PRICE INTERDEPENDENCE IN THE INTERNATIONAL AND BRAZILIAN BEEF CATTLE MARKET[1]

Mercado internacional e brasileiro de bovinos de corte: interdependência de preços

Odilon José de Oliveira Neto

Administrador. Doutor em Administração de Empresas. Professor Adjunto de Finanças na Universidade Federal de Uberlândia (Campus Pontal). UFU/FACES (Campus Pontal), Rua 20, nº 1600, Bairro Tupã, Ituiutaba – MG, CEP: 38304-402. professorodilon@gmail.com

Reginaldo Santana Figueiredo

Engenheiro de Materiais. Doutor em Economia da Indústria e da Tecnologia. Professor na Universidade Federal de Goiás. Escola de Agronomia, Av. Esperança s/n, Campus Samambaia, Goiânia - GO. CEP 74690-900. emaildesantana@gmail.com

Alcido Elenor Wander

Engenheiro Agrônomo. Doutor em Ciências Agrárias. Pesquisador da Empresa Brasileira de Pesquisa Agropecuária (Embrapa). Embrapa Arroz e Feijão, Rodovia GO-462, Km 12, Santo Antônio de Goiás – GO, CEP 75375-000. alcido.wander@embrapa.br

Abstract: The objective of this study is to verify the interdependence and asymmetry in price transmission between the main Brazilian and international slaughter beef cattle markets. We opted for causality and cointegration tests, and application of a multiple regression model to analyse the asymmetry in price transmission between the main Brazilian and international markets. The results showed that there is an interdependent relationship between the prices of live cattle in the Brazilian market and the prices of beef cattle in international markets. However, the direction of transmission between them is significant only from the prices of live cattle in the main Brazilian markets to the prices of beef cattle in international markets.

Keywords: Asymmetry price transmission; Beef cattle; International and brazilian market; Price transmission.

Resumo: Este estudo tem por objetivo principal verificar a interdependência e a assimetria na transmissão de preços entre os principais mercados brasileiros e internacionais de bovinos de corte em ponto de abate. Optou-se por testes de causalidade e de cointegração, e aplicação de um modelo de regressão múltipla, que permitisse analisar a assimetria na transmissão de preços entre os principais mercados brasileiros e internacionais. Os resultados da pesquisa apontaram que existe relação de interdependência entre os preços do boi gordo no mercado brasileiro e os preços dos bovinos de corte nos mercados internacionais. Porém, a direção da transmissibilidade entre eles é significativa tão-somente dos preços do boi gordo nas principais praças brasileiras para os preços dos bovinos de corte nos mercados internacionais.

Palavras-chave: Assimetria na transmissão de preços; Bovinos de corte; Mercado internacional e brasileiro; Transmissão de preços.

1 The research received financial support from the CNPq–Brasil (Process: PDJ 150870/2018-3 and Process: APQ 409560/2018-9) and from FAPEMIG (Process: APQ 02341- 17) and scientific and technological support from the Center for Studies and Research in Administration and Accounting Sciences Universidade Federal de Uberlândia (NEPACC-CTINFRA II-UFU/FACES). Translation to Portuguese: "A pesquisa recebeu apoio financeiro do CNPq–Brasil (Processo: PDJ 150870/2018-3 e Processo: APQ 409560/2018-9) e da FAPEMIG (Processo: APQ 02341- 17) e apoio científico e tecnológico do Núcleo de Estudos e Pesquisas em Administração e Ciências Contábeis da Universidade Federal de Uberlândia (NEPACC-CTINFRA II-UFU/FACES)."

Recebido em 31 de dezembro de 2019
Aceito em 14 de junho de 2021

1 INTRODUCTION

Price transmission has often been assessed in agricultural commodity markets. Numerous studies have raised this issue with the intensification of trade relations between agents from various productive chains and the maximization of business' internationalization. Hypothetically, this contributes to the integration between markets as well as allows for greater consideration of information and changes in the dynamics of price transmission that, technically, can drive the response to shocks within a market or between markets that trade and compete. Shocks are events that take into consideration information that may affect prices, causing its decrease or increase (GILBERT; MORGAN, 2010). In the short term, for example, the "shock" or the sudden reduction of a product supply would entail the immediate increase in the price of this product, on the contrary, would lead to a price fall. This transfer via shocks is scientifically known as price transmission.

In this context, the discussion on issues that contribute to the evolution of management in agricultural marketing must develop not only following the findings of studies for decision-making in the production chains, but also due to the need to generate relevant knowledge to increase the effectiveness of price risk management. So, by assisting the agro-industrial chains with data and information capable of helping in decisions and making them more effective, it is possible to contribute to the economic sustainability of agribusiness, which is one of the main sectors of the Brazilian economy. Agribusiness represents one-quarter of the Brazilian gross domestic product (GDP) and employs 20% of the labour force in Brazil (CEPEA, 2019).

Given the representativeness of the production set, industrialization, domestic consumption and export of beef in Brazil, in addition to the characteristics that surround this environment, it is clear that one of the agricultural markets which are most susceptible to price uncertainties is that of the live cattle. Regarding the magnitude and reach, it is worth mentioning that Brazil, with approximately 14% of total bovine animals and 17% of the international beef market, is positioned first in the contingent ranking of commercial beef cattle and bovine meat exports. Still on the scope of the beef market, Brazil, in 2018, was positioned 2nd in the world ranking in beef production, with approximately 16.5% of the total produced, behind only the United States of America (USA), with about 19% of world production (ABIEC, 2018; USDA, 2019).

In addition to Brazil, other relevant countries in the set of production, export and domestic per capita consumption of beef are the USA, Australia, Argentina, Paraguay, and Uruguay. India also has representative numbers, but, for religious reasons, the country produces mainly buffalo meat. Together, Argentina, Australia, Brazil, USA, Paraguay, and Uruguay, are responsible for approximately 35% of the world's bovine contingent and 60% of global beef exports. In the beef export arena, the prominent are Brazil, Australia, and the USA, which, with 17%, 13% and 12%, respectively, are the top three in the world ranking, and for Argentina, Paraguay and Uruguay, which, aggregates, reach 11% of the international market, a significant amount given the number of cattle in these countries (ABIEC, 2018; USDA, 2019).

As for the total volume of beef demanded domestically, the USA, China, Brazil, and Argentina are the largest markets; in terms of per capita consumption, Uruguayans and Argentines are the largest consumers of beef, both with approximately 55 kilograms of average consumption per year. Brazilians, Americans, and Paraguayans, on average, consume approximately 38 kilograms of beef per year, while Australians' demand is around 30 kilograms per inhabitant per year (USDA, 2019).

Concerning Brazilian beef cattle, an important point to be featured is the distribution of this activity in the regions of the country, given that this activity is present in a large part of the national territory, with emphasis on the states of the Midwest region, which together are responsible for approximately 35% of the total Brazilian cattle herd. The states of Mato Grosso, Mato Grosso do Sul, Goiás, occupy, respectively, the 1st, 2nd and 3rd positions in the ranking. In addition to the Midwest region, other regions and states stand out in Brazilian beef cattle breeding; Southeast,

with the states of Minas Gerais and São Paulo covering 16% of the total cattle and occupying, respectively, the 4th and 11th positions in the ranking. In the North, the states of Pará, Rondônia, and Tocantins, comprise 19.5% of the total cattle and occupy, respectively, the 5th, 7th and 10th positions in the ranking; and in the South, with the states of Rio Grande do Sul and Paraná covering 10.5% of the bovine contingent and occupying, respectively, the 8th and 9th positions in the Brazilian ranking (ABIEC, 2018).

Despite the significance of Brazilian beef cattle, the lack of scientific and transparent information about the interdependence between prices in the Brazilian and international markets is an important problem to be considered. Also, the fact that it is unknown whether the transmission occurs exclusively via shocks in the prices of the market itself or whether it comes from shocks in the prices of competing or competitive interacting markets, added to the lack of knowledge about the dominance in the transfer and the unfamiliarity whether this diffusion of cross-market pricing is symmetrical between transmitters and receivers, they are also important elements to be researched.

