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Article

Vertical and Spatial Price transmission Analysis of the Uruguayan beef chain

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Abstract: The aim of this research is to analyze the market efficiency in terms of price transmission, integration, asymmetry of price transmission, of the Uruguayan beef chain and the international market, in both a spatial and vertical dimension for the period from January 2000 to December 2020. Using cointegration and price transmission analysis techniques based on the Law of One Price, we aim to study the dynamics of the Uruguayan beef chain. Through the Johansen cointegration test, corrected for structural breaks detected by the Bai-Perron test and Augmented Dickey-Fuller (with Breaks), we determined the degree of cointegration between the Uruguayan beef chain and the international market. The results of the Granger Causality test indicated that, in most cases, there is no short-term causality between international market prices (represented by the US Standing steer) and domestic prices. In cases where a causal relationship was identified, VECM models were used to examine market efficiency and estimate the adjustment speed between domestic and international prices (long and short-term adjustment). In parallel, VECM models were created for the meat chains of Brazil and Canada, and the transmission of international prices to these countries was analyzed. The results showed that price transmission in the Uruguayan meat chain is slow, leading to reduced market efficiency. An adjustment speed was observed from 3% to 7.8% of domestic prices to international ones, with a return to long-term equilibrium between 14 and 22 months. The impulse response function (IRF) revealed an asymmetry in the domestic market's responses to international price shocks or impulses and a delayed effect accompanied by a low pass-through coefficient (6-26%). Through the Forecast Error Variance Decomposition and its generalized version (FEVD & GFEVD), it was determined that after a shock, the international market could only explain a limited percentage (0.4-13% (FEVD) and 0.6%-28% (GFEVD)) of the variance of Uruguayan prices in the first six months after the shock, reaching a maximum of between 3.5 to 20% (FEVD) and 4.6 to 36% (GFEVD) twelve months after the initial shock. Contrary to logical and intuitive appreciation, econometric study results indicate that the variance in prices of the Uruguayan meat chain depends more on endogenous shocks than on the repercussions of exogenous shocks from the international market. In contrast, in Brazil and Canada, international prices explain a higher percentage of the price variation in their respective domestic markets. The efficiency in price transmission in these markets was significantly higher, around 30 to 36%, with a return to long-term equilibrium in just 3 months. The results of FEVD & GFEVD indicated that international prices can explain between 34%-54% of the variance in Brazilian and Canadian prices, values significantly higher than the Uruguayan case. In summary, the low causality (Granger), delayed transmission (IRF &VECM), impulse asymmetries (IRF), and the limited influence of international prices on Uruguayan prices (FEVD & GFEVD), compared to other evaluated countries, suggest inefficiencies in the Uruguayan beef chain. Oligopsonic market structures could explain partly this inefficiency. The concentration determined by the emergence of the Minerva Foods economic group could trigger even greater inefficiency, decoupling, and potential asymmetries in price transmission.

Keywords: Price Transmission; Asymmetric Price Transmission; FEVD; GFEVD; VECM; IRF

1. Introduction

The Uruguayan meat market stands as one of the pillars of the country's primary production sector, involving over 44,000 livestock producers and covering more than 13,000,000 hectares (DIEA Yearbook, 2022). The significance of this sector goes beyond Uruguay's borders, as in 2022, the country exported over USD 3.2 billion in meat products, equivalent to 3% of global meat trade (INAC Yearbook, 2022). China remains the main buyer of Uruguayan beef, accounting for 54% of the total export value, while the United States and the European Union accounted for 14% and 12%, respectively (INAC, 2022). In this context, the recent acquisition of three meat processing plants belonging to Marfrig by the Brazilian company Minerva Foods has reignited the debate on competition in the Uruguayan beef sector. Both politically and productively, concerns have been raised about the impending market concentration. The president of the Rural Association of Uruguay, Patricio Cortabarría, stated, "With this transfer, one company would control 42% of the slaughtering capacity, while its immediate competitor would have only 10%." He also warned that the "free competition market would be altered."

Price transmission analysis is a prevalent method for examining market competitive dynamics, and in the context of the Uruguayan meat market, it serves as a valuable tool to scrutinize competition effectiveness and its impact on price relations. The process of transmitting price signals operates both spatially (horizontally) and vertically, affecting economic agents' decisions, resource allocation, and market dynamics. Understanding the extent to which price changes in one place impact prices elsewhere, and over what time frame, can offer valuable insights into market efficiency and functionality.

Price transmission refers to the speed and completeness with which price changes are reflected in different market segments. Two extremes can be identified in this context: At the "Complete Price Transmission" end, price changes propagate efficiently and quickly throughout the market, suggesting a functional market without significant competition restraints. In contrast, "The Absence of Price Transmission" implies that prices do not adjust adequately in response to supply or demand changes, questioning market effectiveness.

The degree of price transmission provides an indication of a market's efficiency and functionality. This concept is vital in economics and has been the subject of extensive theoretical and empirical research to understand how markets operate and how economic forces and governmental policies affect prices. Given the significant export orientation of the Uruguayan beef sector, where approximately 70-75% of the production is destined for foreign markets (Uruguay XXI, 2021), it's valuable to analyze price transmission between international prices and local producer prices.

In perfectly competitive markets, local prices tend to converge with international prices (Law of One Price). However, various factors can hinder this convergence, including transportation costs, exchange rate fluctuations, tariffs, and government regulations. Additionally, differences in product quality and domestic peculiarities like climate and seasonal factors also influence price differences. Market power and imperfect competition structures, like monopolistic and oligopsony's behaviors, transaction costs, etc., can potentially cause temporary delays and asymmetries in price transmission from international to domestic markets.

Through this comprehensive examination, we aim to provide a deeper understanding of the price transmission dynamics of the Uruguayan meat industry and international markets, shedding light on the complexities shaping market behavior and outcomes.

1.1. *Literature Review*

1.1.1. Theories and Empirical Models of Price Transmission

Price transmission, the process through which prices change at different market levels or across geographical locations, plays a pivotal role in market functioning. It is influenced by various factors, including market integration, competition, transaction costs, and policy interventions, among others (von Cramon-Taubadel and Goodwin, 2021). A key theory to understand the dynamics of price transmission is the Law of One Price (LOP). According to this theory, in the absence of trade barriers and transaction costs, and when markets are perfectly competitive, the price of a specific commodity should be the same across all markets when expressed in a common currency. Deviations from the LOP indicate market segmentation, market decoupling, and efficiency issues.

