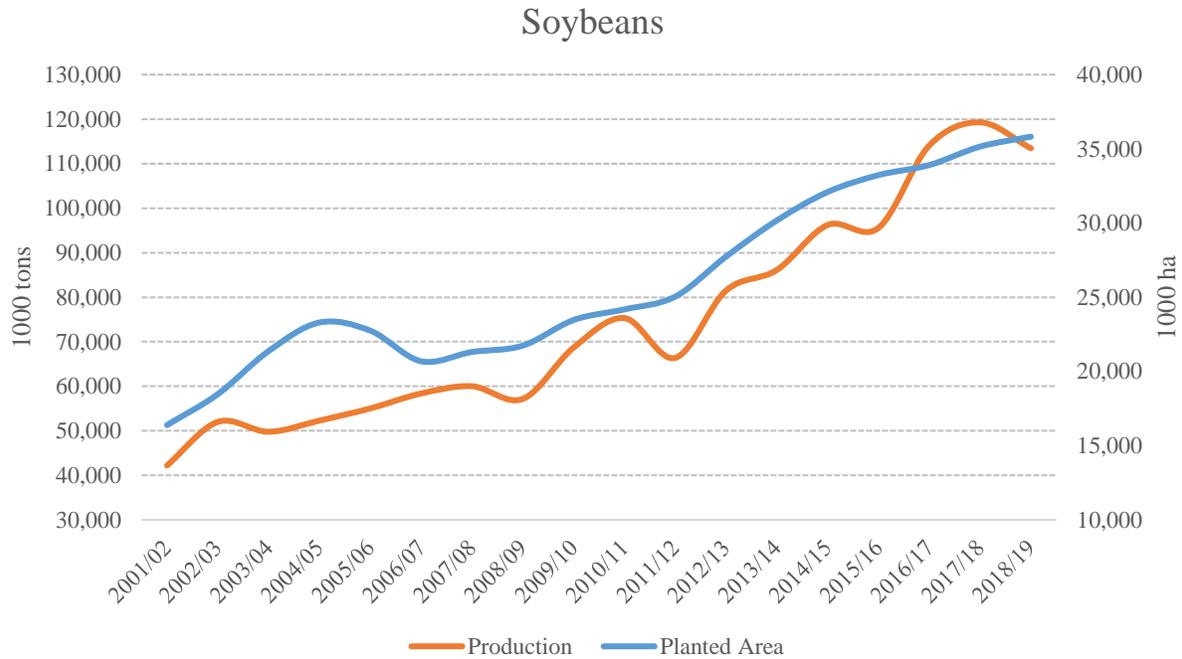
being Mato Grosso, Parana, Rio Grande do Sul, Goias and Mato Grosso do Sul, as shown in Figure 4.



**Figure 4 - Soybean Production Map**

Source: Conab (2019)

From the top 5 producers, 4 of them (north of Parana) allow the farmer to double crop. The fact that an area that, before the second crop, used to be destined for corn (or other crop) is now destined for beans allowed productions to significantly increase, as shown in Figure 5, going from 40 million tons to 120 million tons (300% increase) in less than 20 years and only doubling planted area.

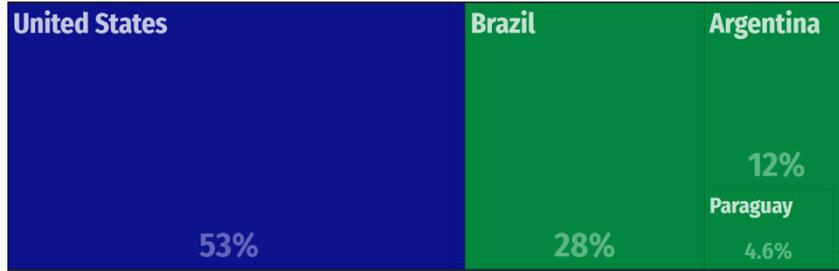


**Figure 5 - Soybeans Production and Planted Area**

Source: Conab (2019) – Built by the author.

This big increase in production allowed Brazil to fulfil increases in global demand. This transformed Brazil in the main exporter of the commodity in the world, surpassing the U.S., as it is possible to compare in Figure 6..

2003



2017

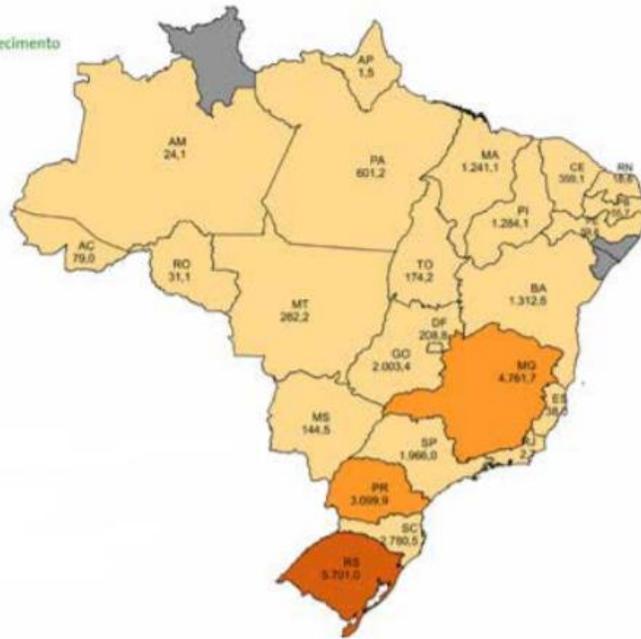


**Figure 6 - Global Soybeans Exports Shares in 2003 and 2017**

Source: UN COMTRADE (2019) – built by Atlas Media.

### 2.2.2 Corn

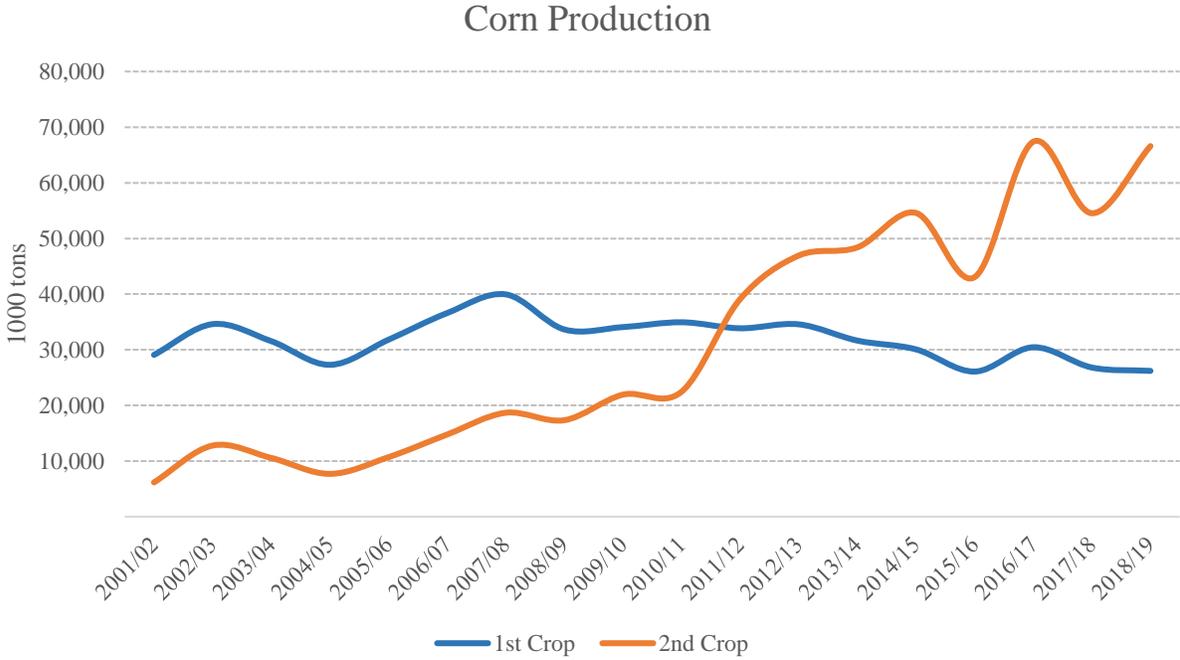
The ability to double crop and use the land available in Cerrado transformed Brazil into a soybean giant, and the same effect can be seen in Corn. While corn can be planted across the entire country, there is a difference between the biggest production regions between first and second crop. The first crop is produced mostly in southern states, as seen in Figure , such as Rio Grande do Sul, and in parts of the Southeast, as in these regions double-cropping is not feasible due to colder weather. The second crop, on the other hand, resembles the soybean production map, as the biggest producing states (Mato Grosso, Parana, and Goias) are the ones that are warm enough and get enough rain to double crop, as seen in Figure 7.



