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ARTICLE

Impacts of El Niño southern oscillation on hedge strategies for Brazilian corn and soybean futures contracts[1]

El Niño Oscilação Sul, razão de preços soja-milho e estratégia de hedge

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Abstract: Climate influences the variations in soybean and corn prices; thus, we assessed the relationship between the El Niño Southern Oscillation (ENSO) with soybean-to-corn price ratio to determine potential impacts on price risk management. The commercial areas of Passo Fundo (RS), Cascavel (PR), Maringá (PR), Uberlândia (Triângulo Mineiro), and Sorriso (MT) covered in the study were chosen according to the MAPA edaphoclimatic classification. To estimate the effectiveness and optimal hedge ratio, the static and generalized model by Myers and Thompson (1989), adapted by Lien and Tse (2000), was used to include the cointegration approach in the analysis. The innovation of this study is the inclusion of the climate variable ENSO in this hedging approach. The findings showed that ENSO, especially La Niña, affects soybean-to-corn price ratio and hedge strategies. These results highlight the need to expand the use of futures contracts to reduce the price risk during the occurrence of ENSO events.

Keywords: soybean, corn, effectiveness, optimal hedge ratio, cross hedge.

Resumo: O clima influencia as variações nos preços da soja e do milho. Assim, avaliamos a relação entre a variável climática Oscilação Sul do El Niño (ENSO) com a razão de preços entre soja e milho para identificar os possíveis impactos no gerenciamento de riscos de preços. As regiões de comercialização de Passo Fundo (RS), Cascavel (PR), Maringá (PR), Uberlândia (Triângulo Mineiro) e Sorriso (MT) abordadas no estudo foram escolhidas de acordo com a classificação edafoclimática do MAPA. Para a estimação da efetividade e razão ótima de hedge, foi utilizado o modelo estático e generalizado de Myers e Thompson (1989) adaptado por Lien e Tse (2000) para incluir na análise a abordagem de cointegração. A inovação desse estudo é a inclusão da variável climática ENSO nessa abordagem de hedge. Os achados da pesquisa demonstram que a ocorrência do ENSO, especialmente a La Nina, exerce influência na razão de preços soja e milho e nas estratégias de hedge. Tal fato destaca a necessidade de ampliar a utilização de contratos futuros para reduzir o risco de preços principalmente na ocorrência de eventos climáticos extremos.

Palavras-chave: soja, milho, efetividade, razão ótima de *hedge*, c*ross hedge*.

1. INTRODUCTION

Despite the increasing use of technology, such as genetically improved seeds, as well as mechanization, fertilizers and pesticides, and techniques for crop management and land use, climatic factors are still potential risk sources for agriculture. Variables, such as evapotranspiration, precipitation, soil moisture, and solar radiation gain more importance due to the occurrence of extreme weather events, namely El Niño Southern Oscillation (ENSO). The occurrence of floods, droughts, and heatwaves is increasing, causing risks to production and even crop failure.

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ENSO is a large-scale seasonal event that arises from atmosphere-ocean interactions and is characterized by Sea Surface Temperature (SST) anomalies. Depending on the type of anomaly, the event is known as El Niño (warming) or La Niña (cooling) (Trenberth, 1997). Evidence shows that these phenomena compromise the favorable climatic conditions for crop development (Grimm et al., 2000; Podestá et al., 2002) mostly through fluctuations in rainfall and temperature, favoring the dissemination of pests and diseases, or intensifying droughts, floods, and storms (Abdolrahimi, 2016).

Studies have investigated climate influence on soybean and corn prices and volatility (Peri, 2017); however, the occurrence of climatic events and their potential effects on the price relationship between grain commodities remains a gap in the literature. This study assessed the influence of climate events on the relationship between soybean and corn prices to evaluate their effects on management strategies of price risk for these commodities, specifically hedge and cross-hedge strategies.

We used the approach of Ubilava (2017) to verify the existence of a relationship between climate events and prices, in which the series of SST anomalies estimate the interaction between ENSO-price. As a methodological innovation, we intend to interact the proxy that measures ENSO occurrence with the soybean-to-corn (STC) price ratio. These variables are included in the expanded model of Lien & Tse (2002), which estimates effectiveness and optimal hedge ratio considering the cointegration approach between the spot and future markets.

In this framework, future prices used were Brasil, Bolsa, Balcão (B3), and Chicago Mercantile Exchange (CME). The spot prices selected cover productive micro-regions, according to the edaphoclimatic classification of Secretariat for Agricultural Policy – Ministry of Agriculture, Livestock and Supply (MAPA), and classified as more representative according to the criteria adopted by Maia & Aguiar (2010). The regions are Passo Fundo (RS), Cascavel (PR), Maringá (PR), Uberlândia (Triangulo Mineiro) and Sorriso (MT) for a weekly price series, covering the period from January 2005 to December 2018.

2. THEORETICAL FRAMEWORK

This section presents the theoretical approaches to climatologically aspects in ENSO events, STC price ratio, and management strategies of price risk through the analysis of the effectiveness and optimal hedge ratio.