In the context of livestock markets, the Spatial Price Equilibrium (SPE) theory proposed by Takayama and Judge, (1964) extends the LOP to include the spatial distribution of supply and demand and the transportation costs that impact price transmission. In an SPE, the expected prices, taking into account transportation costs, should be the same across different markets. This principle can be applied to the international meat market, where the delivery prices of meat in different countries are influenced by transportation costs and the spatial distribution of supply and demand.

When studying price transmission dynamics, economic models help capture the complexities inherent in these systems. Vector Error Correction Models (VECM) have been widely used in analyzing long-term and short-term relationships between prices in different markets (Engle & Granger, 1987). These models consider both the level and speed at which prices adjust to changes, allowing a comprehensive understanding of market dynamics.

Similarly, the application of threshold autoregressive models (TAR) and momentum-threshold autoregressive models (MTAR) has provided significant insights into the potentially asymmetric nature of price transmission processes (Enders and Siklos, 2001). This means that the rate and extent of price change in response to increases or decreases in the causal price may differ. In their seminal work, Fackler and Goodwin, (2001) outlined the asymmetric nature of price transmission in commodity markets. Rapsomanikis, Hallam, and Conforti, (2013) further explored this asymmetry and proposed its interaction with market integration, demonstrating that imperfect market integration could partially account for asymmetric price transmission. They emphasized that policy interventions, though potentially beneficial, might inadvertently exacerbate price asymmetry.

In the context of the international meat market, empirical studies like those conducted by Barrett & Li, (2002) and Peltzman, (2000) highlight the elasticity of price transmission as a common approach to measuring price transmission. Changes in import and export prices relative to domestic prices provide valuable insights into how price signals are transmitted between countries and how these changes impact suppliers and consumers.

1.1.3. Price Transmission in the Uruguayan Market.

Several studies have explored the various factors that potentially influence price transmission, market efficiency, and power in the Uruguayan beef market. Picerno & Mayid (2001) utilized the Vector Autoregression (VAR) methodology and Johansen Cointegration to understand the relationship between wholesale, producer, and retail prices, determining a relatively efficient market due to high elasticity of response. Similarly, Fossati and Rodriguez (2002) analyzed the integration of domestic and international markets for various commodities, concluding in particular that the beef market is not fully integrated due to unresolved wastage issues.

In an exploration of beef export prices, Alfaro, Salazar & Troncoso (2003) identified a long-term relationship between Uruguayan export prices and benchmark prices in international markets that included Argentina, Australia, Brazil, and the USA. Bedat & Ois (2005) analyzed the determinants of price formation using LOGIT models in Uruguay's livestock replacement market and identified significant impacts of various factors on prices; however, their study did not cover components of transmission and market power. Similarly, Borraz & Rossi (2008) studied the degree of transmission of international beef prices to producer prices in Uruguay. They found that while there is transmission, it's imperfect with an elasticity of 0.76.

Alfaro and Olivera (2009) studied Price Transmission and Market Power in the beef cattle market for slaughter in Uruguay. While they found an elasticity of 0.99 between steer prices and slaughter, this was not the case between steer prices and average export revenue, where elasticity was 0.69. The authors concluded that there might exist oligopsony power on the part of the slaughterhouses but highlighted possible mitigating factors like climate and the domestic market (around 30% of slaughter). Freiria (2018) studied the transmission of prices from export prices to the price perceived by the producer using the Johansen cointegration test and the Vector Error Correction Model (VECM) finding cointegration and a moderate to slow adjustment rate to the long-term equilibrium of 14% (7.2 months). They also investigated the relationship from the industry price to the producer price, finding a moderately slow adjustment rate of 16% (6 months) to return to the long-term equilibrium.

Caputi and Invernizzi (2007) evaluated Uruguay's beef payment system by comparing it with systems in Argentina, Australia, and Brazil. They concluded that the official grading system of INAC does not significantly correlate with the payment systems of private companies. Predominantly, carcass weight determines price payment in Uruguay, a disparity also found in Argentina and Brazil, but not in Australia, which considers multiple aspects in price valuation. Murguía (2007) investigated competition within the Uruguayan meat market, emphasizing the role of the payment system in price formation and analyzing the existence of market power. They attributed significant information asymmetries between producers and slaughterhouses to product characteristics and identified them as the reason for lesser incentives for producers to add value. This study provides extraordinary insight into market power due to asymmetric information, opening new research lines on how to improve information quality and use.

1.2. *Objectives of the Work.*

The central purpose of this research is to carry out a detailed diagnosis of the efficiency of the national meat chain, delving into the interrelation between its various internal links and their interaction with the international market. Our analysis places special emphasis on key aspects such as market cointegration, price transmission along the chain, and any asymmetries that might arise during this process.

A primary objective is to establish causality between domestic and international prices, both in the short and long term. We aim to precisely understand how shocks and impulses originating in the international scenario impact and propagate in the domestic market, and at the same time determine essential characteristics such as symmetry, persistence, and the "pass-through" coefficient of these price shocks. Another interest is to discern to what extent the variance of national prices is influenced or explained by fluctuations in international prices.

Concurrently, a comparative analysis will be conducted with markets from significant producer countries, specifically Brazil and Canada. The goal of this comparison is to evaluate and contrast the efficiency of the Uruguayan market with these other major global players in the realm of meat production.

Finally, based on the empirical evidence gathered in this study, we seek to illustrate the implications that buyer concentration and the emergence of imperfect market structures, such as oligopsony, might have on the efficiency of the meat chain, especially considering current market trends.