**Figure 7 - 1<sup>st</sup> and 2<sup>nd</sup> Corn Crop Production Map**

Source: Conab (2019)

Over the period, corn production more than doubled in the country, but with an interesting dynamic. As seen in Figure 8, 1<sup>st</sup> crop production decreased in the period, from almost 40 million tons to less than 30 million tons (mostly due to area being switched to soybeans), while 2<sup>nd</sup> crop production had a tremendous increase, going from less than 10 million tons to nearly 70 million tons, a 700% increase.



**Figure 8 - Corn Production**

Source: Conab (2019)

This change was the main reason why Brazil moved from representing less than 5% of global exports in 2003 (Figure 9) and became the second largest exporter in the world 15 years later.

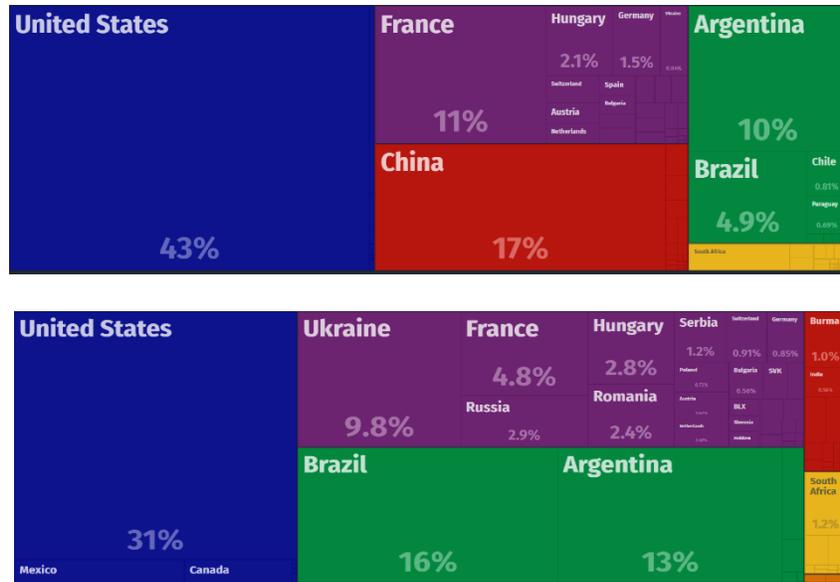


Figure 9 - Global Corn Export Shares in 2003 and 2017

Source: UN COMTRADE (2019) – built by Atlas Media.

## 2.3 MARKETS

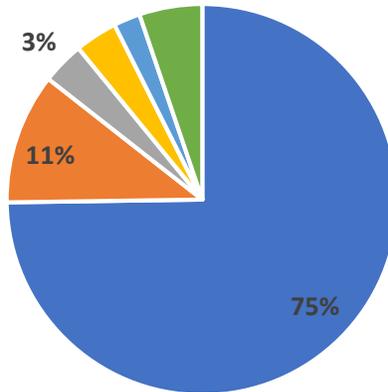
### 2.3.1 International Markets

As previously discussed, Brazil plays a leading role both in corn and soybeans exports markets. However, buyers for these grains are very different.

On the soybeans side, Brazilian shipments are mostly directed to China, which imports 75% of the total volume, as shown in Figure 10, while the rest is mainly exported to European Union countries.

### Total Soybean Imports

■ China ■ Spain ■ UK ■ Netherlands ■ Russia ■ Others



**Figure 10 - Brazilian Soybeans Exports Destination**

Source: MDIC (2019), built by the author.

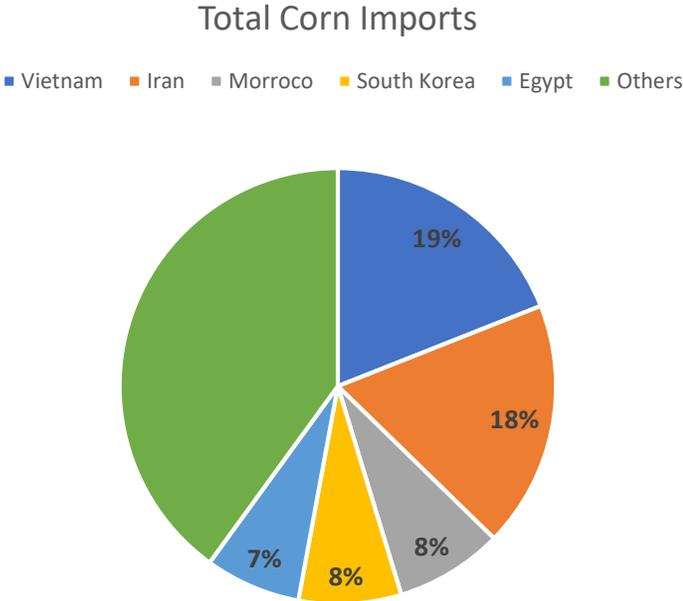
It is also worth mentioning that China is the largest importer of soybeans in the world, as seen in Figure 11, and is also the biggest destination for U.S. beans. Because of that, Brazilian and US soybeans are big price competitor in international markets.



**Figure 11 - Global Soybeans Import Shares**

Source: UN COMTRADE (2019) – built by Atlas Media.

Corn buyers are very different from soybeans buyers. While China is the biggest player in soybeans, importing more than everyone else together, corn destinations are more scattered. As Figure shows, most of the Brazilian corn is destined towards the Middle East and Asia, with Vietnam and Iran being the biggest buyers.



**Figure 12 - Brazilian Corn Exports Destination**

Source: MDIC (2019), built by the author.

In contrast to soybeans, in which Brazil and the US compete for the Chinese market, corn destination for the two biggest exporters do not overlap. US biggest buyers are Japan, Mexico, and the European Union. As we can see in Figure 13, there is no clear hub destination for corn.

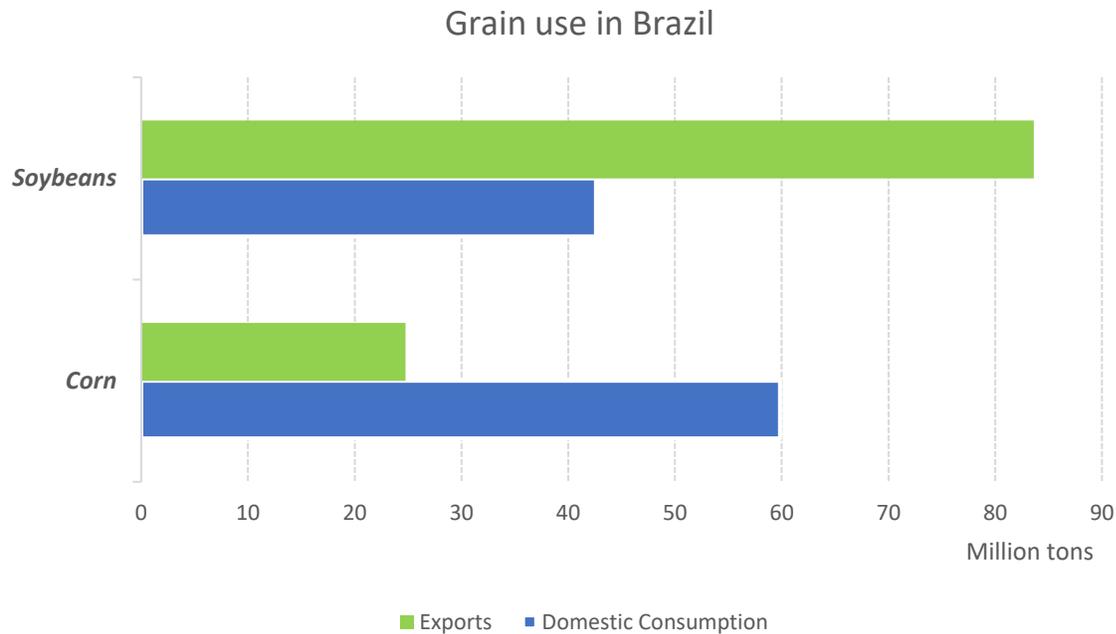


**Figure 13 - Global Corn Import Shares**

Source: UN COMTRADE (2019) – built by Atlas Media.

### 2.3.2 Domestic Market

While a big participant in international markets for soybeans and corn, Brazil is also a big consumer of grain. The country has not only the largest commercial cattle herd in the world, but also is a leader in pork and the second-largest poultry producer in the world. As Figure 14 shows, more than 50% of the corn produced in the country stays is consumed in the country.



**Figure 14 - Grain use in Brazil**

Source: CONAB (2019), built by the author.