ENSO originates from atmosphere-ocean interactions in the Tropical Pacific Ocean, in which SST anomalies occur near the Peruvian coast to the west of the Pacific in Australia. In the natural dynamics of oceans, waters are cooler on the South American coast and warmer on the Australian coast. When the atmosphere acts on the ocean surface, it redistributes heat and causes changes in the wind fields, generating teleconnections (Trenberth, 1997; Grimm et al., 2000).

ENSO can be divided into a neutral state (N) as well as El Niño (EN) and La Niña (LN) (Adams et al., 1999). The abnormal warming of the surface and sub-surface waters of the Equatorial Pacific Ocean represents signs of EN, whose allusion means "Menino Jesus", since the event was mainly observed close to Christmas (Berlato & Fontana, 2003; Grimm et al., 1998). In turn, LN has inverse characteristics to EN (Trenberth, 1997). However, the formation of ENSO depends not only on oceanic variations represented by SST anomalies but also on the joint association with the atmospheric component.

Climate variability, associated with ENSO, impacts agricultural production. Effects identified in the literature comprise the influence of the phenomenon on future prices of soybean and wheat by LN in 1982/83 and by EN in 1986/87 (Keppenne, 1995), losses in the 1997/198 harvest caused by EN for agriculture in the United States (Adams et al., 1999) and Brazil (Teracines, 2000). Therefore, the ENSO-price relationship has important socio-economic implications, particularly for a developing country (Ubilava, 2017) and a major exporter of primary commodities, such as Brazil.

The STC price ratio is an indicator of relative prices, used by rural producers to shape their expectations regarding soybean or corn planting (Lin & Riley, 1998). Historically, the STC price ratio in the United States remains close to 2.52 (Zulauf, 2013). The choice between planting soybean or corn in the next crop is linked to expectations regarding prices of these commodities, production costs, seasonality, previous crops, among others (Ubilava, 2008). Intuitively, the STC price ratio represents a trade-off faced by rural producers.

On the other hand, to mitigate price risks, Shah (1997) proposes diversification, insurance, and hedging of crops. In hedging, hedgers assume equivalent positions in the spot and future markets (naive hedge), expecting a complete coverage of the price risk (perfect hedge). Although spot prices move in line with futures prices, Working (1953) demonstrated that a perfect hedge is rare in the wheat market of the United States.

The hedge theory has received important contributions over time, as when variance was adopted as a risk measurement with the advent of portfolio theory (Markowitz, 1952). The hedger takes a position in the market not only hoping to protect its crops but also showing concerns with profit optimization. In other words, the concept of a hedge ratio was created that satisfies hedger's preferences considering the risk and return, known as the expected-utility paradigm (Johnson, 1960; Stein, 1961). Thus, hedgers can conveniently keep covered and non-covered positions (Ederington, 1979).

According to their preferences in risky conditions and based on estimates of the spot position for a future period, the hedger determines the hedge ratio, which corresponds to the size of the commitment to be assumed in the opposite position, with the acquisition of futures contracts. In turn, for the calculation of the optimal hedge ratio, the minimum-variance hedges (MVH) approach was disseminated in the literature, which consists of minimizing the variance of a hedged portfolio, composed of a particular asset and the futures contract that is designed to protect it.

The MVH approach became popular due to its easy estimation by econometric techniques (Lence, 1995). The modeling, despite the static hedge ratio, gained a generalized version with the inclusion of lagged price changes (Myers & Thompson, 1989) and took into account cointegration relations (Castelino, 1992). The hedge ratios and hedging performance may change sharply when the co-integrated variable is mistakenly omitted from the statistical model (Lien, 1996). The different ways of applying this approach represent advances. Anderson & Danthine (1983) innovated by using this hedge with the use of futures contracts that did not have the same characteristics of the underlying asset, the cross-hedge.

3. MATERIAL AND METHODS

The primary purpose of this study was to interact the climate variable with the STC price ratio and other control variables. For that, we adopted two different specifications:

$$STC_{it} = \alpha + \beta CE_t + \gamma PREC_{it} + \theta TEMP_{it} + \mu Dol_{cpat} + \varepsilon_t \quad (1)$$

Where: CE climate events represent variable $Nino3.4_t$ in a first regression, or $ENSO_t$ in second regression; $Nino3.4_t$ represents anomalies in Sea Surface Temperature (SST), collected by KNMI

Climate Explorer and the National Oceanic and Atmospheric Administration (NOAA / NCDC); $ENSO_t$ is climate proxy; $STC_{it} = SOYBEAN_{it} / CORN_{it}$ is soybean-to-corn price ratio, where SOY_{it} and $CORN_{it}$ are daily series of spot prices for soybean and corn, respectively, for *i* markets in *t* periods, $PREC_{it}$ and $TEMP_{it}$ are meteorological variables, precipitation, and temperature, respectively, and Dol_{cpat} is exchange rate series.