2. Methodology

The econometric analysis was conducted following the same procedure for the price transmission analysis as suggested by Barboza Martignone et al. (2022). This measured the asymmetry of transmission as suggested by Barboza Martignone et al. (2023a), and determining connectivity or spillover risk as suggested by Barboza Martignone et al. (2023b). Initially, the order of integration of the time series was determined using the Augmented Dickey–Fuller (ADF) stationarity test (Dickey and Fuller, 1986). As an additional verification measure, the Phillips and Perron stationarity test (1988) was utilized. Structural breaks in these series were then identified using an adapted version of the ADF test (with structural breaks) and the Bai-Perron Multiple breaks points test (Bai and Perron, 1998) to ensure result robustness. Once these breaks were identified and associated with various exogenous shocks, cointegration between the series was examined using the Johansen cointegration test, which determined pairwise cointegration in all series combinations. The procedure was repeated including previously found structural breaks (ADF with breaks, Bai-Perron multiple break test) as exogenous variables to better identify and correct the test, enhancing cointegration equation detection.

The Granger Causality test (Granger, 1969) was incorporated to establish this causal relationship between variables (Dependent/Independent). Granger causality tests are another mechanism allowing us to understand market interrelations, diagnose short-term causality, and discern if international prices affect Uruguayan prices. Similarly, they determine the causality of different cattle categories in the country. According to Engle and Granger (1987), if two series are cointegrated, they can be described in a Vector Error Correction Model (VECM). This model evaluates market efficiency, specifically horizontal price transmission (between international and Uruguayan prices) and vertical transmission among different links in the Uruguayan meat chain. Through the error correction coefficient, alpha (α), it is possible to infer market efficiency levels. When structuring a VECM, short and long-term coefficients can be determined, allowing for price elasticity identification. The significance of these coefficients determines short and long-term price causality.

The VECM provides a simplified representation of price relationships between different markets. Models were constructed to determine efficiency in the transmission of international prices to the Uruguayan market. Models were also created to assess price transmission among different links in the Uruguayan meat chain. Using the previously described methodology, models were developed to analyze price transmission from the international market to other cattle countries, like Brazil and Canada. Additionally, the impulse-response function (IRF) was employed to analyze how prices in the Uruguayan market respond to shocks or disturbances in international markets and those cattle countries mentioned. The IRF observes the temporal dynamics of one variable's response when faced with an impulse in another variable, better elucidating market interdependence and adaptability. The forecast error variance decomposition (FEVD) and its generalized version (GFEVD) were also utilized to break down variations in a time series and attribute them to different shock sources. This helps understand what proportion of price change or variation in the Uruguayan market can be attributed to unexpected changes in other international markets or external events.

Secondary data from various sources were used to bolster results. Referenced sources included INAC (Uruguayan National Meat Institute), IPCV (Institute for the Promotion of Argentine Beef), and FAO (Food Agriculture Organization of the United Nations). The series are distinguished in different groups: Consumer price (Butcheries), Behalf Beef carcass of steer, Behalf Beef carcass of cow, and Behalf cow/ beef carcass (Uruguay). Producer price (Livestock or second-scale payment): Field steer 480 kg, Special standing steer, Standing steer, Fat standing cow, Standing cow, Special standing cows , Heifers 310 standing, Standing heifer Uruguay, Cow on the Hook Uruguay (Second scale), steer on the Hook (Second scale). International Prices: Standing steer Canada, Standing steer United States, Price of the fat steer Brazil. FAO beef index.

The study period was from January 2000 to December 2020. All series were transformed into natural logarithm and differentiated in the first difference. These transformations were essential to remove variation sources, simplify series patterns, and enhance model accuracy. It's necessary to clarify that for most econometric models and tests, there are two statistical assumptions to verify before modeling. The first is series stationarity. This assumes statistical properties, like mean, variance, and autocorrelation structure, don't change over time. The second assumption is that the series are cointegrated;

cointegration implies a long-term equilibrium between series. Although individual series might trend over time, the relationship between them remains constant. This means any deviation from this long-term relationship will be temporary, and eventually, the series will return to their equilibrium relationship. In other words, if the prices of the Uruguayan meat chain are cointegrated with international prices, a long-term relationship between Uruguayan and international prices is expected, allowing short-term deviations but following a long-term equilibrium.

3. Results

Initially, assumptions of stationarity and cointegration of the time price series were verified, using the application of the following tests:

3.1. Dickey-Fuller (ADF), Phillips-Perron Unit root test, ADF with Breaks, and Bai-Perron multiple break test.

Unit root tests (Dickey-Fuller (ADF) and Phillips-Perron) are used to determine if a time series is stationary or not. Non-stationarity is a common characteristic in many economic time series, and, generally, working with stationary series is preferred in modeling and forecasting. The prob (Probability) column < 0.05 indicates whether the null hypothesis can be rejected at the 5% significance level. "Yes" means that the series is stationary.

The results indicate that all original series (Level) are non-stationary but become stationary after transforming them to the first difference. This is critical to continue with the analysis because most econometric models and tests assume that the series are stationary. In practice, to model and forecast these time series, one could use the first difference instead of the original values.

The results from ADF with breaks and Bai-Perron multiple breaks test, and all the structural breaks of the studied series are presented in Appendix 3.

Table 1. ADF Unit root test & Phillis-Perron Unit Root test

			ADF Unit Root test				Phillips-Perron Unit Root test			
			Level		**First difference**		**Level**		**First difference**	
Data source	**Index**	**Time series**	**t-statistic**	**prob < 0.05**	**t-statistic**	**prob < 0.05**	**t-statistic**	**prob < 0.05**	**t-statistic**	**prob < 0.05**
INAC	**C**	Beef half-carcass - Steer	-1.42	No	-11.27	Yes	-1.40	No	-8.65	Yes
	C	Beef half-carcass - Cow	-1.39	No	-11.84	Yes	-1.77	No	-11.40	Yes
	C	Beef half-carcass - Steer/Cow	-1.39	No	-11.48	Yes	-11.40	No	-10.95	Yes
	P	Standing steer Uruguay	-1.48	No	-10.62	Yes	-1.43	No	-8.28	Yes
	P	Standing cow Uruguay	-1.36	No	-10.54	Yes	-1.47	No	-8.35	Yes
	P	Standing heifer	-1.25	No	-10.29	Yes	-1.36	No	-10.55	Yes
IPCVA	**P**	Heifers 310 standing	-2.21	No	-9.04	Yes	-2.07	No	-12.27	Yes
	P	Special standing cows	-2.45	No	-11.46	Yes	-2.09	No	-11.45	Yes
	P	Standing cow Uruguay	-2.38	No	-10.82	Yes	-2.01	No	-10.59	Yes
	P	Cow on the hook	-1.94	No	-9.31	Yes	-1.96	No	-10.59	Yes
	P	Steer on the hook Uruguay	-2.23	No	-9.66	Yes	-2.00	No	-10.68	Yes
	P	Special standing steer Uruguay	-2.47	No	-11.52	Yes	-2.03	No	-12.21	Yes
	P	Field steer 480 Uruguay	-2.24	No	-9.68	Yes	-1.99	No	-1.99	Yes
	I	Standing steer United States	-2.07	No	-15.42	Yes	-1.81	No	-16.42	Yes
	I	Standing steer Canada	-2.45	No	-14.73	Yes	-2.29	No	-2.46	Yes
FAO	**I**	Bovine Price Index FAO	-0.84	No	-19.78	Yes	-0.64	No	-19.95	Yes
BR1	**I**	Standing steer Brazil	-1.05	No	-21.79	Yes	-0.77	No	-23.89	Yes