Given this problem, the following research questions emerged: (i) is there an interdependent relationship between the prices of live cattle in the Brazilian market and the prices of beef cattle at the point of slaughter in the international market? and, if the direction of causality between prices is identified, (ii) does price transfer occur between these markets? and, still, (iii) are the positive and negative variations in the prices of interacting markets transmitted in the same magnitude? Therefore, this study aims to verify the interdependence and asymmetry in the transmission of prices between the main Brazilian and international markets for beef cattle at the slaughter age. As a specific objective, this research aims to investigate the question of dominance in the transfer of prices between the prices of live cattle in the Brazilian market and those of beef cattle at slaughter age in international markets.

2 THEORETICAL BACKGROUND

In order to theoretically base and offer a better understanding of the interdependence and asymmetry in the transmission of prices in the live beef cattle and beef market, the results of important studies published in national and international scientific journals are presented and discussed below, including a discussion on the characteristics, features, and results of these studies.

One of the precursor studies of the discussion on asymmetry in the transmission of livestock prices was carried out by Bailey and Brorsen (1989). In this study, the spatial price transmission asymmetries between four US-beef cattle markets were analysed, more precisely, Texas, Nebraska, Colorado, and Utah. The results of the investigation rejected the symmetry in price transmission and suggested that adjustments via price increases and decreases in these markets occur with differences in magnitude and speed.

With a focus on the Brazilian beef cattle market, Gaio, Castro Júnior and Oliveira (2005) assessed the elasticity of price transmission and the integration between the markets of the *Bolsa de Mercadorias & Futuros* (BM&F)[2] and the main Brazilian beef cattle markets. The results showed that the markets are spatially integrated, which suggests that a shock to the price of live cattle at BM&F can change the prices of live cattle in the main Brazilian markets. Also, based on Johansen's (1988) cointegration tests, Granger's (1969) causality, the balanced relationship between prices in the long term was confirmed and they concluded that the BM&F beef market acted as a good predictor of the price behaviour of other commercial centres in the period of 2000-2004.

Using methodological procedures close to those of Gaio, Castro Júnior and Oliveira (2005), an investigation was carried out by Zilli *et al*. (2008) on the causal relationship between live cattle prices at BM&F and in the main beef cattle markets in the Southeast and Midwest regions of

2 Brazilian Commodities and Futures Exchange.

Brazil in the period of 2002-2007. The results pointed out that cattle ranchers in the Southeast and Midwest should follow, mainly, the prices of fat cattle at BM&F and in Campo Grande, in the state of Mato Grosso do Sul, since these are robust predictors of price behaviour in their respective commercial areas.

Mattos and Lima (2009) set out to examine the effects of transaction costs on the integration between prices in the beef cattle markets of the states of Minas Gerais and São Paulo in the period of 1972-2005, in the context that the analysis of the integration of agricultural commodity markets is based only on price information. Therefore, the effects of transaction costs in the process of adjusting prices and risks are ignored. The results of the estimated Threshold Vector Error Correction (TVEC) model showed that transaction costs are significant and that price shocks below 10% of the average price are not transmitted between markets. The option for the threshold model was based on the argument that, by not ignoring transaction costs, more robust conclusions are reached about the integration between markets (GOODWIN; PIGGOTT, 2001).

In a methodological line like that outlined by Mattos and Lima (2009), researchers Cunha, Lima and Braga (2010) studied the integration of the Brazilian beef cattle market, under the judgment that the existence of transaction costs can create asymmetries or even hinder the process. From this perspective, the researchers opted for an analysis based on Threshold Autoregressive (TAR) and Momentum-Threshold Autoregressive (M-TAR) Cointegration models for the main Brazilian livestock markets for the period of 1994-2008. The results indicated that the live cattle markets are integrated, but the transaction costs influence the spatial link between them since the negative shocks of low magnitude are eliminated distinctly from the positive ones. Therefore, the benefits of these changes would be less than the costs of the adjustment.

Bender Filho and Alvim (2008) expanded the perspective of analysis. They jointly evaluated the markets of Mercosur member countries and the USA, regarding the transmission of fresh beef prices in the period of 1994-2005. Thereunto, Granger's (1969) and Johansen's (1988) cointegration tests were applied, in addition to the impulse-response analysis. The results suggested the presence of causality in the formation of prices among the markets of the Mercosur member countries, as well as the intensity of the price shocks in each country analysed.

Recent research by Dong *et al*. (2018) also brings with it the focus on analysing the transmission of beef prices at retail, in this case, between the Australian, Chinese and Southeast Asian markets. In this investigation, the same set of methods applied in the research by Bender Filho and Alvim (2008) was used to analyse the problem of price transfer. The results showed that the impact of Australian beef prices on the Chinese and Vietnamese markets is not statistically significant but is significant in the Indonesian market. It was also found that the Australian and Chinese markets have their volatility affected only by variations in the markets themselves.

3. METHODOLOGY: DATA AND PROCEDURES

3.1 Characterization of study and research data

Aiming to achieve the objectives of this study, which involve the investigation of defined research questions, a quantitative approach was proposed, supported by a specific set of statistical methods and techniques. Therefore, in the sequence, the characterization of the price series is discussed, including sources for obtaining the data, also in section 3.2 there is the econometric procedure used to answer the research questions and achieve the study objectives.

The survey data are composed of the weekly price series quoted in US-dollars per kilogram / live weight of beef cattle at slaughter age in the international market and of live cattle in the main Brazilian beef cattle markets, in the period between January 6, 2007 and December 29, 2018, to-

talling 627 observations. The denominations and the respective acronyms, fat oxen (FO) and beef cattle at slaughter age and weight (BCSAW) will be used in this study to name the Brazilian beef cattle and cattle at slaughter age or finished in the Brazilian and international markets, respectively. In turn, the time frame was defined based on the availability of successive and uninterrupted data. Also, the series were logarithmised to remove exponential trends, which is a process that follows the standards adopted in the leading international research on the subject.

Regarding the BCSAW price series in the international market, it is noteworthy that these were provided by Minerva Foods' Market Intelligence (Business Intelligence - BI) and originated from institutional databases in the Argentine, Paraguayan, Uruguayan, Australian and American markets. Some specificities of the international BCSAW and the research data sources are described in Table 1.

Table 1 – Data sources and denomination of beef cattle at slaughter age in the international market

Country	Argentina	Paraguay	Uruguay	Australia	USA
Name	Novillo	Fat Ox	Novillo	Young Cattle	Live Cattle
Data: Way of access	Tardáguila Agromercados	Tardáguila Agromercados	World Beef Report	World Beef Report	United States Department of Agriculture
Data source	Mercado de Liniers S.A.	Asociación Rural del Paraguay ARP/ CICPCB	Instituto Nacional de Carnes del Uruguay (INAC)	Meat & Livestock Australia (MLA)	Chicago Board of Trade (CBOT)

The series of beef cattle prices in the Brazilian market were obtained from Minerva Foods' BI and are based on data from the Center for Advanced Studies in Applied Economics (CEPEA) of Luiz de Queiroz School of Agriculture (ESALQ) of the State University of São Paulo (USP). The most relevant Brazilian markets (Brazilian states or commercial markets) in beef cattle were represented, in this study, by the main commercial markets for live cattle, as shown in Table 2.