Due to the absence of some observations in the daily series of precipitation and temperature, we used the filling method for missing values in the meteorological series developed by Tabony (1983). The method consists of choosing a meteorological station (data to be provided), three neighboring stations, and estimating the missing values using the Multiple Linear Regression (MLR). The choice of neighboring stations considered correlation with the test station, directional dependency, and orographic conditions, and the linear relationship was assumed between the stations (Tabony, 1983).

On the other hand, $ENSO_t$ is an index that represents the three phases (N, EL, and LA) of the SST behavior. Therefore, thresholds were created for the different phases (Table 1) using the Nino Index 3.4, with the application of the Variable Factor technique (Baum, 2010; Williams, 2012).

Table 1. Composition of the ENSO climatological variable.

Sea surface temperature (SST) anomalies	Nino 3.4 Index	Classification
$SST \geq 0.5°C$	$\begin{cases} if\ Nino3.4 \geq 0.5°C = 1 \\ otherwise = 0 \end{cases}$	El Niño (EN)
$SST \leq -0.5°C$	$\begin{cases} if\ Nino3.4 \leq -0.5°C = 1; \\ otherwise = 0 \end{cases}$	La Niña (LN)
$-0.5°C \leq SST \leq 0.5°C$	$\begin{cases} if\ -0.5°C \leq Nino3.4 \leq 0.5°C = 1; \\ otherwise = 0v \end{cases}$	Neutral state (N)
Climate Interaction Operator	$\begin{cases} EN = 1; \\ Neutral = 0; \\ LN = 2 \end{cases}$	ENSO

Fonte: Adapted from Minaki & Montanher (2019)

In a second step of the analysis, we estimated the models to calculate effectiveness and optimal hedge ratio (OHR) in its generalized form and considering the cointegration approach (Lien & Tse, 2002). In the traditional model, one of the equation parameters provides the estimates for the MVH ratio. This estimator represents the optimal hedge ratio $h^* = \sigma_{pf} / \sigma_f^2$, and σpf is the covariance between future and spot prices (σpf) and σ_f^2 is the future price variance (Myers & Thompson, 1989).

The methodological innovation of our study is to interact the variable that measures the OHR with variables that represent climatic events ($Nino3.4_t$ or $ENSO_t$). This allows differentiating the hedge ratio levels in periods of occurrence of climate events resulting from SST anomalies.

$$\Delta p_{i,t} = \alpha_1 + \beta_1 CE_t \Delta f_{j,t} + \sum_{k=1}^{N} \gamma_i p_{i,t-k} + \sum_{k=1}^{N} \delta_j \Delta f_{j,t-k} + \rho u_{t-1} + \varepsilon_t \quad (2)$$

Where: CE_t represents variables $Nino3.4_t$ or $ENOS_t$ in each regression, $\Delta p_{i,t}$ and $p_{i,t-k}$ are the series of return or lagged levels for *i* spot prices, respectively; $\Delta f_{j,t}$ and $f_{j,t-k}$ are the series of return or lagged levels for *j* future prices, respectively; β_1 represents the optimal hedge ratio; $CE_t \Delta f_{j,t}$ represents the interaction of variables of climate events with future corn or soybean price returns, and it is u_t Error Correction Term (ECT) from the equation $\Delta_{p_t} = \alpha + \beta \Delta f_t + \varepsilon_t$.

After specifying the model, we used the Dickey-Fuller Generalized Least Square (DF-GLS) unit root test, following Elliott et al. (1996), with several lags determined by the information criteria (AIC, SIC). Finally, the Johansen cointegration test was used to assess the long-term relationships between the series of spot and future prices.

3.1 Data

Data on air temperature ($TEMP_{i,t}$) and rainfall ($PREC_{i,t}$) were extracted from the National Water Agency (ANA) and Meteorological Database for Teaching and Research (BDMEP) that systematize the historical series of the various conventional meteorological stations of the National Institute of Meteorology (INMET). The daily series of spot market prices for corn and soybean, R$/60 kg bag, were collected from the Center for Advanced Studies in Applied Economics (CEPEA-Esalq/USP). The analysis period was from January 2005 to December 2018 (Chart 1).

Chart 1. Description of variables, source, and measurement unit.

Description	Variable	measurement unit	Source
Rainfall	$PREC_{i,t}$	mm	ANA/BDMEP
Air temperature	$TEMP_{i,t}$	°C	ANA/BDMEP
Corn spot price	$CORN_{i,t}$	R$/60 kg bag	CEPEA/ESALQ
Soybean spot price	$SOYBEAN_{it}$	R$/60 kg bag	CEPEA/ESALQ
Soybean-to-corn price ratio	$STC_{i,t}$	index	Prepared by the author
Corn futures prices	$CORN_{B3,t}$	R$/60 kg bag	Brasil, Bolsa, Balcão (B3);
	$CORN_{CME,t}$	cents US$ /bushel	Chicago Mercantile Exchange (CME);
Soybean futures prices	$SOYBEAN_{CME,t}$	cents US$ /bushel	Chicago Mercantile Exchange (CME);
Exchange rate	$DOLcpa_t$	R$/ US$	(Banco Central do Brasil, 2019)
Climate proxy	$Nino3.4_t$	index	National Oceanic and Atmospheric Administration (NOAA) and (KNMI, 2020)
	$ENSO_t$,	index	Prepared by the author