Test critical values:	1% level	-3.46
	5% level	-2.87
	10% level	-2.57

*MacKinnon (1996) one-sided p-values.

3.2. Johansen Cointegration

The Johansen test is a statistical test used to determine the presence of cointegration among time series. Cointegration refers to a long-term equilibrium relationship between non-stationary time series. If two or more time series are cointegrated, it means that there is a linear combination of them that is stationary, even though the individual series themselves are not. Cointegration is a statistical concept used in econometrics and time series analysis that pertains to the long-term equilibrium relationship between non-stationary time series. Simply put, if two or more time series have a common stochastic trend, they are said to be cointegrated. There exists a long-term equilibrium relationship: although two non-stationary time series might not seem related when viewed individually, there may be a stable long-term relationship between them. This implies that, while both series might have individual trends, the distance between them remains constant over time.

Determining cointegration is crucial for continuing with econometric modeling, given the previously explained assumption. The absence of cointegration between the Uruguayan series and the international price series would suggest that the price dynamics perceived by Uruguayan producers and consumers are largely independent of international price dynamics. In other words, if the results indicate a lack of cointegration between international and Uruguayan prices, it would imply that the processing plants are not transmitting price variations to either the producers or the consumers.

To verify the cointegration, the Johansen test was applied to all combinations of time series in pairs. The result was presented in the cointegration matrix of Table 2.

The primary conclusion was that not all the time series were cointegrated. This lack of cointegration could be justified by structural breaks in the price series, which could cause dislocations and loss of market efficiency. These breaks were previously identified using the ADF tests (with breaks) and the Bai-Perron test. Each structural break was associated with different exogenous factors, as explained earlier. The next step involved repeating the cointegration analysis, this time considering the structural breaks as dummy variables. Through this approach, we managed to identify complete cointegration among all the time series, as shown in Table 3.

Table 2. Johansen Cointegration

Unrestricted Cointegration Rank Test (Trace)

			I Standing steer Canada Novillo Canadá en pie	C Beef half-carcass - Steer Media res Novillo	C Beef half-carcass - Cow Media res Vaca	C Beef half-carcass - Steer/Cow Media res Novillo-Vaca	P Field steer 480 Uruguay Novillo campo 480 Uy	P Special standing steer Uruguay Novillo especial en pie Uy	C Steer on the hook Uruguay Novillo gancho Uy	P Standing steer Uruguay Novillo en Pie	I Standing steer United States Novillo EE. UU. en pie	C Cow on the hook Vaca al gancho Uy	P Standing cow Uruguay Vaca gorda en pie	P Standing cow Vaca en Pie	P Special standing cows Vaca especial en pie	P Heifers 310 standing Vaquillona 310 en pie	P Standing heifer Vaquillona en Pie	P Fat steer Brazil Novillo Gordo Brasil	I Bovine Index FAO Indice Bovino FAO
I	Standing steer Canada	Novillo Canadá en pie		2	2	2	2	2	2	2	1	2	1	2	2	2	2	1	1
C	Beef half-carcass - Steer	Media res Novillo	2		0	0	2	2	2	2	0	2	2	2	2	2	2	0	0
C	Beef half-carcass - Cow	Media res Vaca	2	0		0	2	2	2	2	0	2	2	2	2	2	2	0	0
C	Beef half-carcass - Steer/Cow	Media res Novillo-Vaca	2	0	0		2	2	2	2	0	2	2	2	2	2	2	0	0
P	Field steer 480 Uruguay	Novillo campo 480 Uy	2	2	2	2		1	0	2	0	0	1	2	1	2	1	0	0
P	Special standing steer Uruguay	Novillo especial en pie Uy	2	2	2	2	1		2	2	0	1	1	2	2	1	1	0	0
C	Steer on the hook Uruguay	Novillo gancho Uy	2	2	2	2	0	2		2	0	1	1	2	2	1	0	0	0
P	Standing steer Uruguay	Novillo en Pie	2	2	2	2	2	2	2		0	1	1	0	2	2	2	0	0
I	Standing steer United States	Novillo EE. UU. en pie	1	0	0	0	0	0	0	0		0	0	0	0	0	0	1	1
C	Cow on the hook	Vaca al gancho Uy	2	2	2	2	0	1	1	1	0		0	2	1	1	0	0	0
P	Standing cow Uruguay	Vaca gorda en pie	1	2	2	2	1	1	1	1	0	0		1	1	1	1	0	0
P	Standing cow	Vaca en Pie	2	2	2	2	2	2	2	0	0	2	1		2	2	0	0	0
P	Special standing cows	Vaca especial en pie	2	2	2	2	1	2	2	2	0	1	1	2		1	1	0	0
P	Heifers 310 standing	Vaquillona 310 en pie	2	2	2	2	2	1	1	2	0	1	1	2	1		1	0	0
P	Standing heifer	Vaquillona en Pie	2	2	2	2	1	0	0	2	0	0	1	0	1	1		0	0
P	Fat steer Brazil	Novillo Gordo Brasil	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0		0
I	Bovine Index FAO	Indice Bovino FAO	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