Most of this corn is destined to pork and poultry production, whose main hubs are in Parana, Santa Catarina and Rio Grande do Sul, all southern states that produce most of the 1<sup>st</sup> corn crop. Because of that, the first crop is considered a domestic crop, supplying this demand, and the second corn crop is usually used to fill the rest of the demand gap and exports.

Another important reason why the second corn crop is exported is that, as it is planted after the soybean harvest; therefore, it does not compete for space in the ports. Brazil’s infrastructure for exports is limited, even though several ongoing expansion projects will help alleviate some of the pressure, according to Maia et al (2013). Having the soybeans exported and then switching to corn makes logistical sense. As Figure 14 illustrates, soybeans export volume is more than three times the actual volume of corn, so soybeans have priority during peak harvest months.

Soybeans are exported because China's biggest demand is for the raw grain, not for the processed products, meal, and oil. Because of that, and Brazil not having a very large crushing industry, the country exports two-thirds of its production.

Due to these reasons, soybeans are, in general, more exposed to global prices, while shifts in domestic production and demand in Brazil can have big impacts in domestic prices, that will not necessarily follow global market prices.

## CHAPTER 3

### LITERATURE REVIEW

Understanding the relationships between cash and futures prices is fundamental for risk managing purposes. The understanding of cointegration was introduced by Engle and Granger (1987) and states that two variables are cointegrated because of the presence of a long-run equilibrium between them. Several studies, like Lai and Lai (1991), present strong evidence of cointegration between a future and its cash market. Ghosh (1993) points out that, when the presence of cointegration is not considered, a smaller than optimal hedge position will likely take place. Lien (1996) adds to that, saying that if cointegration is not taken into account, hedge performance will be worse and will likely cost more for the errant hedger. Lien (1996) also adds that, while GARCH effects will not affect the under/over hedge derived from the cointegration relationship, they play an important role in allowing for a time-varying minimum risk hedge ratio. Understanding GARCH effects between two prices, then, is also important.

Modeling volatility spillovers through GARCH models linking different futures markets or futures and cash markets can be done in several different ways. Ng (2000) proposes a two-factor model that allows for an external shock to spillover over the studied markets utilizing univariate and multivariate GARCH models for stock indexes. Other authors investigate these relationships across energy and agricultural markets.

Utilizing the BEKK specification, proposed by Engle and Kroner (1995), Zhang et al. (2009) examined how food prices were affected by US energy markets. Serra et al. (2011) use the BEKK to analyze volatility spillovers between crude oil, ethanol, and Brazilian sugarcane prices. Wu, Guan, and Myers (2010) use a similar approach Ng (2000) but allowing for a time-

varying volatility spillover coefficient and analyze how spillover effects coming from crude oil to corn were enough to utilize crude oil as a cross-hedge tool to hedge corn. Trujillo-Barrera, Mallory, and Garcia (2012) use a two-step approach to calculate volatility spillovers between crude oil, corn and ethanol, finding that crude oil and corn spillover ethanol.

Another set of studies focuses on impulse response to price shocks. Among them, Garderbroek and Hernandez (2013) derive impulse response functions from a tri-variate T-BEKK model and a DCC-GARCH for crude oil, corn, and ethanol. Most of these studies, however, are focused on the relationship between energy and agricultural markets.

Studies that focus on grain and oilseed markets include Booth and Ciner (1997), who study corn markets and spillovers for different regions, Goychuk and Meyers (2001) that focus on wheat and Fossati, Lorenzo and Rodriguez (2009) that study cattle markets and grains. Global market relations are also studied by Yang et al. (2003), who look at wheat futures among North America and Europe.

Brazilian markets were also topics of different studies. Balcombe et al. (2007) analyzed how Brazilian, Argentine and US grain markets were related, investigating possible threshold effects. They approach it using Eq-TAR and Band-TAR models with a Bayesian approach. Utilizing data up to 2006, their study finds that threshold effects exist, and transmission was bigger for corn markets and US and Argentine markets, with Brazil not affecting at all.

Mattos and Silveira (2015) measure the impacts of the second corn crop in Brazil on seasonality, basis behavior and integration to international markets. They find that, after the double crop, Brazilian markets became more integrated into international markets. Cruz Jr. et al. (2016) builds on this and, utilizing futures and cash prices for soybeans and corn, using causality

tests find that the level of market integration increased and price sensibility to global markets has also increased.

This study will contribute to the literature in two forms. We test for market cointegration only using Brazilian cash prices and US futures prices, as Brazilian Futures markets for soybeans and corn were found to be inefficient for hedging purposes by Rodrigues and Martines Filho (2015). This is important as studies that considered Brazilian futures could have distorted results deriving from the inefficiency present in these markets.

Our second contribution is that we are the first ones measuring volatility spillovers seasonal changes, only possible through our calculation of time-varying spillover ratios obtained through the BEKK conditional variances. Our measure is different from Wu, Guan and Myers (2010) and Trujillo-Barrera, Mallory, and Garcia (2012) because we do not have a market defined as exogenous, but we allow both markets to generate spillovers. And, unlike Garderbroek and Hernandez (2013), we do not generate impulse response functions as our measure, but we generate daily spillover ratios.

These new metrics help to enhance the understanding of spillover relationships. Exploiting the fluid nature of the BEKK model the way proposed, that provides a moving variance-covariance matrix, allows researchers to better analyze the seasonal patterns in spillovers relationships and the evolution of the relationships (if the markets are spilling over more or less).

## CHAPTER 4

### DATA

We use daily closing futures log prices<sup>2</sup>, as they are easier to be used to compute returns on the models, for Soybeans (S) and Corn (C) from CME, using most active contract prices rolled on a per volume basis, ranging from September 10<sup>th</sup>, 2003 to March 26<sup>th</sup>, 2019 as our benchmark for US Futures prices. Brazilian prices are the daily average price at the Port of Paranaguá, for soybeans, and daily average prices from Chapecó and Sorriso for corn. These prices are from CEPEA and are converted to US\$/bu using daily foreign exchange rates from the Federal Reserve Economic Data (FRED – St Louis Fed). Figure 15 illustrates the selected cash prices locations.

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<sup>2</sup> Results are robust for prices not converted to log. Available upon request.



**Figure 15 - Cash Prices Location in Brazil**

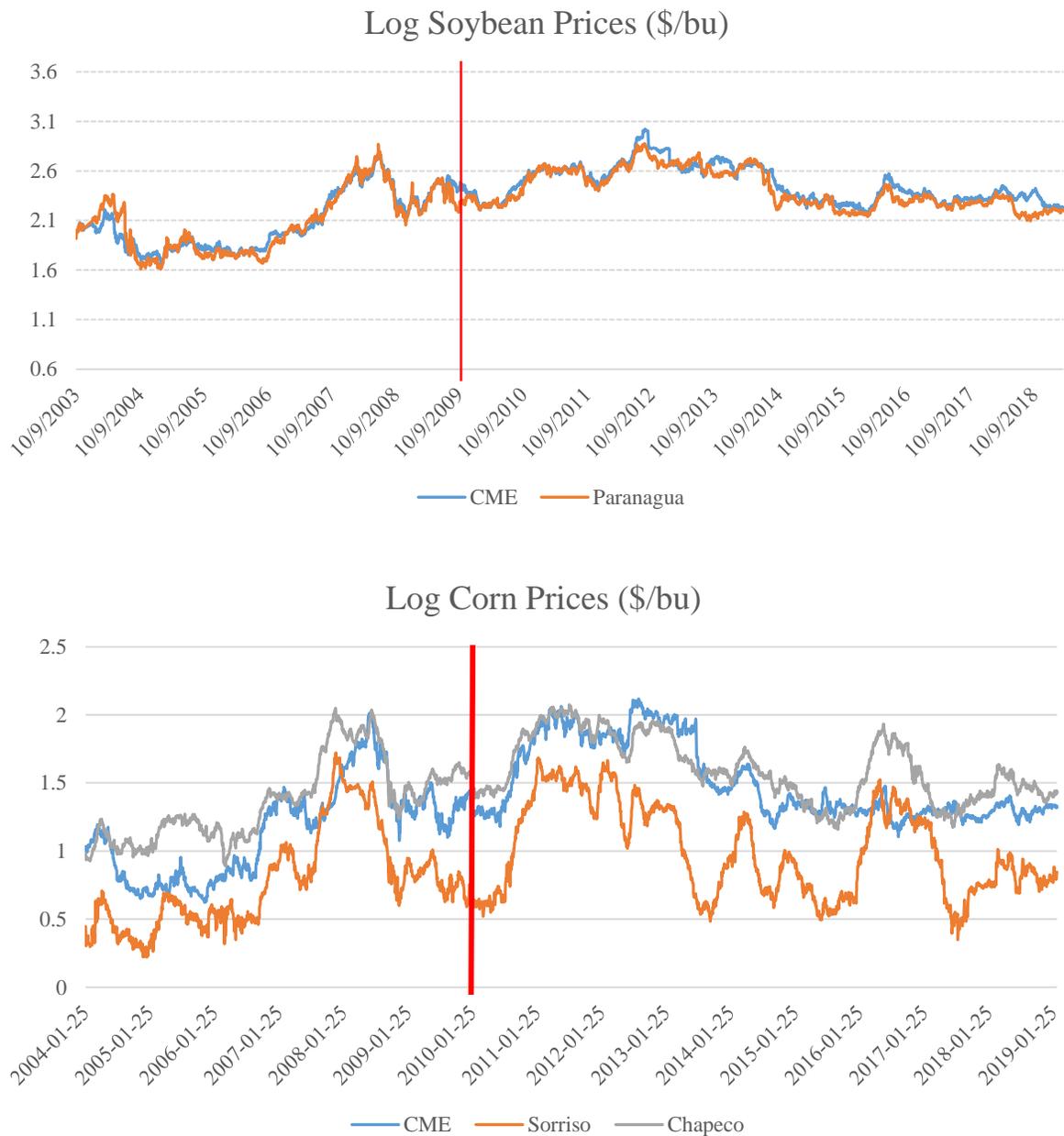
Source: Departamento Nacional de Infraestrutura de Transportes (DNIT) (2019), adapted by the author.