Note 1: Daily series of CME futures prices were converted to R $/60 kg bags. Note 2: For variables $CORN_{i,t}$, *i* represents the different regions of commerce, namely Passo Fundo ($CORN_{pf}$), Cascavel ($CORN_{csvel}$), Maringá ($CORN_{mga}$), Triângulo Mineiro ($CORN_{tm}$) and Sorriso ($CORN_{sorr}$). Note 3: Following the same approach adopted for corn, we obtained the representative variables of the soybean spot market (SOY_{pf} , SOY_{csvel} , SOY_{mga} , SOY_{tm} and SOY_{sorr}) and for the soybean-to-corn price ratio (STC_{pf} , STC_{csvel} , STC_{mga} , STC_{tm} and STC_{sorr}),

Regarding future prices, using futures contracts with different settlement dates, the grouping of contracts in a unified series was used, corresponding to the nearby futures contract. For the rollover position, we followed the proposal by Ma et al. (1992) who considered the contract with the highest trading volume. Tonin (2019) used this technique and when the most liquid maturity is considered, the rollover between contracts is anticipated, avoiding distortions that may occur at the contract end.

In turn, the choice of spot markets took into account the approach proposed by Martins & Aguiar (2004) and Maia & Aguiar (2010) to select the localities in micro-regions with the most representative producers. For this purpose, we used Normative Instruction No. 1 of February 2012 from the Secretariat for Agricultural Policy (SPA), Ministry of Agriculture, Livestock, and Supply (MAPA). This regulation divides the planted area of soybean and corn into five macro-regions, based on the edaphoclimatic characteristics, numbered according to the expansion of the Brazilian agricultural frontier (Brasil, 2012). The selected regions were Passo Fundo (RS), Cascavel (PR), Maringá (PR), Uberlândia - Triangulo Mineiro (MG), and Sorriso (MT). In this context, Maringá, Cascavel, and Sorriso belong to the largest grain-producing micro-regions, Paraná and Mato Grosso, in the southern and midwestern regions of Brazil, respectively (Martins & Aguiar, 2004; Maia & Aguiar, 2010; Tonin, 2019).

4. RESULTS AND DISCUSSION

Firstly, we implemented the DF-GLS statistical test proposed by Elliott et al. (1996). This test showed that estimated returns are stationary of spot and futures price series for soybean and corn (Table 2, panel A1 and A2). Jiang & Fortenbery (2019) found a similar result for spot and future soybean price returns in the United States market between 2001 and 2016.

Table 2. Results of the Cointegration and DF-GLS Unit Root test on spot and future price series.

Panel A1) DF-GLS Unit Root test for the corn market							
Statistics	$CORN_{pf}$	$CORN_{csvel}$	$CORN_{mga}$	$CORN_{tm}$	$CORN_{sorr}$	$CORN_{B3}$	$CORN_{CME}$
Level							
τ_τ	-1.846	-0.826	-0.756	-0.321	-0.346	0.230	0.105
Lags	2	1	1	2	2	1	1
				1st Difference			
τ_μ	-8.179	-6.964	-6.851	-6.619	-5.529	-6468	-6.272
Lags	1	1	1	9	1	2	1
Panel A2) DF-GLS Unit Root test for the soybean market							
Statistics	$SOYBEAN_{pf}$	$SOYBEAN_{csvel}$	$SOYBEAN_{mga}$	$SOYBEAN_{tm}$	$SOYBEAN_{sorr}$	$SOYBEAN_{B3}$	$SOYBEAN_{CME}$
Level				Level			
τ_τ	0.587	0.064	0.067	0.537	0.871	1.317	-5.729
Lags	2	2	2	3	3	1	1
1st Difference				1st Difference			
τ_μ	-7.194	-7.193	-7.189	-7.282	-6.717	-6.589	-7.629
Lags	3	2	1	2	2	3	1

Table 2. Continued...