			I Standing steer Canada Novillo Canadá en pie	C Beef half-carcass - Steer Media res Novillo	C Beef half-carcass - Cow Media res Vaca	C Beef half-carcass - Steer/Cow Media res Novillo-Vaca	P Field steer 480 Uruguay Novillo campo 480 Uy	P Special standing steer Uruguay Novillo especial en pie Uy	C Steer on the hook Uruguay Novillo gancho Uy	P Standing steer Uruguay Novillo en Pie	I Standing steer United States Novillo EE. UU. en pie	C Cow on the hook Vaca al gancho Uy	P Standing cow Uruguay Vaca gorda en pie	P Standing cow Vaca en Pie	P Special standing cows Vaca especial en pie	P Heifers 310 standing Vaquillona 310 en pie	P Standing heifer Vaquillona en Pie	P Fat steer Brazil Novillo Gordo Brasil	I Bovine Index FAO Indice Bovino FAO
I	Standing steer Canada	Novillo Canadá en pie		0	0	0	0	2	0	0	1	0	0	2	2	2	0	1	1
C	Beef half-carcass - Steer	Media res Novillo	0		0	0	0	2	2	2	0	0	0	2	2	0	2	0	0
C	Beef half-carcass - Cow	Media res Vaca	0	0		0	2	2	2	2	0	2	2	2	2	2	2	0	0
C	Beef half-carcass - Steer/Cow	Media res Novillo-Vaca	0	0	0		2	2	2	2	0	2	0	2	2	2	2	0	0
P	Field steer 480 Uruguay	Novillo campo 480 Uy	0	0	2	2		1	0	2	0	0	1	2	1	2	1	0	0
P	Special standing steer Uruguay	Novillo especial en pie Uy	2	2	2	2	1		0	2	0	1	1	2	2	1	1	0	0
C	Steer on the hook Uruguay	Novillo gancho Uy	0	2	2	2	0	0		2	0	0	0	2	2	0	0	0	0
P	Standing steer Uruguay	Novillo en Pie	0	2	2	2	2	2	2		0	1	1	0	2	1	0	0	1
I	Standing steer United States	Novillo EE. UU. en pie	1	0	0	0	0	0	0	0		0	0	0	0	0	0	1	0
C	Cow on the hook	Vaca al gancho Uy	0	0	2	2	0	1	0	1	0		0	2	1	1	0	0	0
P	Standing cow Uruguay	Vaca gorda en pie	0	0	2	0	1	1	0	1	0	0		1	1	1	0	0	0
P	Standing cow	Vaca en Pie	2	2	2	2	2	2	2	0	0	2	1		2	2	0	0	0
P	Special standing cows	Vaca especial en pie	2	2	2	2	1	2	2	2	0	1	1	2		1	2	0	0
P	Heifers 310 standing	Vaquillona 310 en pie	2	0	2	2	2	1	0	1	0	1	1	2	1		0	0	0
P	Standing heifer	Vaquillona en Pie	0	2	2	2	1	1	0	0	0	0	0	0	2	0		0	0
P	Fat steer Brazil	Novillo Gordo Brasil	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0		0
I	Bovine Index FAO	Indice Bovino FAO	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	

Table 2. Johansen Cointegration corrected by structural breaks

Unrestricted Cointegration Rank Test (Trace)

			I Standing steer Canada Novillo Canadá en pie	C Beef half-carcass - Steer Media res Novillo	C Beef half-carcass - Cow Media res Vaca	C Beef half-carcass - Steer/Cow Media res Novillo-Vaca	P Field steer 480 Uruguay Novillo campo 480 Uy	P Special standing steer Uruguay Novillo especial en pie Uy	C Steer on the hook Uruguay Novillo gancho Uy	P Standing steer Uruguay Novillo en Pie	I Standing steer United States Novillo EE. UU. en pie	C Cow on the hook Vaca al gancho Uy	P Standing cow Uruguay Vaca gorda en pie	P Standing cow Vaca en Pie	P Special standing cows Vaca especial en pie	P Heifers 310 standing Vaquillona 310 en pie	P Standing heifer Vaquillona en Pie	P Fat steer Brazil Novillo Gordo Brasil	I Bovine Index FAO Indice Bovino FAO
I	Standing steer Canada	Novillo Canadá en pie		1	1	1	2	1	1	1	2	1	2	2	2	2	2	1	1
C	Beef half-carcass - Steer	Media res Novillo	1		1	2	1	2	2	1	1	1	1	2	2	1	1	1	2
C	Beef half-carcass - Cow	Media res Vaca	1	1		2	2	2	2	2	2	2	2	1	2	2	1	2	2
C	Beef half-carcass - Steer/Cow	Media res Novillo-Vaca	1	2	2		1	2	2	1	2	2	2	1	2	2	1	2	1
P	Field steer 480 Uruguay	Novillo campo 480 Uy	2	1	2	1		2	2	2	2	2	2	2	2	2	2	2	2
P	Special standing steer Uruguay	Novillo especial en pie Uy	1	2	2	2	2		1	2	2	2	2	2	2	2	1	2	2
C	Steer on the hook Uruguay	Novillo gancho Uy	1	2	2	2	2	1		2	1	2	2	2	1	2	1	2	2
P	Standing steer Uruguay	Novillo en Pie	1	1	2	1	2	2	2		1	1	2	1	2	1	1	2	2
I	Standing steer United States	Novillo EE. UU. en pie	2	1	2	2	2	2	1	1		1	1	1	2	2	1	2	2
C	Cow on the hook	Vaca al gancho Uy	1	1	2	2	2	2	2	1	1		2	2	2	2	1	2	2
P	Standing cow Uruguay	Vaca gorda en pie	2	1	2	2	2	2	2	2	1	2		2	2	2	1	1	2
P	Standing cow	Vaca en Pie	2	2	1	1	2	2	2	1	1	2	2		2	2	1	1	2
P	Special standing cows	Vaca especial en pie	2	2	2	2	2	2	1	2	2	2	2	2		2	2	1	2
P	Heifers 310 standing	Vaquillona 310 en pie	2	1	2	2	2	2	2	1	2	2	2	2	2		1	1	2
P	Standing heifer	Vaquillona en Pie	2	1	1	1	2	1	1	1	1	1	1	1	2	1		1	2
P	Fat steer Brazil	Novillo Gordo Brasil	1	1	2	2	2	2	2	2	1	2	2	1	1	1	1		1
I	Bovine Index FAO	Indice Bovino FAO	1	2	2	1	2	2	2	2	2	2	2	2	2	2	2	1	