Table 2 – Specificities of the data regarding live cattle in the Brazilian market

Region	State	Market location/State
Southeast	*Minas Gerais*	*Triângulo Mineiro/MG*
	São Paulo[(1)]	*Araçatuba/SP, Bauru/SP, Marília/SP, Presidente Prudente/SP and São José do Rio Preto/SP*
Mid-west	*Goiás*	*Goiânia/GO*
	Mato Grosso do Sul[(2)]	*Campo Grande/MS, Dourados/MS and Três Lagoas/MS*
	Mato Grosso	*Cuiabá/MT*
South	*Paraná*	Northwest Region/PR
	Rio Grande do Sul	West Region/RS
North(3)	*Rondônia*	The Southwest Region/RO
	Tocantins	The Northern Region/TO

Notes: (1) The prices in the state of São Paulo were represented by Indicator Esalq/B3, which refers to the weighted average of the ox in the state of São Paulo (represented by markets of *Araçatuba/SP, Bauru/SP, Marília/SP, Presidente Prudente/SP*, and *São José do Rio Preto/SP*). More details on the methodology of calculation of the Esalq/B3 Indicator can be found on the website of the Center for Studies in Applied Economics (www.cepea.esalq.usp.br). (2) The prices in the state of Mato Grosso do Sul were represented by the arithmetic average of the prices of the ox in the three main markets of the state (*Campo Grande/MS, Dourados/MS* and *Três Lagoas/MS)*. (3) The state of *Pará* was removed from the sample by the fact that there are no consistent data on the prices of the ox in the period between the years of 2007 and 2012, resulting in the lack of 314 observations, which potentially compromises the results of the research.

3.2 Econometric procedures and methods of analysis

To check the interdependence relationship between FO prices in the Brazilian market and BCSAW prices in the international market as well as the direction of causality between prices, an econometric procedure was defined, which includes the set of estimates, tests, and analyses. First, central tendency measures, dispersion, and linear correlation were estimated to describe the avera-

ge, maximum and minimum values, as well as to inform about the variation around average prices and indicate the direction of the linear relationship between prices. Then, the unit root test ADF or Augmented by Dickey and Fuller (1981) was applied to verify that the statistical properties of the series are maintained over time, having been identified that the series is stationary in the first difference. In summary, this is a fundamental procedure to avoid obtaining spurious results in the regression analysis that usually occurs when regressing independent non-stationary series.

The next step was to define the order of optimal lags by the information criterion of Akaike (1974) added to the autoregressive vector modelling and verification of the causal direction between prices in the short term through the application of the Granger (1969) causality test in the paired context and blocks.

The application of the Granger causality test for the stationary variables y_t and x_t, begins with the specification of the autoregressive model, according to equations (1) and (2), in which it is assumed that both e_{yt} and e_{xt} are error terms not correlated over time.

$$y_t = a_1 + \Sigma_{i=1}^{n} \beta_1 x_{t-1} + \Sigma_{j=1}^{m} y_j y_{t-j} + e_{yt} \quad (1)$$

$$x_t = a_2 + \Sigma_{i=1}^{n} \theta_i x_{t-1} + \Sigma_{j=1}^{m} \delta_j y_{t-j} + e_{xt} \quad (2)$$

Therefore, Granger's (1969) causality test allowed: a) to test whether past events can cause present events; b) to check if a time series x helps to predict another series y, or vice versa; c) to find out whether x causes y, that is, whether past values of x_{t-i} (lagged variables, x_{t-i}) contribute to determining y_t, regardless of the contribution of past values of y_{t-j}, or vice versa; d) to determine if the sets of terms of *x* and *y* are statistically different from zero in equations 1 and 2, so that there is bidirectional causality; e) to examine whether the sets of terms *x* and y are not statistically different from zero in equations 1 and 2, so that x_t is independent of y_t. Granger's causality test for x_t and y_t allowed us to conclude on the direction of causality between market prices. After the paired Granger test, that is, market by market, this same test was applied in addition to Wald's (1943) exogeneity test to analyse the block effect. Therefore, it was possible to examine the causality of the series of group markets on a specific market.

After applying the Granger (1969) causality test, the study followed with the use of Johansen's (1988) cointegration test to try the hypothesis of equilibrium in the long-term relationship between FO prices in Brazilian markets and of BCSAW in international markets. Johansen's cointegration test (1988) is based on equations (3) and (4), described below:

$$\Delta y_t = \mu + \Pi y_{t-1} + \cdots + \Sigma_{I=1}^{p-1} \Gamma y_{t-1} + \epsilon_t \quad (3)$$

$$\Pi = \Sigma_{i=1}^{p} A_i - 1 \; e \; \Gamma = -\Sigma_{J=i+1}^{P} A_j \quad (4)$$

wherein the matrix coefficient Π is positioned as r < n, with r x n matrices (α and β), each with rank r, so that Π = αβ and Π = β'yt are stationary. In this case, r refers to cointegration vectors; α is the adjustment parameter in the error correction vector; and β is the representative coefficient of the error correction vector. For a given r, the estimate of the maximum likelihood of the matrix β indicates the combination of y_{t-1}, which results in *r* greater canonical correlations between Δy_t and y_{t-1}, after correcting differences in lags and identifying deterministic variables, if found. The significance of the likelihood ratio is estimated by the trace test, according to equation 5, below.

$$\lambda_{trace} = -T\Sigma_{i=r+1}^{n} In(1 - \lambda_t) \quad (5)$$

wherein *T* refers to the sample size and λ_{r+1} is the element of the *i*-th largest canonical correlation. The trace test tests the null hypothesis that the number of cointegration vectors is less than or

equal to r versus the alternative hypothesis that the number of cointegration vectors is greater than r. The test hypotheses consist of $r = 0$, there is no cointegration; and $r \geq 1$, $r \geq 2$, ..., $r \geq n$, there is cointegration between one or more markets. The level of statistical significance for the hypothesis test and the critical values are those proposed by Johansen and Juselius (1990).

Once the directions of causality and the conditions of equilibrium in the long-term relationship between markets have been identified (or cointegration), the study proceeds with the analysis of price transmission and verification of the asymmetry phenomenon, which focuses on verifying the existence or not of the magnitude divergence of the price transfer increases or decreases between markets. Thus, to achieve the objectives of the study and answer the two central research questions, we decided for the application of a multivariate version of the model proposed by Houck (1977) to analyse the asymmetry in the price transmission (ATP) between the FO prices in the Brazilian market and BCSAW prices in international markets. Houck's model (1977) was widely used in empirical studies, among which, internationally, as references for its application, the research of Kinnucan and Forker (1987) and Griffith and Piggott (1994) stand out. Among the studies involving Brazilian agricultural markets, we highlight the research by Silva Neto and Parré (2012) and Alves, Tonin and Carrer (2013) who, despite initially opting for the applications of Griffith and Piggott (1994), for not including the quantities produced and the production costs, the authors ended up applying a model similar to the one of Houck (1977) to verify the asymmetry in the transmission of prices.

Because it is not a vertical analysis, i.e., it specifically involves links in a production chain (e.g.,: producer, industry, wholesale and retail), and, also, because it is an analysis of spatial transmission, that is, between markets (Brazilian and international), in this study, we deliberated on a multivariate version that allowed to verify whether positive and negative price variations in interacting markets are transmitted to the same magnitude. Thus, equation 6, below, represents the multivariate version applied in the analysis of asymmetry in the transmission of prices between the Brazilian FO and international BCSAW markets.

$$\Delta Y_t = \beta_{0t} + \beta_1 \Sigma \Delta X_{1t}^{+} + \beta_1 \Sigma \Delta X_{1t}^{-} + \cdots + \beta_k \Sigma \Delta X_{kt}^{+} + \beta_k \Sigma \Delta X_{kt}^{-} + \varepsilon_t \qquad (6)$$

wherein:

$$\Delta X_t^{+}: X_t - X_{t-1}, if\ X_t > X_{t-1}, 0 \text{ otherwise} \qquad (7)$$

$$\Delta X_t^{-}: X_t - X_{t-1}, if\ X_t < X_{t-1}, 0 \text{ otherwise} \qquad (8)$$

Once the angular coefficients (βetas) of the positive and negative variations in prices in the markets (independent variables), represented by β, were estimated, the Wald test was applied under the hypothesis of symmetry in the price transmission (acronym, SYM), represented by $h_0: \beta_1 += \beta_1 - or\ \beta_k += \beta_k -$, in which case the positive or negative variations in prices in a given statistical market are also transmitted in magnitude to another market. In the case of rejection of the null hypothesis, the alternative hypothesis of asymmetry in price transmission (ASYM), represented by $h_1: \beta_1 +\neq \beta_1 - or\ \beta_k +\neq \beta_k -$, is not rejected, being, in this case, the positive or negative variations in prices in a given market are statistically and differently transmitted in magnitude to another market. In the case where $\beta_1 += \beta_1 -= 0\ or\ \beta_k += \beta_k -= 0$, it does not apply (DNA), rejecting both hypotheses, since the transmission of prices between markets is discarded.