Panel B) Johansen's cointegration test for corn						
			$CORN_{B3}$			
Statistics	*rank*	$CORN_{pf}$	$CORN_{csvel}$	$CORN_{mga}$	$CORN_{tm}$	$CORN_{sorr}$
λ trace	*r=0*	191.38	162.75	157.70	114.60	69.32
	r<1	3.16***	4.65***	4.36***	3.95***	4.97***
λ max	*r=0*	188.21	158.10	153.34	110.64	64.34
	r<1	3.16	4.65	4.36	3.95	4.97
			$CORN_{CME}$			
Statistics	*rank*	*CORNpf*	*CORNcsvel*	*CORNmga*	*CORNtm*	*CORNsorr*
λ trace	*r=0*	27.84	17.05***	17.35***	16.97***	14.00***
	r<1	2.85***	3.40	3.35	3.53	3.66
λ max	*r=0*	24.98	13.65	13.99	13.43	10.34
	r<1	2.85	3.40	3.35	3.53	3.66
			$SOYBEAN_{CME}$			
Statistics	*rank*	*CORNpf*	*CORNcsvel*	*CORNmga*	*CORNtm*	*CORNsorr*
λ trace	*r=0*	53.92	38.48	36.97	62.92	44.07
	r<1	2.82***	2.85***	2.78***	2.85***	2.95***
λ max	*r=0*	51.09	35.63	34.18	60.07	41.11
	r<1	2.82	2.85	2.78	2.85	2.95
Panel C) Johansen's cointegration test for soybean						
			$CORN_{B3}$			
Statistics	*rank*	$SOYBEAN_{pf}$	$SOYBEAN_{csvel}$	$SOYBEAN_{mga}$	$SOYBEAN_{tm}$	$SOYBEAN_{sorr}$
λ trace	*r=0*	14.23***	14.89***	14.93***	15.97***	17.44***
	r<1	2.47	2.52	2.43	2.73	2.53
λ max	*r=0*	11.75	12.36	12.49	13.23	14.90
	r<1	2.47	2.52	2.43	2.73	2.53
			$CORN_{CME}$			
Statistics	*rank*	$SOYBEAN_{pf}$	$SOYBEAN_{csvel}$	$SOYBEAN_{mga}$	$SOYBEAN_{tm}$	$SOYBEAN_{sorr}$
λ trace	*r=0*	22.26***	17.29***	17.46***	19.28***	18.93***
	r<1	2.92**	2.88	2.78	3,03	3.09
λ max	*r=0*	19.34	14.40	14.67	16.88	15.84
	r<1	2.92	2.8	2.78	3.03	3.09
			$SOYBEAN_{CME}$			
Statistics	*rank*	$SOYBEAN_{pf}$	$SOYBEAN_{csvel}$	$SOYBEAN_{mga}$	$SOYBEAN_{tm}$	$SOYBEAN_{sorr}$
λ trace	*r=0*	53.92	38.48	36.97	62.92	44.07
	r<1	2.82***	2.85***	2.78***	2.85***	2.95***
λ max	*r=0*	51.09	35.63	34.18	60.07	41.11
	r<1	2.82	2.85	2.78	2.85	2.95

Note 1: For Johansen (1988) cointegration test, the equation includes a constant variable in the model (rconstant); thus, it has an intercept (drift), but not a deterministic trend. Note 2: Model with drift and deterministic trend (τ_τ); critical values of Elliott et al. (1996), (10%=-2.64; 5%=-2.93; 1%=-3.46). Model with drift without deterministic trend (τ_μ); critical values of Dickey & Fuller (1979, 1981) (10%= - 1.62, 5%=-1.95; 1%=-2.58). *, ** and *** denote 10, 5, and 1% significance levels, respectively.

The results of Johansen's cointegration test demonstrated the existence of long-term relationships between corn spot price series and $CORN_{CME}$ and SOY_{CME} futures prices and soybean spot prices and SOY_{CME} futures. However, this relationship did not occur between corn prices and $CORN_{CME}$ corn futures (Table 2b and Table 2c).

Further, were estimated the models using the Multiple Linear Regression to ascertain if the presence of phenomena El, LN, and N affected the STC price ratio (Table 3).

Table 3. Estimated regression results for the relationship between STC and Climate Events.

Variables/ Models	STC_{pf}		STC_{csvel}		STC_{mga}		STC_{tm}		STC_{sorr}	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.12***	-	0.08**	-	0.10***	-	0.09***	-	0.35***	-
EN	-	0.13***	-	0.07*	-	0.06	-	0.04	-	0.24***
N	-	0.06	-	0.14	-	0.08	-	0.09	-	0.50***
LN	-	0.12***	-	0.15***	-	0.13**	-	0.18***	-	0.51***
PREC	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00***	-0.00***	-0.00	-0.00
TEMP	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.03***	-0.03***	0.08***	0.08***
DOLcpa	0.00***	0.11***	0.14***	0.01***	0.12***	0.14***	0.06**	0.07***	-0.00	-0.01
Constant	1.91***	1.92	2.16***	2.17	2.19***	2.15	3.22***	3.16	0.29	0.28
R^2-Adj.	0.094	0.093	0.072	0.073	0.074	0.070	0.112	0.116	0.10	0.103

Note1: EN, N, and LN correspond to the threshold of $ENSO_t$ variable. Note 2: NC: non-climatic variable; C: Climatic variable. *, ** and *** denote 10, 5, and 1% significance levels, respectively.

The results in Table 3 show that the interaction of variable Nino34 and STC price ratio presented an increase of 1ºC in the sea surface temperature, raising the STC price ratio by 0.12 in Passo Fundo region (Model A). The same was found for the other regions analyzed, with emphasis on Sorriso, where this effect was 0.35. In turn, the threshold that determines the presence of EN, LN, and N (Model NC and C) detects that La Niña has the most intense effect. Similar results were found by Deng et al. (2010) for rice production in Jiangxi province. In addition, Jiang & Fortenbery (2019) for spot and future soybean prices on the United States market between September 2001 and August 2016.