*El numero en el cuadro representa el numero de equaciones de cointegracion (Cointegrating Equations)

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

			I Standing steer Canada Novillo Canadá en pie	C Beef half-carcass - Steer Media res Novillo	C Beef half-carcass - Cow Media res Vaca	C Beef half-carcass - Steer/Cow Media res Novillo-Vaca	P Field steer 480 Uruguay Novillo campo 480 Uy	P Special standing steer Uruguay Novillo especial en pie Uy	C Steer on the hook Uruguay Novillo gancho Uy	P Standing steer Uruguay Novillo en Pie	I Standing steer United States Novillo EE. UU. en pie	C Cow on the hook Vaca al gancho Uy	P Standing cow Uruguay Vaca gorda en pie	P Standing cow Vaca en Pie	P Special standing cows Vaca especial en pie	P Heifers 310 standing Vaquillona 310 en pie	P Standing heifer Vaquillona en Pie	P Fat steer Brazil Novillo Gordo Brasil	I Bovine Index FAO Indice Bovino FAO
I	Standing steer Canada	Novillo Canadá en pie		1	1	1	0	1	1	1	2	1	0	2	2	2	0	1	1
C	Beef half-carcass - Steer	Media res Novillo	1		1	2	1	2	2	1	1	1	1	2	2	1	1	1	2
C	Beef half-carcass - Cow	Media res Vaca	1	1		0	2	2	2	2	0	2	2	1	2	2	1	0	2
C	Beef half-carcass - Steer/Cow	Media res Novillo-Vaca	1	2	0		1	2	2	1	0	2	2	1	2	2	1	0	1
P	Field steer 480 Uruguay	Novillo campo 480 Uy	0	1	2	1		2	2	2	0	2	2	2	2	2	2	0	0
P	Special standing steer Uruguay	Novillo especial en pie Uy	1	2	2	2	2		1	2	2	2	2	2	2	2	1	2	2
C	Steer on the hook Uruguay	Novillo gancho Uy	1	2	2	2	2	1		2	1	0	0	2	1	0	1	0	1
P	Standing steer Uruguay	Novillo en Pie	1	1	2	1	2	2	2		0	1	2	1	2	1	1	2	2
I	Standing steer United States	Novillo EE. UU. en pie	2	1	0	0	0	2	1	0		1	1	1	0	0	1	1	2
C	Cow on the hook	Vaca al gancho Uy	1	1	2	2	2	2	0	1	1		2	2	2	2	1	0	2
P	Standing cow Uruguay	Vaca gorda en pie	0	1	2	2	2	2	0	2	1	2		2	2	2	1	0	2
P	Standing cow	Vaca en Pie	2	2	1	1	2	2	2	1	1	2	2		2	2	1	1	2
P	Special standing cows	Vaca especial en pie	2	2	2	2	2	2	1	2	0	2	2	2		2	2	1	2
P	Heifers 310 standing	Vaquillona 310 en pie	2	1	2	2	2	2	0	1	0	2	2	2	2		1	1	2
P	Standing heifer	Vaquillona en Pie	0	1	1	1	2	1	1	1	0	1	1	1	2	1		1	2
P	Fat steer Brazil	Novillo Gordo Brasil	1	1	0	0	0	2	0	2	1	0	0	1	1	1	1		1
I	Bovine Index FAO	Indice Bovino FAO	1	2	2	1	0	2	0	2	2	2	2	2	2	2	2	1	

3.3. Granger Causality Test

This test was pivotal in this research to understand market price dynamics in terms of causality and allowed us to create a causal map of the market. The basic idea behind Granger causality is as follows: if a time series X "Granger-causes" another series Y, then past values of X should contain information that helps predict Y. In other words, if including past values of X significantly improves the predictions of Y (compared to a model based solely on predicting Y values with only its past values), then it is said that X Granger-causes Y. To carry out this test, it was necessary to determine the optimal lag time where Granger causality operates. For this, VAR (Vector Autoregression) models were created for all combinations of the series in pairs. Using the optimal lag selection criteria (LR: sequentially modified LR statistical test; FPE: Final Prediction Error; AIC: Akaike Information Criterion; SC: Schwarz Information Criterion; HQ: Hannan-Quinn Information Criterion), the optimal lag for each pair combination was determined, ensuring an appropriate specification of the test. Table 4 summarizes the causality interactions based on optimal lag selection.

The international series that showed the most unidirectional causality towards other series was US Standing Steer, this series affects 6 of the 17 studied series and is influenced only by the FAO beef index. However, this series does not have causality relationships with all consumer price series, which could indicate a short-term independence between the consumer price and the international cattle price. Moreover, the price series for cows and heifers on foot show a lack of short-term effects. The Brazilian series generally shows few causality relationships with the Uruguayan series, influencing only the FAO index, as it weighs, among other things, Brazilian beef. The Canadian series is affected both by international and Uruguayan series. This situation could be explained if the Uruguayan series adjusted to international variations faster than the Canadian ones, inducing a spurious causality.

The FAO index is the series that presents the most causality relationships, either being caused, causing, or presenting bidirectional causality. As this series is composed of weights from several international series, it is likely to have indirect causality, meaning it can predict or be predicted without there being actual causality.

Within domestic categories, it's clear that the price of "Media res" and all its variants lead in terms of causality. These series represent the price set by the processing plants for the domestic consumer and is the one that most explains or predicts producer prices. This suggests that, for the most part, producer prices are primarily determined by the prices set by the processing plants and, to a lesser extent, by international prices.