4 RESULTS AND DISCUSSION

The presentation of the results begins with Table 3, which covers the descriptive set of measures of central tendency and dispersion of the weekly series of BCSAW prices in the international market and the main Brazilian production and commercialization markets quoted in US-dollars per kilogram of live weight for the period of 2007-2018. In terms of the central trend, it should be noted, at first glance, that the average prices of FO in the main Brazilian markets and of BCSAW in the Argentine, Paraguayan and Uruguayan markets are considerably close.

Nevertheless, in the arena of central trend estimates, it is noteworthy that the highest average price in the period was that of the US-BCSAW, which is between 29.30% to 53.66% higher than that practiced in the Brazilian, Argentine, Paraguayan, and Uruguayan markets, and 25.10% higher than that practiced in the Australian market. This suggests that the higher average price of the US-BCSAW is because the USA is positioned as the largest world market demanding beef. Another important piece of information refers to the superiority of the average price of Australian BCSAW, which was between 3.35% and 22.82%, more than that practiced in Brazilian markets and the Argentine, Paraguayan and Uruguayan markets. However, the average prices of Uruguayan BCSAW and FO in the Brazilian state of São Paulo (or São Paulo FO) are particularly close to the Australian market. In this context, it is worth noting that the beef from the slaughter of Australian, Uruguayan and São Paulo FO beef ranks among those with the most considerable appeal for export among the markets under study.

In the field of dispersion, it is notable that the coefficient of variation in Argentine BCSAW prices is approximately 45% higher than that of FO in the main Brazilian markets and the prices of BCSAW in other international markets. This finding suggests that the greater variability in the price of Argentine BCSAW in the period is due to several factors. Among those factors the following emerge: interventions by the Argentine federal government in the beef market that occurred, mainly, from the year 2008; increases in export taxes; weight restrictions for slaughter; limitation of export volumes by the Hilton quota for a specified time; and, in a short time, until the export ban (OLIVEIRA NETO; GARCIA, 2013).

Also, when investigating the standard deviations of BCSAW prices in the international market it was found that they are higher than the standard deviation of FO prices in Brazilian markets, except for BCSAW in the Paraguayan market, which is at the same level as those measured for the FO in the main Brazilian markets. When looking at the standard deviations in the prices of US, Argentine, Australian, and Uruguayan BCSAW, it was found that these exceed, by approximately, 55%, 40%, 15% and 10% the standard deviations of prices of Brazilian FO and Paraguayan BCSAW, which makes their lower volatility evident when compared to the volatility of other international markets. Still, on the dispersion of the data exposed in Table 3, the estimates of asymmetry and kurtosis of the Brazilian FO price series suggest that they show distributional normality, which is confirmed by the Jarque and Bera (1987) test statistics. However, the asymmetries, shortcuts, and statistics of the Jarque-Bera test referring to the series of BCSAW prices in the international market rejected the null hypothesis of distributional normality.

Table 3 – Descriptive statistics of prices at slaughter age in the international market and the fat oxen in the main Brazilian production and marketing places - quoted in US-dollar per kilogram live weight

	International markets					BR/Southeast		BR/Mid-West			BR/South		BR/North	
	AR	PY	UY	AUS	USA	MG	SP	GO	MS	MT	PR	RS	RO	TO
Mean	2.952	2.872	3.129	3.234	4.046	2.789	3.034	2.760	2.809	2.689	2.926	2.936	2.633	2.651
Maximum	4.868	4.340	4.155	4.974	6.016	4.089	4.456	4.183	4.074	3.924	4.182	4.032	3.794	3.846
Minimum	1.258	1.486	1.816	1.786	2.787	1.508	1.604	1.490	1.447	1.378	1.531	1.657	1.239	1.275
SD	0.849	0.548	0.606	0.633	0.783	0.514	0.561	0.513	0.553	0.525	0.553	0.507	0.563	0.518
VC(%)	28.8%	19.1%	19.4%	19.6%	19.4%	18.4%	18.5%	18.6%	19.7%	19.5%	18.9%	17.3%	21.4%	19.5%
Asymmetry	-0.639	-0.477	-0.673	0.006	0.435	-0.109	-0.010	-0.020	-0.041	-0.044	-0.209	-0.146	-0.204	-0.357
Kurtosis	1.999	3.068	2.268	2.499	2.525	2.926	2.967	2.879	2.783	2.830	2.935	2.697	2.689	3.170
JB stat.	68.81	23.84	61.27	6.575	25.65	1.377	0.039	0.424	1.404	0.953	4.655	4.618	6.867	14.09
P-value JB	0.000	0.000	0.000	0.037	0.000	0.502	0.981	0.809	0.496	0.621	0.098	0.099	0.032	0.001

Note: (BR) Brazil, (AR) Argentina, (PY) Paraguay, (UY) Uruguay, (AUS) Australia, (USA) United States of America, Brazilian states (MG = Minas Gerais; SP = São Paulo; GO = Goiás; MS = Mato Grosso do Sul; MT = Mato Grosso; PR = Paraná; RS = Rio Grande do Sul; RO = Rondônia; TO = Tocantins), (SD) standard deviation, (VC%) coefficient of variation percentage, (stat.) Statistics, (JB) Jarque-Bera.

Source: Data from the survey.

So, when considering the importance of knowing the statistical relationship between prices for decision making by agents in the beef production chain, it was decided to start this process by analysing linear correlation. Ergo, in Table 4, there are positive linear correlations, from moderate to strong, between FO prices in the main Brazilian commercial markets and BCSAW prices in the Argentine, Paraguayan and Uruguayan markets, with emphasis on the strong positive association with the Paraguayan BCSAW market. As opposed to this, positive linear correlations, from weak to moderate, were found between FO prices in the main Brazilian markets and BCSAW prices in the Australian and American markets. In this context, despite not being directly conditioned to causality, the degree of linear association measured suggests the interdependence between FO prices in the Brazilian market and BCSAW prices in the international market, which points to the need to ascertain the relationship of transmissibility between them.

In the search for a connection with the empirical results of other studies, reference is made to the investigation by Bender Filho and Alvim (2008), which showed the causality between prices in the markets of Mercosur member countries and the intensity of shocks in prices between them. Notwithstanding, due to the monthly temporariness of the data and the exclusivity of the evaluation of a product category (fresh meat), the potential for decision-making information captured in the investigation has decreased. Since the dynamics in the transmission of agricultural prices generally presents immediate responses to impulses (daily or weekly) and should not ignore the potential for transferring the price of the standardized product in its primary trading version, characterized as a commodity, fattened beef or beef at the point of slaughter.