The yellow dot indicates the Port of Paranaguá region. Data from COMEXSTAT (2019) shows that the Port of Paranaguá exported approximately 15 million tons of soybeans, second only to the Port of Santos (20 million tons). The difference between the two ports is that, while Santos only exports grain coming from the Center-West and Southeast, Paranaguá exports grains from these regions and also grain originated in the South, so it will serve as our Brazilian proxy for soybeans prices.

The red dot represents Chapeco, our proxy for first crop corn supply and demand, as farmers around this area do not double-crop and most poultry and pork feedlots are in this area, meaning that domestic consumption is mainly there. The green dot represents Sorriso, the biggest producer of grain in the country and one of the largest areas for double-cropping. Most of

the corn produced there is second crop, as Figure 15 shows. It will serve as our proxy for the second crop.

Figure 16 shows the prices across the time studied. Red lines indicate where we are separating our sample in two distinct periods (Pre and Post Second Crop).



**Figure 16 - Log Soybean and Corn Prices**

Source: CME and CEPEA, built by the author. (2019)

Correlations for the sample are shown in Table 1. Soybeans returns correlations are higher than corn, which is important to notice as this foreshadows the expected higher spillovers to be found in soybeans markets.

**Table 1 - Correlations**

	Correlations	Corn CME	Corn Sorriso	Corn Chapeco	Soybeans CME	Soybeans Paranagua
Levels	Corn CME	1.00	0.76	0.85	-	-
	Corn Sorriso	0.76	1.00	0.93	-	-
	Corn Chapeco	0.85	0.93	1.00	-	-
	Soybeans CME	-	-	-	1.00	0.96
	Soybeans Paranagua	-	-	-	0.96	1.00
Returns	Corn CME	1.00	0.14	0.13	-	-
	Corn Sorriso	0.14	1.00	0.24	-	-
	Corn Chapeco	0.13	0.24	1.00	-	-
	Soybeans CME	-	-	-	1.00	0.53
	Soybeans Paranagua	-	-	-	0.53	1.00

Table 2 presents the summary statistics for the data used. The distribution of returns looks skewed to the left side for soybeans. Variance and Standard Deviations look fine for the returns, but there is some excess kurtosis in the soybeans series, that will be smoothed as we use t-distributions for our models, not normal.

Stationarity tests using the Augmented Dickey Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) are performed. Both indicate that our sample and sub-samples are non-stationary and stationary of order 1. We also perform the Zivot-Andrews test to make sure that the unit-root processes are not due to structural breaks, which the test indicate that is not the case. Because of that, we will proceed with a VAR in first differences and a VECM in price levels.

**Table 2 - Summary Statistics**

	<b>Statistics</b>	<b>Minimum</b>	<b>Maximum</b>	<b>1st Quartile</b>	<b>3rd Quartile</b>	<b>Mean</b>	<b>Median</b>
<i>Levels</i>	Corn CME	1.86	8.31	3.42	4.89	4.17	3.74
	Corn Sorriso	1.24	5.59	1.87	3.43	2.66	2.31
	Corn Chapeco	2.43	7.97	3.69	5.73	4.72	4.42
	Soybeans CME	5.18	20.50	8.67	12.75	10.57	10.41
	Soybeans Paranagua	5.00	17.69	8.63	12.44	10.18	9.81
<i>Returns</i>	Corn CME	-0.11	0.13	-0.01	0.01	0.00	0.00
	Corn Sorriso	-0.16	0.26	-0.01	0.01	0.00	0.00
	Corn Chapeco	-0.11	0.14	-0.01	0.01	0.00	0.00
	Soybeans CME	-0.09	0.11	0.00	0.00	0.00	0.00
	Soybeans Paranagua	-0.26	0.18	0.00	0.01	0.00	0.00

	<b>Statistics</b>	<b>Variance</b>	<b>SD</b>	<b>Skewness</b>	<b>Excess kurtosis</b>
<i>Levels</i>	Corn CME	2.30	1.52	0.80	-0.13
	Corn Sorriso	1.02	1.01	0.83	-0.46
	Corn Chapeco	1.78	1.33	0.50	-0.75
	Soybeans CME	8.99	3.00	0.27	-0.25
	Soybeans Paranagua	8.02	2.83	0.21	-0.62
<i>Returns</i>	Corn CME	0.00	0.02	0.04	2.87
	Corn Sorriso	0.00	0.03	0.37	5.77
	Corn Chapeco	0.00	0.02	-0.19	4.96
	Soybeans CME	0.00	0.01	-0.55	9.80
	Soybeans Paranagua	0.00	0.02	-1.70	37.09

## CHAPTER 5

### RESEARCH METHOD

Our empirical analysis will be done using a three-step approach. The first step is to determine the presence, or not, of unit-roots and/or structural breaks in the series. This is a crucial step as it will allow us to better determine how to approach our data. The second step of our analysis determines the existence of cointegration between the studied pairs, to model our series either through a Vector Autoregressive (VAR) process or through a Vector Error Correction Model (VECM). Lastly, our third step extracts residuals from the VAR or VECM to estimate a BEKK model. The BEKK model is a multivariate GARCH model that will allow us to model conditional volatilities and the spillover ratios.

#### 5.1 Unit-Root Tests

In this section, we present all the methods to define whether there is a unit-root in our sample. The first thing we need to do is define the number of lags we will utilize for our sample. Due to the high number of data points in our sample, our lag selection method will be the Hannan-Quinn Information Criterion (Hannan and Quinn, 1979), an alternative to the Akaike Information Criterion (AIC). The main difference between the two methods is that AIC selects a true model that overfits (larger than the true model), so we opt to use HQ, that selects a more parsimonious model. The test statistic is presented in Equation 1:

$$HQC = -2LMAX + 2k\ln(\ln(n)) \quad (1)$$

$L_{max}$  = log likelihood,  $k$ = number of parameters, and  $n$ = number of observations

We test our data for stationarity using two different methods: Augmented Dickey-Fuller and KPSS. Even though they are testing stationarity, these tests have some differences.

The ADF test was introduced by Dickey and Fuller (1979) and tests with its null hypothesis being that the process has unit-root or is “difference stationary”. The alternative hypothesis is that the process does not have unit-root (in our test, rejecting the null means that the process is stationary). On the other hand, the KPSS’ null hypothesis is that the process is stationary, while the alternative hypothesis is that the process has unit-root, as proposed by its authors in 1992.

In addition, we perform the Zivot-Andrews (Z-A)(1992) test for Structural Breaks. We run the Z-A test after the stationary tests because we want to make sure that the unit-root process that we found in the ADF and KPSS tests are not due to a structural break in the series. The Z-A test must be run after we perform the stationarity tests, and after we find a unit-root in those tests, otherwise it is misspecified.

## **5.2 Cointegration Test and Model Selection**

We proceed in this second step by breaking our corn and soybeans series in two series, one pre-double cropping and one post double cropping. Figure 5 indicate an increased growth in production starting in the crop year of 2009/10, so we will separate our data in these points.

After separating our data, we will use Johansen's (1991) Cointegration Test. This well-known multivariate test will allow us to determine if there is a long-run equilibrium relationship. If we find that there is one cointegrating relationship, we assume the markets are cointegrated.

Determining the existence of cointegration is important as it will direct us to our first model selection. If the test suggests no cointegration, we proceed fit a VAR in first differences; otherwise we fit a VECM.