Table 3. Granger Causality test

	C	C	C	P	P	P	P	P	C	I	P	C	P	I	P	P	I
	Beef half-carcass - Steer/Cow	Beef half-carcass - Cow	Cow on the hook	Heifers 310 standing	Standing heifer	Standing cow	Special standing cows	Standing cow Uruguay	Steer on the hook Uruguay	Standing steer United States	Standing steer Uruguay	Beef half-carcass - Steer	Special standing steer Uruguay	Standing steer Canada	Field steer 480 Uruguay	Fat steer Brazil	Bovine Index FAO
Beef half-carcass - Steer/Cow		0	→	→	→	0	→	→	→	0	←	←	→	→	→	→	→
Beef half-carcass - Cow	0		→	→	→	←	→	→	→	0	←	0	→	0	→	→	→
Cow on the hook	←	←		→	↔	↔	0	→	0	←	↔	↔	↔	→	↔	0	→
Heifers 310 standing	←	←	←		←	↔	←	←	←	0	←	←	→	→	→	0	↔
Standing heifer	←	←	↔	→		←	↔	↔	↔	0	↔	←	↔	→	↔	0	→
Standing cow	0	→	↔	↔	→		↔	↔	↔	0	↔	←	↔	→	→	0	→
Special standing cows	←	←	0	→	↔	↔		0	0	0	↔	←	→	→	→	0	↔
Standing cow Uruguay	←	←	←	→	↔	↔	0		←	0	↔	↔	→	→	→	0	↔
Steer on the hook Uruguay	←	←	0	→	↔	↔	0	→		←	↔	←	→	→	→	0	↔
Standing steer United States	0	0	→	0	0	0	0	0	→		0	0	→	→	→	→	←
Standing steer Uruguay	→	→	↔	→	↔	↔	↔	↔	↔	0		←	↔	→	→	0	→
Beef half-carcass - Steer	→	0	↔	→	→	→	→	↔	→	0	→		→	→	→	0	→
Special standing steer Uruguay	←	←	↔	←	↔	↔	←	←	←	←	↔	←		→	0	0	↔
Standing steer Canada	←	0	←	←	←	←	←	←	←	←	←	←	←		←	→	←
Field steer 480 Uruguay	←	←	↔	←	↔	←	←	←	←	←	←	←	0	→		0	↔
Fat steer Brazil	←	←	0	0	0	0	0	0	0	←	0	0	0	←	0		→
Bovine Index FAO	←	←	←	↔	←	←	↔	↔	↔	→	←	←	↔	→	↔	←	

3.4. Vector Error Correction Model (VECM)

It is important to analyze market efficiency and understand to what extent an imperfect market structure affects its efficiency. The Vector Error Correction Model is a tool used to assess such efficiency through price transmission, its adjustment speed, and the implicit causality in short and long-term equations. The outcome of the VECM is a system of equations that incorporate both short and long-term relationships of the series. This methodology was applied in pairs to map individual and combined interactions.

VECMs were created in pairs, based on the Granger causality which identified short-term causality and the direction of the transmission (Dependent Variable/Independent Variable). Each model was properly specified, and several diagnostic tests were conducted to avoid spurious regressions and ensure the reliability of the results. The Wald test was used to find the significance of short and long-term regressors. The normality of the residuals was studied using the Cholesky orthogonalization test (Lutkepohl), and the serial correlations of residuals were checked using the Breusch-Godfrey test (Autocorrelation). Lastly, the heteroscedasticity of the residuals was diagnosed using the Breusch-Pagan-Godfrey test. (see Appendix 2)

4.1 VECM Models

4.1.1 VECM Cow on the Hook UY/US Standing Steer

The first model (Equation 1) represents the price transmission from the US Standing Steer to the Uruguayan Cow on the Hook (Cow on the second scale). The transmission speed, or the adjustment speed to the long-term equilibrium (λ), is around 4.5% per period. This coefficient, which multiplies the error correction term, determines a market efficiency and adjustment speed. This implies that, in the face of an external shock or a deviation in the US Steer price, the Cow on the Hook price would take about 22 months to return to the long-term equilibrium. According to the Wald test, the long and short-term coefficients are significant (excluding the independent term). This suggests that there is indeed causality from international prices (represented by the US Standing Steer) to Uruguayan beef farmer prices (represented by the Cow on the Hook in Uruguay).

Equation 1.

$$\Delta \text{Log Cow on the Hook UY} = -0.045(\text{Log Cow on the Hook UY (t-1)} - 1.36\text{Log US Standing Steer(t-1)} + 0.24) + 0.291\Delta \text{ Cow on the Hook UY(t-1)} - 0.193\Delta \text{ US Standing Steer(t-1)} + 0.0023$$

4.1.2 Steer on the Hook/US Standing Steer

Equation number 2 represents the price transmission from the Steer on the Hook (Steer on the second scale). The speed of adjustment in this case is 4%, indicating that in the face of a price deviation in the international market represented by the US Steer, the Steer on the Hook (Uruguay) would return to its long-term equilibrium in approximately 25 months. These results indicate a slow price transmission speed and low market efficiency. However, according to the Wald test, the coefficients for the short and long-term equations are significant, illustrating a short and long-term causality from international prices to the domestic price.

Equation 2.

$$\Delta \text{LogSteer on the Hook UY} = -0.04(\text{LogSteer on the Hook(t-1)} - 0.73\text{Log US Standing Steer(t-1)} - 0.408) - 0.07\Delta \text{Log Steer on the Hook(t-1)} + 0.16\Delta \text{Log Steer on the Hook(t-2)} - 0.26\Delta \text{Log Steer on the Hook(t-3)} - 0.17\Delta \text{Log Steer on the Hook(t-4)} + 0.17\Delta \text{Log Steer on the Hook(t-5)} - 0.202\Delta \text{Log Steer on the Hook(t-7)} - 0.157\Delta \text{Log US Standing Steer(t-1)}$$

4.1.3 Canadian Steer/US Standing Steer

The equation number 3 represents the price transmission from the US Steer to the Canadian Steer. The Wald test demonstrated that the short-term adjustment coefficients are not significant, hence there is no short-term causality from US prices to Canadian prices. However, the alpha error correction coefficient is negative and significant. This means that the Canadian steer, in the long run, relates to equilibrium with the price of the American steer. The adjustment coefficient is 31%, which denotes a high adjustment speed and high market efficiency. Facing a shock in the international prices of the US steer, the Canadian steer would return to the long-term equilibrium in an approximate period of 3 months.