Table 4 – Linear correlation between the prices of cattle at slaughter age in the international market and the fat oxen in major Brazilian centres of production and marketing

	BR/Southeast		BR/Mid-West			BR/South		BR/North	
	MG	SP	GO	MS	MT	PR	RS	RO	TO
AR	0.7061***	0.6485***	0.6858***	0.6887***	0.6759***	0.7321***	0.7549***	0.7072***	0.7216***
PY	0.8411***	0.7936***	0.8183***	0.8309***	0.8186***	0.8476***	0.8136***	0.8469***	0.8332***
UY	0.7319***	0.6840***	0.7112***	0.7304***	0.7105***	0.7627***	0.7563***	0.7528***	0.7529***
AUS	0.4354***	0.3404***	0.3938***	0.3875***	0.3794***	0.4434***	0.4884***	0.4006***	0.4345***
USA	0.4703***	0.4299***	0.4646***	0.4749***	0.4560***	0.5114***	0.5777***	0.5015***	0.4780***

Note: (***) was statistically significant at the level of 1%. (BR) Brazil, (AR) Argentina, (PY) Paraguay, (UY) Uruguay, (AUS) Australia, (USA) United States of America, Brazilian states (MG = Minas Gerais; SP = São Paulo; GO = Goiás; MS = Mato Grosso do Sul; MT = Mato Grosso; PR = Paraná; RS = Rio Grande do Sul; RO = Rondônia; TO = Tocantins).

Source: Data from the survey.

The verification of a possible interdependence relationship between FO prices in the Brazilian market and BCSAW prices in the international market was indicated. An attempt was made to identify the direction of causality between markets in the short term, using the Granger (1969) causality test paired and block, as described in section 3.2. In short, the difference between paired and block Granger causality tests lies in the fact that the first analytically considers the relationship between the prices of two markets and the second considers the direction of the joint causality of two or more markets over a specific one.

Granger's (1969) causality test was applied after the selection of the optimal lags defined by the Akaike information criterion added to the autoregressive vector modelling, as announced in section 3.2. Akaike information criterion (AIC) statistics were estimated for the ratio of BCSAW prices in the Argentine (AIC = -79.3735), Paraguayan (AIC = -80.0907), Uruguayan (AIC = -81.6169), Australian (AIC = -80.6392) and American (AIC = -81.1657), with FO prices in the main Brazilian markets together. In this way, the AIC statistics set two optimal lags to be applied in verifying the interdependence of BCSAW prices between each international market, in isolation, compared to the set of Brazilian markets. The interdependence analysis between the markets is composed of the Granger (1969) causality tests, shown in Tables 5 and 6, and Johansen's (1988) cointegration tests, shown in Table 7.

In particular, the data in Table 5 show Granger's causality of BCSAW prices in the international market directed to FO prices in the main Brazilian production and commercialization markets. By analysing them, it was found that past changes in BCSAW prices in the international market do not act as robust predictors of changes in Brazilian FO prices. The only exception found relates to the causality in Granger's sense of the price of BCSAW in the Uruguayan market for the price of FO in the Brazilian state Rio Grande do Sul, in which the variation in the price of the first acts as a robust predictor of changes in the price of the second.

Table 5 – Granger Causality (paired and block) between the prices of cattle at slaughter age in the international market and the fat oxen in major Brazilian centres of production and marketing

	BR/Southeast		BR/Mid-West			BR/South		BR/North	
	MG	SP	GO	MS	MT	PR	RS	RO	TO
AR	0.6653ns	0.1685ns	0.8730ns	0.2160ns	0.6021ns	0.2182ns	0.8564ns	0.1236ns	0.9839ns
PY	0.3734ns	1.1717ns	0.5076ns	0.9710ns	0.8023ns	1.1511ns	1.5693ns	0.6990ns	0.9130ns
UY	1.2458ns	2.0525ns	1.0767ns	1.7542ns	1.5890ns	2.3924*	4.2383**	2.5060*	2.6634*
AUS	0.1636ns	0.4081ns	0.0393ns	0.4092ns	0.5241ns	0.4762ns	0.4407ns	0.3171ns	0.4044ns
USA	0.5317ns	0.5029ns	0.3156ns	0.5505ns	0.5708ns	0.5170ns	0.0207ns	0.8860ns	0.4735ns
Block	10.135ns	11.426ns	9.6820ns	10.951ns	10.951ns	12.453ns	23.122ns	11.633ns	14.515ns

Note 1: The estimated statistics to test for paired Granger causality and block are the statistic F and x2 - chi-square test, respectively. Note 2: (ns) without statistical significance, (***,**,*) was statistically significant at the level of 1%, 5%, and 10%, respectively. Note 3: (BR) Brazil, (AR) Argentina, (PY) Paraguay, (UY) Uruguay, (AUS) Australia, (USA) United States of America, Brazilian states (MG = Minas Gerais; SP = São Paulo; GO = Goiás; MS = Mato Grosso do Sul; MT = Mato Grosso; PR = Paraná; RS = Rio Grande do Sul; RO = Rondônia; TO = Tocantins).

Source: Data from the Survey.

In sequence, Table 6 shows the results of Granger's (1969) causality test, paired and in a block in the opposite direction, that is, of FO prices in the main Brazilian markets towards BCSAW prices in the international market. In contrast to that in Table 5, the data in Table 6 indicate that past changes in FO prices in the main Brazilian markets act as predictors: (i) significantly robust changes in BCSAW prices in the Paraguayan, Uruguayan and Australian markets; (ii) reasonably robust prices for BCSAW in the US-market; and (iii) unreliable BCSAW prices in the Argentine market. Only FO prices in Paraná and Rio Grande do Sul (or Paraná and Rio Grande do Sul states) precede changes in the price of Argentine BCSAW.

Table 6 – Granger Causality (paired and block) between the prices of the ox in major Brazilian centres of production and marketing of cattle at slaughter age in the international market

	AR	PY	UY	AUS	USA
MG	1.9927ns	25.2882***	7.3882***	5.4348***	2.8365*
SP	2.3331*	25.3097***	8.3869***	4.1823**	2.7828*
GO	2.3289*	22.8539***	7.0146***	6.1762***	2.9310*
MS	2.5726*	27.3041***	10.2864***	7.8404***	3.0205**
MT	2.5537*	19.5549***	9.3998***	6.7947***	2.3196*
PR	3.1032**	28.2628***	9.6532***	6.5754***	3.1971**
RS	3.1520**	23.4174***	22.0935***	4.4939**	3.3483**
RO	2.1841ns	19.4593***	7.4315***	7.1607***	2.6247*
TO	2.6376*	20.6996***	8.5951***	4.9888***	2.9348*
Block	20.5332ns	90.6822***	69.7300***	36.6162***	25.8895*

Note 1: The statistics estimated to test for paired Granger causality and block are the statistic F and x^2 - chi-square test, respectively. Note 2: (ns) without statistical significance, (***,**,*) was statistically significant at the level of 1%, 5%, and 10%, respectively. Note 3: (BR) Brazil, (AR) Argentina, (PY) Paraguay, (UY) Uruguay, (AUS) Australia, (USA) United States of America, Brazilian states (MG = Minas Gerais; SP = São Paulo; GO = Goiás; MS = Mato Grosso do Sul; MT = Mato Grosso; PR = Paraná; RS = Rio Grande do Sul; RO = Rondônia; TO = Tocantins).

Source: Data from the Survey.

After Granger's causality test had indicated the direction and forecast capacity in the short term between the prices of BCSAW in international markets and FO in Brazilian markets, the study related to interdependence followed with the analysis of long-term equilibrium relationship between prices in these markets through the application of the Johansen (1988) cointegration test. The results are shown in Table 7.

In highlight, the data in Table 7 point to the existence of, at least, eight vectors of cointegration between BCSAW prices in the Paraguayan and Uruguayan markets and FO prices in Brazilian markets, which suggests a balanced long-term relationship between these markets, indicating that they are tightly integrated. The estimates of the trace test of the relationship between BCSAW prices in the Australian and American markets with FO prices in Brazilian markets point to the non-rejection of the hypothesis that there are at least five cointegration vectors between these markets. This suggests a balanced long-term relationship between the Australian and American markets with at least five Brazilian markets, showing a moderate integration between prices in these markets.

Another relevant information contained in the cointegration tests presented in Table 7 refers to the finding of a low integration between the price of BCSAW in the Argentine market and the prices of FO in Brazilian markets. However, it is worth noting that the hypothesis of at least four vectors of cointegration in this relationship was not rejected, which suggests the long-term balanced relationship of the Argentine market with at least four Brazilian markets, but this result denotes the inferiority in integration between prices in these markets.