The authors identified that in case of occurrence of LN events, there were substantial increases in volatility in the soybean market in the United States. For the analysis of the hedge strategies, we used the recommendations of Sanches et al., (2016), the Schwarz Criterion (SC), to select the number of optimal lags required for the spot and future soybean and corn price series (Table 4).

Table 4. Estimation of effectiveness and optimal hedge ratio (OHR).

Panel A) Results of effectiveness and OHR using spot prices for corn and future corn prices (B3).

Variables/ Models	$CORN_{B3}$									
	$CORN_{pf}$		$CORN_{csvel}$		$CORN_{mga}$		$CORN_{tm}$		$CORN_{sorr}$	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.08***	-	0.32***	-	0.33***	-	0.23***	-	0.32***	-
h^* EN	-	0.06**	-	0.24***	-	0.25***	-	0.12**	-	0.32**
h^* N	-	0.09***	-	0.36***	-	0.38***	-	0.28***	-	0.28***
h^* LN	-	0.11***	-	0.32***	-	0.33***	-	0.25***	-	0.43***
$CORN_{i,t-1}$	0.38***	0.38***	0.15***	0.15***	0.08**	0.08**	-0.04	-0.04	-0.03	-0.03
$CORN_{i,t-2}$	0.15***	0.15***	0.01	0.01	-0.00	-0.00	0.12***	0.12***	0.08**	0.08**
$CORN_{i,t-3}$	-0.00	-0.00	-0.02	-0.01	0.00	0.01	0.03	0.04	-0.00	-0.00
$CORN_{B3,t-1}$	0.07***	0.07***	0.25***	0.25***	0.28***	0.28***	0.26***	0.26***	0.26***	0.26***
$CORN_{B3,t-2}$	0.09***	0.09***	0.15***	0.15***	0.18***	0.18***	0.20***	0.19***	0.30***	0.30***
Constant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
e	0.438	0.438	0.363	0.365	0.326	0.328	0.199	0.202	0.104	0.103

Table 4. Continued...

Panel B) Results of effectiveness and optimal hedge ratio using spot prices for corn and future corn prices (CME).

Variables/ Models	$CORN_{CME}$									
	$CORN_{pf}$		$CORN_{csvel}$		$CORN_{mga}$		$CORN_{tm}$		$CORN_{sorr}$	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.05***	-	0.16***	-	0.18***	-	0.12***	-	0.33***	-
h^* EN	-	0.08***	-	0.15***	-	0.18***	-	0.07	-	0.33***
h^* N	-	0.04**	-	0.14***	-	0.16***	-	0.14***	-	0.31***
h^* LN	-	0.04	-	0.28***	-	0.30***	-	0.12*	-	0.41***
$CORN_{i,t-1}$	0.44***	0.44***	0.30***	0.31***	0.22***	0.23***	0.05	0.05	0.00	0.00
$CORN_{i,t-2}$	0.16***	0.16***	0.02	0.02	0.02	0.02	0.16***	0.16***	0.07**	0.07**
$CORN_{CME,t-1}$	0.05***	0.05***	0.13***	0.13***	0.14***	0.14***	0.08**	0.09**	0.11**	0.11**
$CORN_{CME,t-2}$	0.05***	0.05***	0.06**	0.06**	0.07**	0.07**	0.06**	0.06**	0.22***	0.22***
constant	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00
e	0.374	0.373	0.225	0.227	0.189	0.191	0.074	0.073	0.097	0.095

Panel C) Results of calculations of effectiveness and optimal ratio of cross hedge using the spot prices of corn and soybean futures (CME).

Variables/ Models	$SOYBEAN_{CME}$									
	$CORN_{pf}$		$CORN_{csvel}$		$CORN_{mga}$		$CORN_{tm}$		$CORN_{sorr}$	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.06***	-	0.18***	-	0.21***	-	0.10	-	0.37***	-
h^* EN	-	0.05*	-	0.10*	-	0.13**	-	0.03	-	0.35**
h^* N	-	0.05**	-	0.18***	-	0.21***	-	0.13*	-	0.39***
h^* LN	-	0.09**	-	0.29***	-	0.32***	-	0.15*	-	0.35**
$CORN_{i,t-1}$	0.44***	0.44***	0.33***	0.33***	0.25***	0.25***	0.05	0.05	0.02	0.02
$CORN_{i,t-2}$	0.15***	0.15***	0.01	0.02	0.02	0.02	0.16***	0.16***	0.09**	0.09**
$SOY_{CME,t-1}$	0.06***	0.06***	0.11***	0.11***	0.13***	0.13***	0.10**	0.10**	0.06	0.06
$SOY_{CME,t-2}$	0.05***	0.05***	0.04	0.04	0.05	0.05	0.08**	0.08**	0.22***	0.22***
constant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
e	0.371	0.371	0.201	0.204	0.166	0.169	0.067	0.067	0.082	0.081

Nota 1: Panels A and B show the results of calculations for effectiveness and optimal hedge ratio and panel C for cross hedge.
Note 2: NC: non-climatic variable, C: Climatic variable. *, ** and *** denote 10, 5, and 1% significance levels, respectively.