### 5.2.1 Vector Autoregressive (VAR)

A generalization of the univariate autoregressive model (AR model), VAR models captures the linear interdependencies intertemporally between two or more variables. The model is shown in Equation 2, as each variable has its own equation, affected by its own lagged term, the lagged term of the other(s) variable(s) and an error term. A simple VAR with one lag and two variables interacting can be described as:

$$\begin{aligned}\Delta br_t &= a_{10} + a_{11}\Delta br_{t-1} + a_{12}\Delta us_{t-1} + e_{1t} \\ \Delta us_t &= a_{20} + a_{21}\Delta br_{t-1} + a_{22}\Delta us_{t-1} + e_{2t}\end{aligned}\tag{2}$$

The significance of the lagged coefficients helps to determine the linear relationships between the two variables. For our next step, we extract the residuals from this system, defined in Equation 3 as:

$$\varepsilon_t = [e_{1t}, e_{2t}]\tag{3}$$

## 5.2.2 Vector Error Correction Model (VECM)

The Vector Error Correction Model is a VAR with an added term. This added term represents the cointegration relationship, or the long-run equilibrium between the studied variables called the Error Correction Term. As we are studying pairs, we can only find no-cointegration (VAR) or one cointegrating relationship, therefore adding one ECT per equation, as in Equation 4.

$$\begin{aligned}\Delta br_t &= \delta_{10} + \alpha_1(\beta_0 + \beta_1\Delta br_{t-1} + \beta_2\Delta us_{t-1}) + \delta_{11}\Delta br_{t-1} + \delta_{12}\Delta us_{t-1} + e_{1t} \\ \Delta us_t &= \delta_{20} + \alpha_2(\beta_0 + \beta_1\Delta br_{t-1} + \beta_2\Delta us_{t-1}) + \delta_{21}\Delta br_{t-1} + \delta_{22}\Delta us_{t-1} + e_{2t}\end{aligned}\quad (4)$$

While the  $\delta$ 's are the same as the regression coefficients in the VAR equations, the error correction term part introduces new terms, the  $\alpha$ 's and the  $\beta$ 's. The ECT is a combination of the equilibrium relationship, determined by  $\beta_0 + \beta_1 br_{t-1} + \beta_2 us_{t-1}$ , and the speed of adjustment terms,  $\alpha_1$  and  $\alpha_2$ .

That means that the  $\beta$ 's indicate how one variable relates to the other in the long-run. The  $\alpha$ 's, on the other hand, indicate how the two series will adjust to a disequilibrium. That means that, for example, if US deviates from BR departing from the long-run equilibrium, the  $\alpha$ 's will bring the relationship back. One important thing is that the  $\alpha$ 's also indicate who responds faster to a disequilibrium, making the VECM a useful model for other applications like price discovery, as in Janzen and Adjemian (2017), and market integration, as in Mjelde and Bessler (2009).

Similar to how we handle the VAR model, we extract the residuals vector, similar to Equation 2, and use those to calculate market volatility spillovers.

### 5.3 BEKK GARCH and Spillover Ratio Estimation

GARCH models are useful to model volatility within a series. When dealing with more than one variable, one should use a multivariate GARCH (MGARCH) to properly model the volatilities and interactions between the series evaluated. While several different specifications for MGARCH exist, this paper will utilize the BEKK-GARCH, defined by Baba, Engle, Kraft, and Kroner (1990).

Using the BEKK model specification guarantees some important benefits against other MGARCH models, like the natural multivariate extension of the GARCH (VEC-MGARCH) and the Dynamic Conditional Correlation (DCC) specifications. The BEKK, that is a restricted VEC in a way, is positive definite, an important definition for the volatility studied in this paper. As Equation 5 shows, the model decomposes the constant term into a product of two triangular matrices makes sure that  $H_t$  (the conditional variance-covariance matrix) is positive semi-definite.

$$H_t = C'C + \sum_{j=1}^q \sum_{k=1}^K A'_{kj} e_{t-j} e'_{t-j} A_{kj} + \sum_{j=1}^q \sum_{k=1}^K B_{kj}' H_{t-j} B_{kj} \quad (5)$$

Guaranteed positive semi-definiteness is plus compared to VEC. Further, it a better choice for our context than the DCC-GARCH once the conditional correlations are flexible in the BEKK model, while the DCC requires them to be static.

As mentioned in section 4.2, we utilize the residuals matrices extracted from the pair studied to estimate the BEKK. Considering a two-variable system ( $br$  and  $us$ ), Equation 5 yields:

$$\begin{bmatrix} h_{brbr,t} & h_{brus,t} \\ h_{brus,t} & h_{usus,t} \end{bmatrix} = \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} c_{11} & 0 \\ c_{21} & c_{22} \end{bmatrix}' + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} e_{br,t-1}^2 & e_{br,t-1}e_{us,t} \\ e_{br,t}e_{us,t-1} & e_{us,t-1}^2 \end{bmatrix} \\ + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' \begin{bmatrix} h_{brbr,t-1} & h_{brus,t-1} \\ h_{brus,t-1} & h_{usus,t-1} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \quad (6)$$

This defines the conditional volatilities of *br* and *us* to be:

$$\begin{aligned} h_{brbr,t} &= c_{11}^2 + a_{11}^2 e_{br,t-1}^2 + 2a_{11}a_{21}e_{br,t-1}e_{us,t-1} + a_{21}^2 e_{us,t-1}^2 + b_{11}^2 h_{brbr,t-1} \\ &\quad + 2b_{11}b_{21}h_{brus,t-1} + b_{21}^2 h_{usus,t-1} \\ h_{usus,t} &= c_{12}^2 + c_{22}^2 + a_{12}^2 e_{br,t-1}^2 + 2a_{12}a_{22}e_{br,t-1}e_{us,t-1} + a_{22}^2 e_{us,t-1}^2 + b_{12}^2 h_{brbr,t-1} \\ &\quad + 2b_{12}b_{22}h_{brus,t-1} + b_{22}^2 h_{usus,t-1} \end{aligned} \quad (7)$$

After defining the conditional volatilities and the terms that calculate them, we will proceed to separate and evaluate the isolated cross-market effects. We define isolated cross-market effects as the effects caused on the target market (i.e. *br*) by, and solely by, the other market (i.e. *us*). Table 3 shows the price shock isolated coefficients and the price volatility isolated coefficients that affect the other market.

**Table 3 - Cross-Market Effects**

Effect	Conditional Volatilities	
	$h_{aa,t}$	$h_{bb,t}$
Price Shocks	$a_{21}^2 e_{b,t-1}^2$	$a_{12}^2 e_{a,t-1}^2$
Price Volatility	$b_{21}^2 h_{bb,t-1}^2$	$b_{12}^2 h_{aa,t-1}^2$

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**a = Brazil / b=US**

Albeit these coefficients are not the only ones that represent market effects, these are the only ones that represent purely information coming from the other market. Our measure, shown in Equation 8, also adds the covariance term, that also represents interactions between the two markets.

Subsequently, to isolating these coefficients, we measure a Spillover Ratio at time  $t$ . As Equation 8 shows, the sum of the price shock effect and the volatility effect are divided by the total conditional volatility of the other market.

$$SR_{us \rightarrow br} = \frac{(a_{21}^2 e_{us,t-1}^2 + b_{21}^2 h_{usus,t-1} + 2b_{11}b_{21}h_{brus,t-1})}{h_{brbr}} \quad (8)$$

As the BEKK defines conditional volatility as always positive and the fact that price shock effects are squared, the ratio automatically assumes a positive or zero value (unless a negative covariance coefficient is present and significative). Also notice that the SR can be higher than 100%. Although the cross-market coefficients will always be positive, by definition, the other coefficients in the calculation are not necessarily positive. The interaction coefficients (i.e.  $2a_{11}a_{21}e_{br,t-1}e_{us,t-1}$ ) from Equation 7 can assume negative values (for example when a shock is negative and the coefficient is positive, or vice versa).

This definition derived from the BEKK conditional volatilities equation will allow the calculated Spillover Ratio from Equation 8 to be bigger than 100%. There are two interpretations of this phenomenon:

- Volatility at  $t$  is markedly lower than at  $t-1$ , so the volatility and price shocks effects from  $t-1$  are representing most of the volatility at  $t$ ;

- The Spillover Ratio presents the **highest** effect one market can have on the other. However, that effect also counts for the covariance effect, which can also count for endogenous effects from the target market on itself.

Although not a perfect measure, this approach to calculating the cross-market effects, or spillovers, allow this study to calculate varying  $t-t_0-t+1$  ratios. This is key to evaluate seasonal effects between markets and the evolution of the relationships, a key feature of this study.