The knowledge of the interdependent relationship between FO prices in the main Brazilian markets and BCSAW in the international market supported by the reach of information on the direction of causality and predictive aptitude obtained through the paired and block Granger (1969) causality test, as well as the data on the balance of the long-term relationship between the markets obtained through Johansen's (1988) cointegration test, are all essential to answer the first research question. Also, this information prepared the field for verifying the asymmetry in the transmission of prices between Brazilian and international markets. Hence, the data in Table 8 are analysed to answer the second and third research questions and reach the completion of the main and specific objectives proposed in this study. In general, the data in Table 8 corroborate the existence of price transmission between the Brazilian and international markets. This is because several estimated coefficients related to the accumulation of negative and positive variations in FO prices in Brazi-

lian markets have shown themselves to be statistically significant transmitters of BCSAW prices in international markets.

Table 7 – Test trace for verification of cointegration between prices of cattle at slaughter age in the international market and the ox in major Brazilian centres of production and marketing

Vectors	VC-value	Trace Test statistics				
		AR	PY	UY	AUS	USA
R = 0	239.2354	325.1198***	337.0370***	322.9399***	344.8892***	331.8145***
R ≤ 1	197.3709	248.7550***	258.1481***	244.6434***	262.0626***	252.7855***
R ≤ 2	159.5297	185.4117***	199.6806***	183.0467***	194.3547***	192.5122***
R ≤ 3	125.6154	134.9981**	155.2606***	142.2901***	139.1968***	134.8547**
R ≤ 4	95.7537	94.9411	113.0617***	108.7874***	98.6183**	96.5200**
R ≤ 5	69.8189	68.8191	78.0216***	77.2756**	67.9822	68.3845
R ≤ 6	47.8561	46.5493	52.8098**	52.2387**	45.5594	44.407
R ≤ 7	29.7971	30.1073	32.0876**	32.6683**	25.9159	27.9975
R ≤ 8	15.4947	17.2619	19.8938**	19.5571**	12.9724	15.1523
R = 9	3.8415	5.863	7.9423	7.3254	1.7588	6.092

Note: (VC-value) critical value of the test trace, (ns) without statistical significance, (***,**,*) was statistically significant at the level of 1% and 5%, respectively.
Source: Data from the Survey.

In this context, the transfer of prices from the Brazilian to the Uruguayan market is prominent, since completeness was identified in the transmission between them and symmetry in the transmission between FO prices in Minas Gerais, São Paulo, Goiás, Mato Grosso do Sul and Rondônia for the Uruguayan BCSAW market. That is, the increases and falls in prices in these places are transmitted in the same magnitude. FO prices in São Paulo, Mato Grosso do Sul and Goiás were those that presented the highest transferability coefficients for BCSAW prices in the Uruguayan market during the period under study. FO prices in Paraná, Rio Grande do Sul, Mato Grosso and Rondônia are transmitted asymmetrically to the Uruguayan BCSAW market. To put it another way, the transfer via fall and increase in the FO prices of these places to the price of Uruguayan BCSAW differs in magnitude.

In addition to the Uruguayan market, there was also a significant transmission of FO prices in the Brazilian market to the BCSAW price in the Australian market, but all this transfer occurs with asymmetry, that is, falls and increases in prices are transmitted with differences in magnitude. It was also found that the variation in the price of FO in the state of São Paulo is the one that presents the greatest transfer intensity for the price of BCSAW in the Australian market. When evidencing that the price of São Paulo's FO is the one with the greatest interdependent relationship with the prices of Uruguayan and Australian BCSAW, it is suggested that, in part, this may be explained by the fact that the beef from these three markets is positioned among the greater market or export reach in the period under study.

It is also noted that the variations in the FO prices of six Brazilian markets are transferred to the prices of the Paraguayan BCSAW, but only the falls and increases in the prices of FO in Mato Grosso do Sul are symmetrically transmitted. This suggests that the geographical proximity and the fact that the border area of Mato Grosso do Sul is the largest among the states of Brazil bordering Paraguay, added to the proximity of production characteristics, to their positioning as important beef exporters for common markets and the presence of refrigeration industries active in both markets. This contributes to the fact that the falls and increases in prices of FO in Mato Grosso do Sul are similarly transmitted to the prices of Paraguayan BCSAW. On the contrary, the falls and increases in FO prices in Minas Gerais, São Paulo, Goiás, Paraná, and Tocantins are asymmetrically transmitted to Paraguayan BCSAW prices. Also, it is important to note that FO

prices in São Paulo and Mato Grosso do Sul were those that presented the highest transferability coefficients for BCSAW prices in the Paraguayan market in the period under study.

As in the relationship between the Brazilian and Paraguayan markets, it was found that variations in the FO prices of six Brazilian markets are transferred to the prices of the Argentine BCSAW. Ergo, there was symmetry in the transmission between FO prices practiced in Goiás, Rondônia, and Tocantins to the Argentine BCSAW market, that is, the increases and falls in prices in these places are transmitted in the same magnitude. From another perspective, positive and negative variations in FO prices in Minas Gerais, São Paulo, and Rio Grande do Sul are asymmetrically transmitted to Argentine BCSAW prices, with increases in FO prices in Minas Gerais and São Paulo and declines in the price of FO in Rio Grande do Sul, presenting a greater magnitude of transfer to BCSAW prices in the Argentine market than in contrary situations.

When checking the transmission coefficients of FO prices in Brazilian markets for the price of BCSAW in the US-market, it was noted that these coefficients are those with the lowest transfer levels compared to the estimated coefficients for other international markets. Nevertheless, the US-BCSAW market presented itself as a receiver of price variations in eight Brazilian markets, more precisely, Minas Gerais, São Paulo, Goiás, Mato Grosso, Paraná, Rio Grande do Sul, Rondônia, and Tocantins, with variations of the FO market in the state of Paraná being the only one to transmit prices with symmetry.

Also, it was noted that falls in prices in Minas Gerais, Rio Grande do Sul, Rondônia and Tocantins are transmitted with greater magnitude than highs. In contrast, increases in prices in São Paulo, Goiás, and Mato Grosso are transmitted with greater magnitude than falls. An important aspect in the relationship between the Brazilian FO and the American BCSAW markets is that the transmission of prices from the FO of Minas Gerais and Rio Grande do Sul to the price of the American BCSAW occurs exclusively via price increases, while the transmission of FO prices in São Paulo and Goiás to the US-BCSAW price comes only from declining prices. In this universe, it is worth noting that São Paulo is the largest Brazilian beef exporter square, both fresh and industrialized.

Table 8 – Asymmetry in price transmission between the markets of fat oxen in major Brazilian centres of production and marketing and international markets for cattle at slaughter age

The market		AR		PY		UY		AUS		USA	
		B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)
MG	B-	3.6160	7.7144 ASYM	1.2660	51.2643 ASYM	0.7220	1.1055 SYM	0.9500	3.4913 ASYM	0.8250	1.0286 ASYM
		[7.77]***		[4.39]***		[2.33]***		[3.89]***		[3.35]***	
	B+	5.2110		-1.2800		1.1240		0.3870		0.5170	
		[9.84]***		[-3.90]***		[3.18]***		[1.39]ns		[1.84]ns	
SP	B-	-1.6660	45.4752 ASYM	-1.6400	9.4384 ASYM	-2.6040	0.2316 SYM	-2.5240	7.5749 ASYM	-0.0240	12.8667 ASYM
		[-3.53]***		[-5.62]***		[-8.29]***		[-10.20]***		[-0.09]ns	
	B+	-5.2720		-0.6230		-2.4320		-1.7510		-1.0390	
		[-14.17]***		[-2.70]***		[-9.82]***		[-8.96]***		[-5.27]***	
GO	B-	-1.8530	2.9762 SYM	-0.6290	11.0707 ASYM	-1.5590	0.3071 SYM	-0.8170	7.3164 ASYM	-0.2630	18.4547 ASYM
		[-4.34]***		[-2.38]***		[-5.48]***		[-3.64]***		[-1.16]ns	
	B+	-1.3080		0.0220		-1.4420		-0.3690		0.4550	
		[-3.70]***		[0.10]ns		[-6.13]***		[-1.99]**		[2.43]**	
MS	B-	0.0060	DNA	1.1440	0.6717 SYM	2.5930	1.8190 SYM	1.2000	16.7216 ASYM	-0.2400	DNA
		[0.01]ns		[3.29]***		[6.93]***		[4.07]***		[-0.80]ns	
	B+	0.1160		1.4340		2.0810		-0.0240		-0.0360	
		[0.25]ns		[4.98]***		[6.73]***		[-0.09]ns		[-0.14]ns	