The results of calculations of effectiveness (e) and optimal hedge ratio (h*) for the spot corn market using corn futures contracts quoted on B3, that is, the adoption of hedge in the squares of Passo Fundo, Cascavel, Maringá, Uberlandia, and Sorriso were 43.84%, 36.57%, 32.84%, 20.25%, and 10.32%, respectively (Table 4), that is, these values according to Oliveira (2000) represent the proportion of risk reduction generated by a strategy. In addition, in the occurrence of the events El Niño (EN), La Niña (LN), and neutral state (N) as observed in Table 4 to obtain a 43.84% risk reduction in the Passo Fundo square, it is necessary to assume the opposite position in the B3 corn futures market, equivalent to 60, 90 and 110 bags of corn for a proportion of 1000 bags purchased (produced) in the spot market. The same can be observed for the squares of Cascavel, Maringá, Uberlandia, and Sorriso, with due proportions. In addition, when comparing the hedging strategies in Table 4, Panel B, and cross hedge in Panel C, it is noted that the strategy with the greatest efficiency in mitigating price risks in the corn spot market is the hedging strategy adopted in Panel A. Strategies for soybean are presented in Table 5.

Table 5. Estimation of effectiveness and optimal hedge ratio (OHR) in hedge and cross hedge operations for soybean.

Panel A: Results of effectiveness and optimal hedge ratio using spot prices of corn and soybean futures (CME).

Variables/ Models	$SOYBEAN_{CME}$									
	$SOYBEAN_{pf}$		$SOYBEAN_{csvel}$		$SOYBEAN_{mga}$		$SOYBEAN_{tm}$		$SOYBEAN_{sorr}$	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.54***	-	0.56***	-	0.58***	-	0.41***	-	0.61***	-
h^* EN	-	0.45***	-	0.50***	-	0.51***	-	0.41***	-	0.54***
h^* N	-	0.48***	-	0.57***	-	0.58***	-	0.42***	-	0.62***
h^* LN	-	0.65***	-	0.65***	-	0.67***	-	0.40***	-	0.69***
$SOY_{i,t-1}$	0.00	0.00	-0.06	-0.06*	-0.06**	-0.06**	-0.18***	-0.18***	-0.25***	-0.25***
$SOY_{i,t-2}$	0.00	0.00	0.03	0.02	0.04	0.04	0.02	0.02	-0.00	-0.00
$SOY_{CME,t-1}$	0.17***	0.17***	0.16***	0.17***	0.16***	0.16***	0.26***	0.26***	0.35***	0.35***
$SOY_{CME,t-2}$	0.06**	0.06**	0.03	0.03	0.02	0.02	0.11***	0.11***	0.14***	0.14***
Constant	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04**
e	0.469	0.477	0.488	0.490	0.503	0.506	0.350	0.348	0.407	0.408

Panel B: Results of hedge effectiveness and optimal hedge ratio using spot prices for soybean and futures corn prices (B3).

Variables/ Models	$SOYBEAN_{B3}$									
	$SOYBEAN_{pf}$		$SOYBEAN_{csvel}$		$SOYBEAN_{mga}$		$SOYBEAN_{tm}$		$SOYBEAN_{sorr}$	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.21***	-	0.22***	-	0.24***	-	0.16***	-	0.25***	-
h^* EN	-	0.19***	-	0.24***	-	0.26***	-	0.19***	-	0.30***
h^* N	-	0.18***	-	0.19***	-	0.20***	-	0.15***	-	0.21***
h^* LN	-	0.30***	-	0.27***	-	0.27***	-	0.16***	-	0.27***
$SOY_{i,t-1}$	0.07**	0.08**	-0.03	-0.02	-0.03	-0.03	-0.07**	-0.07**	-0.13***	-0.13***
$SOY_{i,t-2}$	0.02	0.02	0.03	0.02	0.03	0.03	0.04	0.04	0.05	0.05
$SOY_{i,t-3}$	-0.00	-0.00	0.05	0.05	0.05	0.05	0.07**	0.07	0.09**	0.09**
$SOY_{B3,\ t-1}$	0.02	0.02	0.05**	0.05**	0.04	0.04	0.08**	0.08**	0.05*	0.06*
$SOY_{B3,\ t-2}$	0.03	0.03	0.04*	0.04*	0.04*	0.04***	0.03	0.03	0.07**	0.08**
cons	0.00	0.00	0.01*	0.01*	0.01	0.01	0.01	0.01	0.03	0.04
e	0.113	0.115	0.107	0.107	0.112	0.112	0.080	0.078	0.105	0.104

Panel C: Results of effectiveness and optimal hedge ratio of cross hedge using the spot prices of soybean and future corn prices (CME).