This is an improvement over other methods, like calculating impulse response function, used by Gardebroek and Hernandez (2013) because it allows a key feature of the BEKK, the changing variance-covariance matrix, to be used. An impulse response function requires a fixed variance-covariance matrix, which would simply average-out the BEKK estimations. It is also an improvement over the regression method used in Wu, Guan and Myers (2011) because it does not require the series to be completely uncorrelated and the determination of which shock is exogenous.

## CHAPTER 6

### RESULTS AND DISCUSSION

We will separate the results and discussion section in two parts, one for corn and the other one for soybeans.

#### 6.1 CORN

We divide our corn series in two sub-samples, with the breaking point in the 09/10 crop year because that is when the “safrinha”, or second crop corn production, started to gain momentum.

The first test that we run is the Johansen test for cointegration. Table 4 shows the results obtained for the two sub-samples.

**Table 4 - Cointegration Test for Corn**

<i>US Futures x Sorriso Spot</i>						
<i>Cointegration Rank</i>	<i>λmax</i>	<b>2004-2009</b>		<b>2010-2019</b>		
		<i>Critical Value</i>		<i>Critical Value</i>		
		<i>95%</i>	<i>99%</i>	<i>λmax</i>	<i>95%</i>	<i>99%</i>
r=0	9.15	15.67	20.20	25.70**	15.67	20.20
r ≤ 1	1.97	9.24	12.97	2.86	9.24	12.97

<i>US Futures x Chapeco Spot</i>						
<i>Cointegration Rank</i>	<i>λmax</i>	<b>2004-2009</b>		<b>2010-2019</b>		
		<i>Critical Value</i>		<i>Critical Value</i>		
		<i>95%</i>	<i>99%</i>	<i>λmax</i>	<i>95%</i>	<i>99%</i>
r=0	9.54	15.67	20.20	22.50**	15.67	20.20
r ≤ 1	2.47	9.24	12.97	1.87	9.24	12.97

It is possible to observe a clear change in both regions, Sorriso and Chapeco. While we cannot reject the null of no cointegration (r=0) for the first period, we are able to reject the null at the 1% level for the second period.

In the second period there is one cointegrating relationship ( $r < 1$  cannot be rejected) between the two price series. These results confirm our suggestion that Brazil has become influential in global corn markets after the country started double-cropping. This is also important, because it indicates the country moving from a domestic based pricing to being more sensitive to globalized price discovery.

After defining the presence of cointegration or not, we proceed with modeling our series. For the first period we use a VAR in first differences. The second period will be modeled through a VECM in price levels. The estimation results<sup>3</sup> can be found in Table and Table .

Table displays the estimated VAR. The VAR indicates that US markets influenced Brazilian corn price changes. In the meantime, Brazilian corn prices changes are not significant on the US equation, suggesting that Brazilian corn did not affect US markets in this period.

**Table 5 – Corn VAR parameters**

<b>VAR Lagged Parameters - 2004-2009</b>			
<i>Sorriso x US Equation</i>	<i>Parameter</i>	<i>Estimate</i>	<i>Std. Error</i>
Sorriso Spot	Sor L1	-0.16054**	0.027
	US L1	0.09176**	0.035
	Sor L2	-0.05391**	0.027
	US L2	0.02824	0.035
US Futures	Sor L1	0.01240	0.021
	US L1	0.02668	0.027
	Sor L2	0.01275	0.021
	US L2	0.01306	0.027
<i>Chapeco x US Equation</i>	<i>Parameter</i>	<i>Estimate</i>	<i>Std. Error</i>
Chapeco Spot	Chap L1	-0.11407**	0.027
	US L1	0.05097**	0.022
	Chap L2	0.02761	0.027
	US L2	0.03086	0.022
US Futures	Chap L1	0.00721	0.034
	US L1	0.02856	0.027
	Chap L2	-0.01920	0.034
	US L2	0.01882	0.027

\*\*(\*) Denotes significance at 1% (5%) level

<sup>3</sup> Results for Sorriso. Chapeco results can be found in Appendix A.

**Table 6 – Corn VECM Coefficients - 2009/2019**

<b>VECM Parameters - 2009-2019</b>			
<i>Sorriso x US Equation</i>	<i>Parameter</i>	<i>Estimate</i>	<i>Std. Error</i>
	$\beta_{sor}$	<i>1</i>	
	$\beta_{us}$	-1.0028**	
Sorriso Spot	$\alpha_{sor}$	-0.010214**	0.003
	2016 Dummy	0.007967**	0.002
US Futures	$\alpha_{us}$	0.005648**	0.002
	2016 Dummy	-0.003408**	0.002
<i>Chapeco x US Equation</i>	<i>Parameter</i>	<i>Estimate</i>	<i>Std. Error</i>
	$\beta_{chap}$	<i>1</i>	
	$\beta_{us}$	-0.8134**	
Chapeco Spot	$\alpha_{chap}$	-0.011443**	0.002
	2016 Dummy	0.005189**	0.001
US Futures	$\alpha_{us}$	0.007546**	0.003
	2016 Dummy	-0.002785*	0.001

\*\*(\*) Denotes significance at 1% (5%) level

The VECM coefficients also provide interesting results. We add a dummy variable for 2016, as a big drought affected Brazilian producers, on both corn crops. As stocks were already low, the country had to import corn and there were several interventions by CONAB through federal auctions to contain prices. The drought was severe enough to reduce yield by 20% (Conab, 2019). We find highly significant  $\alpha$  and  $\beta$ . The sum of the  $\beta$  is very close to zero, as expected when we are pricing the same commodity and assuming no constant arbitrage relationship, as discussed in Baffes (1991). The  $\alpha$  also provides insight on the relationship. In absolute terms, the  $\alpha$  for Sorriso is two times bigger than the US, indicating that Brazilian prices respond faster and with more intensity to a disequilibrium.

After extracting the residuals from the VAR and from the VECM, the BEKK GARCH coefficients estimation are presented in Table 7 and 8.

**Table 7 – Corn BEKK Coefficients for Sorriso**

<b>BEKK GARCH</b>	<b>2004-2009</b>		<b>2010-2019</b>	
<i>Variable</i>	<i>Coefficient</i>	<i>t-Statistic</i>	<i>Coefficient</i>	<i>t-Statistic</i>
C(1,1)	0.004**	6.98	0.006**	6.07
C(2,1)	0.000	-0.43	0.000	0.17
C(2,2)	0.002**	2.89	0.001**	2.94
A(1,1)	0.269**	11.74	0.196**	6.58
A(1,2)	0.016	1.00	-0.052**	-3.41
A(2,1)	0.007	0.02	0.059**	2.74
A(2,2)	0.179**	6.82	0.244**	10.80
B(1,1)	0.951**	131.71	0.941**	53.64
B(1,2)	-0.005	-0.82	0.008	1.10
B(2,1)	0.007	0.86	-0.002	-0.42
B(2,2)	0.978**	116.48	0.966**	167.62

\*\*(\*) Denotes significance at 1% (5%) level

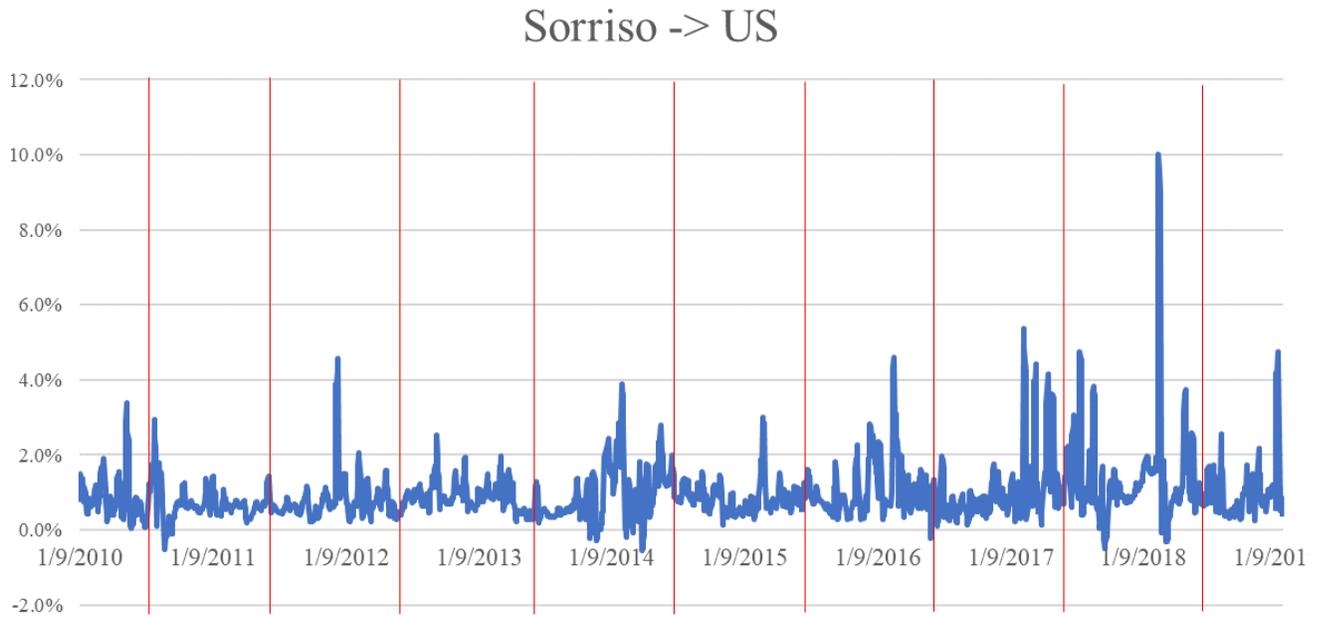
**Table 8 – Corn BEKK Coefficients for Chapeco**