The market		AR		PY		UY		AUS		USA	
		B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)	B coef. [T-Stat.]	Wald test (χ2)
MT	B-	-0.2250	DNA	0.5210	DNA	1.5900	35.2598 ASYM	0.3490	1.1604 ASYM	-0.2500	19.2271 ASYM
		[-0.48]ns		[1.82]ns		[5.18]***		[1.44]ns		[-1.02]ns	
	B+	0.8040		0.1220		-0.5190		0.6510		0.9890	
		[1.92]ns		[0.47]ns		[-1.86]ns		[2.96]***		[4.46]***	
PR	B-	-0.0800	DNA	0.7430	6.3200 ASYM	0.2380	8.8444 ASYM	2.4160	44.5764 ASYM	-0.7370	0.3705 SYM
		[-0.17]ns		[2.61]***		[0.77]ns		[10.01]***		[-3.02]***	
	B+	0.8230		1.6730		1.4210		0.3210		-0.9290	
		[1.95]ns		[6.39]***		[5.05]***		[1.44]ns		[-4.15]***	
RS	B-	1.2060	14.955 ASYM	-0.0490	DNA	0.4410	7.5138 ASYM	0.0220	20.9852 ASYM	0.8540	78.2389 ASYM
		[6.93]***		[-0.45]ns		[3.80]***		[0.24]ns		[9.27]***	
	B+	0.3940		-0.1640		0.0580		0.5270		-0.1290	
		[2.86]***		[-1.92]ns		[0.63]ns		[7.29]***		[-1.77]ns	
RO	B-	-1.5280	0.0209 SYM	-0.3940	DNA	-1.3000	0.8812 SYM	-1.1420	3.6987 ASYM	1.0080	46.7968 ASYM
		[-4.24]***		[-1.76]ns		[-5.42]***		[-6.04]***		[5.29]***	
	B+	-1.5950		-0.1080		-1.0100		-0.6740		-0.6710	
		[-4.37]***		[-0.47]ns		[-4.16]***		[-3.52]***		[-3.47]***	
TO	B-	1.2150	0.6872 SYM	-0.1770	0.3076 ASYM	0.4390	15.3918 ASYM	0.1660	65.921 ASYM	-1.1410	134.620 ASYM
		[4.28]***		[-1.00]ns		[2.32]**		[1.11]ns		[-7.60]***	
	B+	1.4790		-0.2870		1.2740		1.5280		0.8220	
		[6.54]***		[-2.05]**		[8.46]***		[12.88]***		[6.87]***	
Constant		0.0280	-	0.0060	-	0.0100	-	0.0140	-	0.0240	-
		[2.44]		[0.82]		[1.28]		[2.27]		[3.86]	

Statistics of the regression models

	AR	UY	UY	AUS	USA
R2	0.8834	0.8702	0.8702	0.9116	0.8986
R^2Set	0.8799	0.8664	0.8664	0.9090	0.8956
F-Stat.	255.3673***	226.1221***	226.1221***	347.9627***	298.8293***

Diagnosis of residues from the regression

		AR	PY	UY	AUS	USA
ADF test		-6.3475***	-6.6365***	-5.0989***	-6.6508***	-5.6183***
JB Test		0.0580ns	43.6302***	23.6343***	19.0372***	18.6751***
LM	F-Stat.	1045.8256***	1040.0796***	1760.5050***	951.0012***	2071.2611***
	X2	485.5554***	484.9544***	534.2091***	474.9311***	546.2258***
ARCH	F-Stat.	775.6455***	592.9761***	988.4657***	777.9621***	2001.3940***
	X2	346.6057***	304.7840***	383.3721***	347.0660***	476.6324***

Note: (β-) accumulated negative variations in prices in the certain market (β+) cumulated positive variations in prices in the certain market (SYM) symmetry in price transmission, (ASYM) asymmetry in price transmission, (DNA) does not apply the test of asymmetry in price transmission, (T-Stat.) T statistics, (F-Stat.) F statistics, (χ2) Chi-square statistics, (ADF) test of unit root increased from Dickey and Fuller, (JB) Jarque-Bera, (LM) LM test for detecting serial autocorrelation, (ARCH) autoregressive conditional heteroscedasticity test to verify the hypothesis of heteroscedasticity of the residues from the regression, (ns) without statistical significance, (***,**,*) was statistically significant at the level of 1%, 5%, and 10%, respectively.

Source: Data from the survey.

After presenting the data from the regression models in Table 8, including a discussion of the estimated coefficients and the results of the asymmetry tests on price transmission between the Brazilian FO and international BCSAW markets, predictive capacity and robustness were assessed on the models based on the adjusted R2 determination coefficient and the residual diagnosis of the regression analysis. Regarding the predictive capacity of the models, it is noteworthy that the adjusted R2 determination coefficients of the regression models were estimated at approximately

0.90, in other words, the set of positive and negative variations in FO prices in Brazilian markets they can explain around 90% of the variations in the prices of BCSAW in international markets.

As for the diagnosis of the residuals of the regression models, it is important to highlight that these were analysed to cover the assumptions of stationarity, normality, homoscedasticity, independence of errors and linearity. Therefore, we opted for the increased tests of Dickey and Fuller (1981), Jarque and Bera (1987), LM for detecting serial autocorrelation and autoregressive conditional heteroscedasticity (ARCH). In short, the results adequately met the assumptions of the regression, except for the normality of the residuals of the regression model, whose BCSAW price in the Argentine market is the dependent variable. Also, several angular coefficients (βetas) of this model were significantly different from the coefficients of the other regression models. However, because the other assumptions of this model have been satisfactorily met, the normality of the residue does not categorically attack its predictive capacity and robustness.

5 FINAL REMARKS

Given the main objective of verifying the interdependence and asymmetry in the transmission of prices between the main Brazilian FO and international BCSAW markets, the research results allow us to conclude that there is an interdependent relationship between FO prices in the Brazilian market and the prices of BCSAW in international markets. However, the direction of causality between them is significant only from FO prices in the main Brazilian markets to BCSAW prices in international markets. The only exception concerns change in the price of BCSAW in the Uruguayan market, which acts as a potential predictor of changes in the price of FO in the state of Rio Grande do Sul.

As for the transmission of prices between markets, the findings showed that there is price transmission between Brazilian and international markets, since the estimated angular coefficients on the negative and positive variations in FO prices in Brazilian markets, and their respective statistics, highlighted that these coefficients act as statistically significant transmitters of BCSAW prices in international markets.

When investigating whether the positive and negative variations in the prices of interacting markets are symmetrically transmitted (i.e., the same magnitude), it was concluded that only the transfer of the FO price in Brazilian markets to the BCSAW price in the Uruguayan market is complete and symmetrical for most Brazilian markets, which suggests a strong integration between these markets. Also, the asymmetry tests pointed to a significant integration between the prices of Brazilian FO and those of Australian and Paraguayan BCSAW, however with asymmetry in the transmission of prices in most cases. In contrast, FO price transfers in Brazilian markets to Argentine and US BCSAW prices showed a lower level of integration between these markets, which is corroborated by the greater asymmetry in transmission and by the more discrepant coefficients when compared to other analysis models.