Variables/ Models	$CORN_{CME}$									
	SOYBEAN pf		*SOYBEANcsvel*		*SOYBEANmga*		*SOYBEANtm*		*SOYBEANsorr*	
	NC	C	NC	C	NC	C	NC	C	NC	C
Nino34	0.25***	-	0.29***	-	0.30***	-	0.22***	-	0.31***	-
h^* EN	-	0.29***	-	0.34***	-	0.35***	-	0.27***	-	0.40***
h^* N	-	0.21***	-	0.26***	-	0.27***	-	0.20***	-	0.28***
h^* LN	-	0.33***	-	0.32***	-	0.33***	-	0.16**	-	0.31***
$SOY_{i,t-1}$	0.05	0.06*	-0.02	-0.02	-0.03	-0.03	-0.08**	-0.08**	-0.12***	-0.12***
$SOY_{i,t-2}$	0.01	0.02	0.03	0.03	0.02	0.03	0.04	0.05	0.05	0.05
$CORN_{CME,t-1}$	0.10***	0.11***	0.11***	0.11***	0.11***	0.10***	0.11***	0.11***	0.19***	0.18***
$CORN_{CME,t-2}$	0.05**	0.05**	0.03	0.03	0.04*	0.04*	0.06**	0.06**	0.04	0.04
constant	0.01**	0.00*	0.02**	0.02**	0.01**	0.01**	0.02	0.02	0.02	0.02
e	0.199	0.203	0.203	0.204	0.212	0.212	0.159	0.160	0.173	0.174

Note 1: *e* represents hedge effectiveness, equivalent to the determination coefficient (ρ). Note 2: NC – non-climatic variable, C – Climatic variable. *, ** and *** denote 10, 5, and 1% significance levels, respectively.

A visual inspection in Table 5 indicates that the risk reduction generated by a hedging strategy between the spot soybean market prices and the soybean futures contracts quoted in the CME for Passo Fundo, Cascavel, Maringá, Uberlandia, and Sorriso are respectively, 47.75%, 49.06%, 50.63%, 34.84% and 40.84%, that is, for the hedging efficiency to be 47.75% in Passo Fundo are necessary to assume a short position in the CME soybean future markets equivalent to 450, 480 and 650 bags of soybeans for a proportion of 1000 bags of soybeans purchased (produced) in the spot market when El Niño (EN), neutral state (N) and La Niña (LN). It is observed that the same occurs for the other markets so that the risk is mitigated by 49.06% in the square of Cascavel, it is expected that the rural producer, hedger, cooperative assumes a short position in the CME soybean future markets for 500 (EN), 570 (N) and 650 (LN) bags of soybeans for a proportion of 1000 bags in the spot market. In addition, the results of cross hedge strategies with corn future contracts listed in B3 and hedge with soybean future contracts listed in the CME presented in Table 5, panels B and C do not indicate efficiency in reducing price risks greater than that of the first hedge strategy presented in Table 5, panel A.

5. CONCLUSIONS

In the present study, the relationships between spot and future markets prices for soybeans and corn and the climatic variations represented by the ENSO proxy in the commercial areas of Passo Fundo, Cascavel, Maringá, Uberlandia, and Sorriso. In addition, there was an absence of observations for meteorological variables, implying the use of Tabony's fault-filling methodology. This method consisted of filling in the data for a given test station using linear regressions using precipitation or air temperature data from neighboring stations. To estimate the effectiveness and optimal hedge ratio, the static and generalized model of Myers & Thompson (1989), adapted by Lien & Tse (2002) was used to include the cointegration approach in the analysis. Because of the context, the risk reduction generated by a strategy through the effectiveness of hedging and the proportion of future contracts necessary to cover such risk in the presence of the El Niño, La Niña, and neutral state events were estimated.

Thus, the estimated results of adopting a hedge and cross hedge strategy in the corn spot market with corn (B3; CME) and soybean (CME) future contracts indicated greater risk reduction efficiency when adopting the hedging strategy with futures contracts for B3 maize for all areas of this research. In turn, the results obtained by simulating hedge and cross hedge strategies between the spot market prices for soybeans and soybean and corn future quoted in CME and B3 respectively, indicate that the strategy with the greatest efficiency in reducing risks was the strategy of hedge between soybean spot market prices using soybean futures contracts quoted at CME and for this strategy it is noted that the proportion of soybeans or corn sacks to be assumed in the future market in the presence of the EN, LN and neutral state are higher than the proportion of bags required to cover the optimal hedge ratio in strategies involving the spot market price of soybeans and soybean future contracts quoted on the CME and the cross hedge strategy with corn future contracts quoted on B3.

It should be noted that the research results obtained indicate that by including the climate component ENSO in the models of effectiveness and optimal hedge ratio, it is possible to verify the influence of climate on hedge and cross hedge strategies as an alternative to reduce price risks. of corn and soybeans in the studied squares. Finally, for future research, we suggest to use the dynamic hedge model and isolate the summer and winter harvests periods of grain commercialization in Brazil.

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