<b>BEKK GARCH</b>	<b>2004-2009</b>		<b>2010-2019</b>	
<i>Variable</i>	<i>Coefficient</i>	<i>t-Statistic</i>	<i>Coefficient</i>	<i>t-Statistic</i>
C(1,1)	0.003**	18.18	-0.011**	-3.63
C(2,1)	0.000	-1.03	0.000	0.01
C(2,2)	0.002**	7.92	0.002**	5.05
A(1,1)	0.323**	11.41	0.111**	8.72
A(1,2)	0.017	0.75	-0.064**	-3.56
A(2,1)	-0.005	-0.23	0.037**	2.25
A(2,2)	0.168**	8.29	0.307**	10.58
B(1,1)	0.915**	93.11	0.990**	413.50
B(1,2)	-0.005	-0.67	0.007	1.39
B(2,1)	0.010	1.95	-0.008	-1.51
B(2,2)	0.9802**	217.58	0.946**	91.26

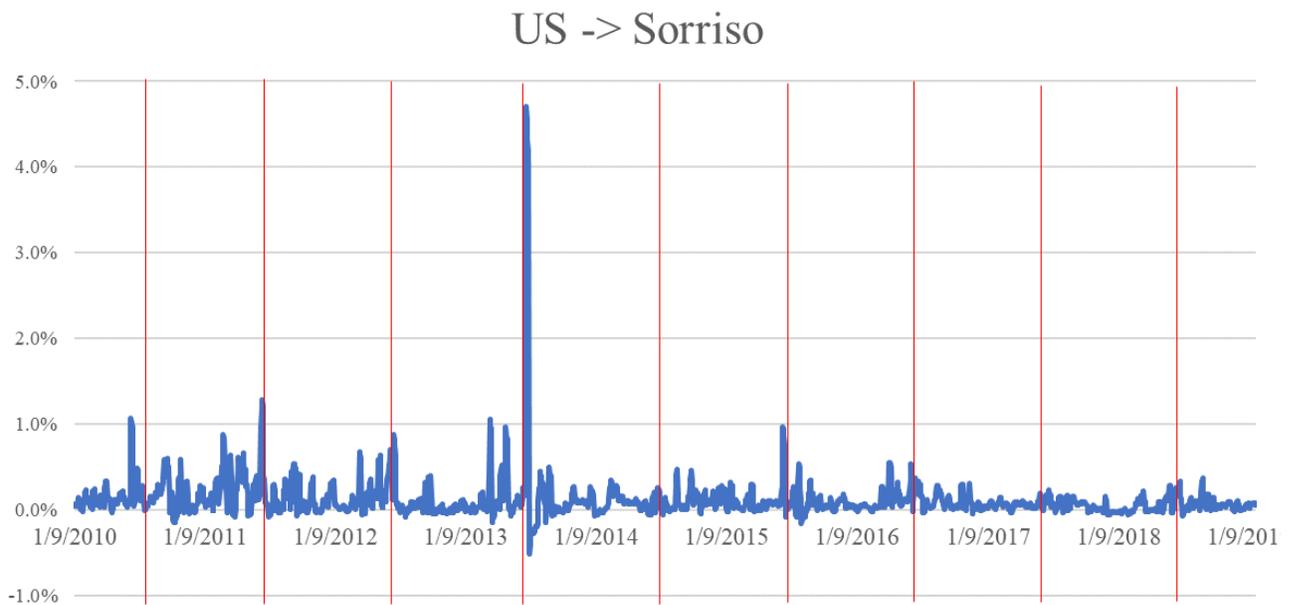
\*\*(\*) Denotes significance at 1% (5%) level

The biggest takeaway from these tables is that on the first period not a single cross-market coefficient is significant, when in the second period the A matrix is significant (price shocks matrix). This indicates that in the pre second crop period there were no clear signs of volatility spillovers from one market to the other. That dynamic changes after the markets become cointegrated, as we find that not only the US is spilling over in Brazil, but Brazil is also

spilling over the US. Figure 17<sup>4</sup> shows the spillover ratios from Sorriso to US markets<sup>5</sup>.



**Figure 17 - Spillover Ratios for Corn – Sorriso -> US**



**Figure 18 - Spillover Ratios for Corn - US -> Sorriso**

<sup>4</sup> Spillovers for the first period are not plotted, as they are all non-significant.

<sup>5</sup> The charts highlight only spillovers from and to Sorriso. Chapeco to and from Chapeco are virtually zero, so they are not shown.

The figure shows a clear pattern in spillover season, as indicated by the red lines that divide the crop years (Aug/Jul). When Brazil is harvesting its first crop and planting its second (Jan – April), spillovers from Brazil to U.S. are higher. Conversely, during the US growing season, Brazil’s spillovers to U.S. are more muted. There is also a trend of increasing spillovers from Brazil into the US in the later years. It is also interesting to compare the figures and notice that Brazil’s effect indicates that the spillover effects are increasing year after year, going along with the increase in production and proportion of global markets.

On the other hand, spillovers from the US to Brazil are decreasing as time passes. This goes along with what has been discussed in terms of a low-volatility cycle in the US and a high volatility cycle in Brazil. The main reason for that is that US corn volatilities have been low for the past 4 years, consistent with a high stocks and low price scenario. Brazil, however, has had big droughts and general uncertainty over the country that caused Brazilian volatility for corn to be almost double the US corn volatility over our sample. Also, with markets more and more integrated every year, volatility relations should be higher.

## 6.2 SOYBEANS

Similar to our corn procedures, we divide our soybeans series in the 09/10 crop year. The results for the Johansen cointegration test can be found in Table 9Table .

**Table 9 - Cointegration Tests for Soybeans**

<i>US Futures x Parangua Spot</i>						
		<b>2004-2009</b>		<b>2010-2019</b>		
		<i>Critical Value</i>		<i>Critical Value</i>		
<i>Cointegration Rank</i>	<i>λmax</i>	<i>95%</i>	<i>99%</i>	<i>λmax</i>	<i>95%</i>	<i>99%</i>
r=0	7.67	15.67	20.20	23.18**	15.67	20.20
r ≤ 1	1.18	9.24	12.97	2.48	9.24	12.97

\*\*(\*) Denotes significance at 1% (5%) level

The results point out to the same conclusions as corn. Even though Brazil was already a big player in soybeans markets before the second crop, its prices were not cointegrated with global prices until 2010. After that, like in corn, prices become cointegrated at the 1% level of significance. Because of this pattern, soybeans modeling will be the same as corn: VAR for the first period and VECM for the second. The results for that are in Table 10 and Table 11.

**Table 10 – Soybeans VAR Parameters**

**VAR Lagged Parameters - 2004-2009**

<i>Equation</i>	<i>Parameter</i>	<i>Estimate</i>	<i>Std. Error</i>
Paranagua Spot	Paranagua L1	-0.14421**	0.033
	US L1	0.20469**	0.048
	Paranagua L2	-0.15786**	0.034
	US L2	0.15603**	0.049
	Paranagua L3	-0.08385**	0.033
	US L3	0.11181**	0.048
US Futures	Paranagua L1	0.1184527**	0.023
	US L1	-0.1030326**	0.033
	Paranagua L2	0.02498	0.024
	US L2	0.00559	0.034
	Paranagua L3	-0.00084	0.023
	US L3	0.00636	0.033

\*\*(\*) Denotes significance at 1% (5%) level

**Table 11 – Soybeans VECM Parameters**

**VECM Parameters - 2009-2019**

<i>Equation</i>	<i>Parameter</i>	<i>Estimate</i>	<i>Std. Error</i>
	$\beta_{par}$	$1$	
	$\beta_{us}$	$-1.034**$	
US Futures	$\alpha_{us}$	$0.018**$	$0.004$
Paranagua Spot	$\alpha_{par}$	$-0.005$	$0.005$

\*\*(\*) Denotes significance at 1% (5%) level

Unlike corn, soybeans coefficients in the VAR regression are all significant for one lag (and lags two and three are significant in the Brazilian prices equation). That goes along with Brazil already being a big player in the oilseed market, not only getting affected, but also affecting global price changes.