With regards to the specific objective of investigating the question of dominance in the transmission of FO prices in the Brazilian market to the prices of BCSAW in international markets, an exclusive dominance was not identified, but rather a joint prevalence in the transmission of FO prices in São Paulo and Minas Gerais, in the Southeast region, and Mato Grosso do Sul and Goiás, in the Mid-west region, for BCSAW prices in international markets, with symmetry in a large part of transfers between markets. Also, it was concluded that the other Brazilian markets also act as price transmitters for the international market, but with a lower magnitude of transfer, as could be seen in the values of the estimated angular coefficients and, also, by the evident asymmetry in the transmission of prices between markets, with rare exceptions.

It is expected that the analysis and conclusions of the study can contribute to decision-making about the link agents in the beef and/or beef production chain, making price and risk management

more effective. Furthermore, it is suggested that future studies also analyse the interdependence and asymmetry in the transmission of prices between other agricultural and non-agricultural commodity markets, since the information from these studies can contribute to the improvement of price management in several chains productive sectors and respective economic sectors. Also, it opens the way for future research to use other methods of analysis, which will allow comparisons not only with the results of this study but will also offer the possibility of expanding the field of appreciation, contributing to scientific advancement and decision making in price management and the definition of marketing strategies.

REFERENCES

ALVES, A. F.; TONIN, J. M.; CARRER, M. J. Assimetria de transmissão de preço na comercialização da uva fina de mesa no Paraná: 1997 a 2011. In: **Revista de Economia e Sociologia Rural**, v. 51, n. 3, p. 479-498, jul./set. 2013. Doi: 10.1590/S0103-20032013000300004.

AKAIKE, H. A new look at the statistical model identification. In: **IEEE Transactions on Automatic Control**, v. 19, n. 6, p. 716-723. Doi: 10.1109/TAC.1974.1100705.

ASSOCIAÇÃO BRASILEIRA DAS INDÚSTRIAS EXPORTADORAS DE CARNES - ABIEC. In: **Perfil da pecuária no Brasil**: relatório anual 2018. Disponível em: http://abiec.siteoficial.ws/images/upload/sumario-pt-010217.pdf. Acesso em: 10 dez. 2018.

BAILEY, D.; BRORSEN, B. W. Price asymmetry in spatial fed cattle markets. In: **Western Journal of Agricultural Economics**, v. 14, n. 2, p. 246-252, dec. 1989.

BENDER FILHO, R.; ALVIM, A. M. Análise de transmissão de preços no mercado de carne bovina entre os países do Mercosul e os Estados Unidos. In: **Revista de Economia e Administração**, v. 7, n. 4, p. 402-418, 2008.

CENTRO DE ESTUDOS AVANÇADOS EM ECONOMIA APLICADA - CEPEA. **PIB do agronegócio brasileiro**. Disponível em: https://www.cepea.esalq.usp.br/br/pib-do-agronegocio-brasileiro.aspx. Acesso em: 30 jan. 2019.

CUNHA, D. A.; LIMA, J. E.; BRAGA, M. J. Integração espacial do mercado de boi gordo: uma análise de cointegração com threshold. In: **Análise Econômica**, v. 28, n. 53, p. 251-267, mar. 2010. Doi: 10.22456/2176-5456.8103.

DICKEY, D. A.; FULLER, W. A. Likelihood ratio statistics for autoregressive time series with a unit root. In: **Econometrica**: Journal of the Econometric Society, v. 49, n. 4, p. 1057-1072, jul. 1981. Doi: 10.2307/1912517.

DONG, X.; WALDRON, S.; BROWN, C.; ZHANG, J. Price transmission in regional beef markets: Australia, China and Southeast Asia. In: **Emirates Journal of Food and Agriculture**, p. 99-106, 2018. Doi: 10.9755/ejfa.2018.v30.i2.1601.

GAIO, L. E.; CASTRO JÚNIOR, L. G.; OLIVEIRA, A. B. Causalidade e elasticidade na transmissão de preço do boi gordo entre regiões do Brasil e a bolsa de mercadorias & futuros (BM&F). In: **Organizações Rurais & Agroindustriais**, v. 7, n. 3, p. 282-297, 2005.

GILBERT, C. L.; MORGAN, C. W. Food price volatility. In: **Philosophical Transactions of the Royal Society B: Biological Sciences**, v. 365, n. 1554, p. 3023-3034, 2010. Doi: 10.1098/rstb.2010.0139.

GOODWIN, B. K.; PIGGOTT, N. E. Spatial market integration in the presence of threshold effects. In: **American Journal of Agricultural Economics**, v. 83, n. 2, p. 302-317, 2001. Doi: 10.1111/0002-9092.00157.

GRANGER C. W. J. Investigating causal relations by econometric models and cross-spectral methods. In: **Econometrica**, v. 37, n. 3, p. 424-438, Aug. 1969. Doi: 10.2307/1912791.

GRIFFITH, G. R.; PIGGOTT, N. E. Asymmetry in beef, lamb and pork farm-retail price transmission in Australia. In: **Agricultural Economics**, v. 10, n. 3, p. 307-316, 1994. Doi: 10.1016/0169-5150(94)90031-0.

HOUCK, J. P. An approach to specifying and estimating nonreversible functions. In: **American Journal of Agricultural Economics**, v. 59, n. 3, p. 570-72, Aug. 1977. Doi: 10.2307/1239663.

JOHANSEN, S. Statistical analysis of cointegrating vectors. In: **Journal of Economic Dynamics and Control**, v. 12, n. 2/3, p. 231-254, Jun./Sep. 1988. Doi: 10.1016/0165-1889(88)90041-3.

JOHANSEN, S.; JUSELIUS, K. Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. In: **Oxford Bulletin of Economics and statistics**, v. 52, n. 2, p. 169-210, May. 1990. Doi: 10.1111/j.1468-0084.1990.mp52002003.x.

KINNUCAN, H. W.; FORKER, O. D. Asymmetry in farm-retail price transmission for major dairy products. In: **American Journal of Agricultural Economics**, v. 69, n. 2, p. 285-292, May. 1987. Doi: 10.2307/1242278.

MATTOS, L. B.; LIMA, J. E. Integração espacial de mercados na presença de custos de transação: um estudo para o mercado de boi gordo em Minas Gerais e São Paulo. In: **Revista de Economia e Sociologia Rural**, v. 47, n. 1, p. 249-274, jan./mar. 2009. Doi: 10.1590/S0103-20032009000100009.

OLIVEIRA NETO, O. J.; GARCIA, F. G. Cross hedging do novilho argentino no mercado futuro do boi gordo brasileiro. In: **Custos e @gronegócio on line**, v. 9, n. 2, p. 117-151, abr./jun. 2013.

SILVA NETO, W. A.; PARRÉ, J. L. Assimetria na transmissão de preços: evidências empíricas. In: **Revista Econômica do Nordeste**, v. 43, n. 1, p. 109-123, jan./mar. 2012.

UNITED STATES DEPARTMENT OF AGRICULTURE - USDA. **Data and Statistics**. Disponível em: http://apps.fas.usda.gov/psdonline/psdQuery.aspx. Acesso em: 20 abr. 2019.

WALD, A. Tests of statistical hypothesis concerning several parameters when the number of observations is large. In: **Transactions of the American Mathematical Society,** v. 54, p. 426-482, 1943. Doi: 10.2307/1990256.

ZILLI, J. B.; SILVA, A. F.; CAMPOS, S. K.; COSTA. J. S. Análise da cointegração e causalidade dos preços de boi gordo em diferentes praças nas regiões sudeste e centro-oeste do Brasil. In: **Revista de Economia Agrícola**, v. 55, n. 2, p. 105-119, jul./dez. 2008.