However, after Brazil started double-cropping, with a big increase in production, the  $\alpha$  for Brazil in the VECM is, in absolute terms, four times smaller than the  $\alpha$  for the US. It is also worth noticing that the  $\alpha$  for Brazil is not significant, indicating that Brazilian bean prices are not being affected by CME. This is an important indication of the behavior of the volatilities' transmission.

Table 12 presents the results of the BEKK GARCH for both periods. Unlike corn, in which cross-markets coefficients are not significant and then significant, soybeans present a different pattern.

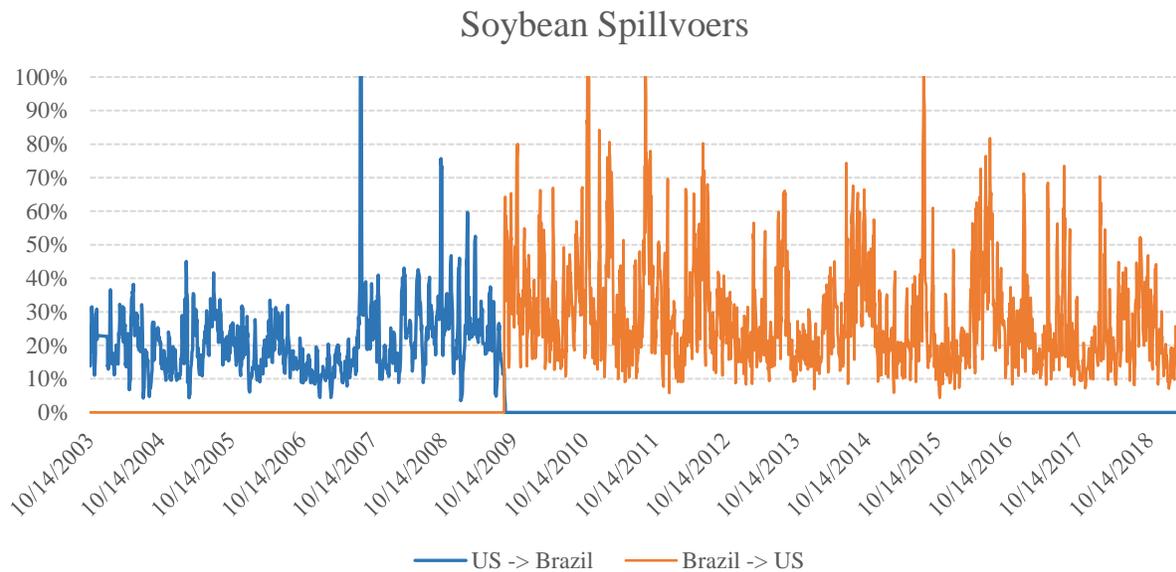
The first period shows that only the cross-markets coefficients related to the US spilling over Brazil are significant, in line considering that the US was the biggest producer and exporter at the time. However, moving to the second period, only the coefficients related to Brazil spilling over the US are significant, indicating a complete change of dynamic between the markets.

**Table 12 – Soybeans BEKK Coefficients**

<b>BEKK GARCH</b>	<b>2004-2009</b>		<b>2010-2019</b>	
	<i>Coefficient</i>	<i>t-Statistic</i>	<i>Coefficient</i>	<i>t-Statistic</i>
<i>C(1,1)</i>	0.002**	6.53	0.001**	4.59
<i>C(2,1)</i>	0.000	0.42	0.004**	23.55
<i>C(2,2)</i>	-0.001**	-5.32	0.000	0.00
<i>A(1,1)</i>	0.607**	11.25	0.156**	3.55
<i>A(1,2)</i>	0.032	1.29	-0.548**	-13.68
<i>A(2,1)</i>	-0.413**	-7.74	0.003	0.11
<i>A(2,2)</i>	0.184**	6.04	0.381**	8.53
<i>B(1,1)</i>	0.803**	23.04	0.976**	81.91
<i>B(1,2)</i>	0.003	0.40	0.138**	3.95
<i>B(2,1)</i>	0.142**	4.24	-0.078	-1.32
<i>B(2,2)</i>	0.970**	93.73	0.200**	2.16

\*\*(\*) Denotes significance at 1% (5%) level

As Figure 19 shows, US was spilling over in Brazil before Brazil started double-cropping. After that, the dynamic switches, and Brazil moves on to spillover in the US. Another difference is in the magnitude of spillovers. The first period has an average spillover of around 10% (meaning that 10% of the volatility in Brazil was explained by the US). The second period, on the other hand, shows an average spillover ratio of about 30% (meaning that 30% of the volatility in the US/CME was due to volatility coming from Brazilian spot). Going in the same line as the VECM, the BEKK GARCH indicates that Brazilian prices are not suffering from volatility spillovers generated in the US.



**Figure 19 - Spillover Ratio for Soybeans**

## CHAPTER 7

### FINAL REMARKS

This study uses cointegration analysis and GARCH models in order to evaluate the changing dynamics in grain markets after Brazil started to double-crop beans and corn. The first change in dynamic captured by our analysis goes against what was found in Cruz Jr. et al (2016). While analyzing different prices sources, our study uses cash prices instead of the inefficient Brazilian corn futures contract, their findings point to the existence of cointegration before and after Brazil's second corn crop. Our results indicate that, for both soybeans and corn, Brazilian markets were not cointegrated with US futures prices before the second crop, but then, soybean and corn prices in Brazil become cointegrated with US Futures. That finding is important as it leads us to understanding that the increase in production in Brazil, highlighted in Figure 5 and Figure , led the country towards being an important part of global prices.

After proceeding our analysis using a VAR for the first period and a VECM for the second, the coefficients from the equations also provide interesting insights. For the first period, the VAR for corn, regardless of the cash price location, indicate that Brazilian prices were affected by changes in global corn prices (US Futures), while not affecting US Futures. For soybeans, however, our VAR indicates that Brazilian beans were affecting and getting affected by US Soybean Futures, as the lagged coefficients were significant both ways.

On the second period the scenario changes. The VECM for corn markets indicate that a long-run equilibrium now exists and that both prices are correcting to it (alphas are significant), as shown in Table . On the other hand, while the autoregressive coefficients for soybeans show the same behavior as in the pre second-crop period, soybean long-run equilibrium is defined by

only one significant alpha, the one for US Futures. Even though the betas are significant, indicating the long-run relationship, the alpha for Brazil is not significant. That indicates that Brazilian cash prices are not correcting for the long-run equilibrium, even though they are affected by US prices on the AR part of the model. These results anticipate what the BEKK GARCH and the volatility spillovers look like.

Our last step is to evaluate the presence, or not, of volatility spillovers between the markets. We can measure the spillovers between the markets by isolation the cross markets terms from the conditional volatility equation. On the pre second crop period, the BEKK for corn does not show any significant cross-market coefficients, indicating that there were no volatility spillovers between the corn markets. On the second period, however, there are significant volatility spillovers from Brazil to the US and vice-versa.

Unlike the results we found on corn, soybean markets present a complete change in volatility spillover direction. The first period is marked by volatility spillovers from the US into Brazil, but not the inverse. After moving to the double-crop era, the spillover gets bigger, mostly due to the increase in cointegration between the markets and is only coming from Brazil to the US. This was anticipated by the VECM results that showed an “exogenous” Brazil on the second period.

Our metrics also allow us to analyze seasonality of the volatility spillovers. Both grain markets present similar behavior, with Brazil spilling over more during its crop cycle, first semester, and the US during the remaining part of the year. This is a big innovation that this paper introduces, as our approach to calculating the spillovers allow us to check for seasonality in the spillovers.

The results are important for risk managers (hedgers), speculators and market regulators. Understanding what is affecting market volatility is fundamental when placing hedges or trading strategies. Our study shows that grain futures markets changed a lot over the last 15 years, with Brazil playing a bigger role in price determination and volatility year after year. Our metrics will help traders better prepare for innovations coming from South American markets, and also allow them to know during what periods effects from Brazil cause the bigger impacts, thanks to our volatility spillover seasonality analysis. As for market regulators, discussions over a new futures contracts for Brazilian Soybeans, for example, can use this study to show that Brazilian beans have an exogenous behavior on the equilibrium relationship and are bringing around 30% of extra volatility to the traditional US Soybeans Futures, which can be a problem.

## CHAPTER 8

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