Equation 3.

$$\Delta LogCanadian\ Steer = -0.31LogCanadian\ Steer(t-1) - 1.04LogUS\ Standing\ Steer(t-1) + 0.107\ )$$

4.1.4 Brazil Fat Steer/ US Standing Steer

Equation 4, corresponding to the VECM, for the Brazilian fat steer (Boi Gordo) indicates a speed of adjustment of 37% (λ) per period. This suggests that, given a deviation from the long-term equilibrium, the price of the Brazilian fat steer would return to its equilibrium relationship in approximately two and a half months. Furthermore, the short-term adjustment coefficients turned out to be statistically significant, implying a short-term causal relationship between the prices of the steer in the US and those of the Brazilian fat steer.

Equation 4.

$$\Delta Log\ Brazil\ Fat\ Steer = -0.37\ (\ Log\ Brazil\ Fat\ Steer(t-1)\ \ -0.18Log\ US\ Standing\ Steer(t-1) - 3.84)\ -0.182\Delta Log\ Brazil\ Fat\ Steer(t-1) + 0.275\Delta\ US\ Standing\ Steer(t-1)$$

4.1.5 Steer on the Hook UY / FAO Index

Equation number 5 represents the VEC model for the Steer on the Hook (dependent variable) and the FAO meat index (independent variable). The model displays statistically significant coefficients for the FAO index, both in the error correction term (long-term adjustment) and in the short-term terms. This indicates a causality relationship from the FAO index to the prices of the Steer on the Hook in both short and long terms. The adjustment speed (lambda) is 7.8% per period, which could be considered a relatively slow adjustment. This speed suggests that, following a shock in the FAO price index, approximately 13 months would be required to return to the long-term equilibrium.

Equation 5.

$$\Delta Log\ Steer\ on\ the\ Hook\ UY = -0.078(\ Log\ Steer\ on\ the\ Hook\ UY\ (t-1) - 0.98*LogIndex\ FAO(t-1) + 3.29\ ) + 0.2\Delta Log\ Steer\ on\ the\ Hook\ UY(t-1)\ \ -0.26\Delta\ Steer\ on\ the\ Hook\ UY(t-3)\ -0.17\Delta\ Steer\ on\ the\ Hook\ UY(t-4) + 0.275\Delta LogIndex\ FAO(t-4)$$

4.1.6 Field Steer 480kg / Beef half-carcass - Steer/Cow

Equation 6 represents a VEC model where the dependent variable is the Field Steer 480kg (UY) and the independent one is the price of the Beef half-carcass - Steer/Cow. There's a moderate speed of transmission (lambda) of 24%. Following an external shock in the Beef half-carcass - Steer/Cow category, the price of the Field Steer 480kg would take around 4 months to return to the long-term equilibrium. Both the long-term and short-term coefficients are statistically significant, indicating a causality of the same nature from the price of the Beef half-carcass - Steer/Cow to the prices of the Field Steer 480kg.

Equation 6.

$$\Delta Log\ Field\ Steer\ 480kg\ \ = -0.24\ Field\ Steer\ 480kg\ (t-1) - 0.93Log\ Beef\ half\text{-}carcass - Steer/Cow\ (t-1) +0.76\ )\ -0.21\Delta Log\ Field\ Steer\ 480kg\ (t-3) + 0.65\Delta Log\ Beef\ half\text{-}carcass - Steer/Cow\ (t-1)$$

4.7 VECM Comparison

On the international stage, Brazil and Canada show a high adjustment speed to price shocks from the international market, evidencing high market efficiency. On the other hand, Uruguay displays low market efficiency, evidenced by an speed of adjustment that ranges between 4.5-7.8%. In other words, following a price shock in the international market (represented by the reference price of the US Standing Steer and the FAO index), Uruguay would take an approximate period of between 13 and 22 months to return to long-term equilibrium. Additionally, domestic efficiency between categories (represented by the relationship between the Half-Carcass Steer Cow and the Standing Steer 480kg UY) would be relatively moderate (λ=24%)(Table 5.)

Table 4. VECM Comparison

Independent Variable	Dependent Variable	Speed of Adjustment (λ)	Estimated time return equilibrium (month)	ECT sig.	Coeff.sig. short term
Standing steer United States	→ Cow on the hook Uruguay	4.5%	22.2	YES	YES
Standing steer United States	→ Steer on the hook Uruguay	4.5%	22.2	YES	YES
Bovine Index FAO	→ Steer on the hook Uruguay	7.8%	12.8	YES	YES
Standing steer United States	→ Standing steer Canada	31%	3.3	YES	No
Standing steer United States	→ Fat steer Brazil	37%	2.7	YES	YES
Beef half-carcass - Steer/Cow	→ Field steer 480 Uruguay	24%	4.16	YES	YES

3.5. Impulse Response Function (IRF)

The Impulse Response Function (IRF) is a tool used to investigate how a variable in a multivariate system reacts to a shock or impulse in another variable of the system, while keeping other disturbances constant. Within the context of a Vector Error Correction Model (VECM), the IRF can illuminate how long-term equilibrium deviations (correction errors) impact the short-term dynamics of endogenous variables.

It is crucial to underscore that IRFs offer conditional responses to specific shocks. Interpretation should be undertaken with caution, particularly in systems where variables might possess intricate relationships and where potential endogeneity concerns exist. The IRF conveys responses to temporary shocks, while the cointegration relation in a VECM provides insights into the long-term equilibrium relationship between the variables. Both aspects, the short-term dynamic adjustments and the long-term equilibrium relationship, are vital for a full comprehension of the relationship between variables within a VECM system.

Figure 1 depicts the impulse response function, and Table 5 showcases the intensity of the shock for each period. A positive unitary shock (equivalent to a standard deviation) in the U.S. Steer leads initially to a decline in the Cow on the How prices. However, this effect reverses around the sixth month, becoming positive from the seventh month and persisting in the following periods. This dynamic might suggest market adjustments or transmission mechanisms that take time to fully unveil. A positive shock of one standard deviation manages to induce an increase of 0.09 standard deviations after 12 months (pass-through). A comparable trend, initially negative and then turning positive from the sixth month, is noticed for the Hooked Steer, and the shock remains even after 12 months. Consequently, this shock can be characterized as asymmetric, of low magnitude, and persistent. Only 0.069SD is transmitted from a 1 SD innovation in the U.S. Steer price.

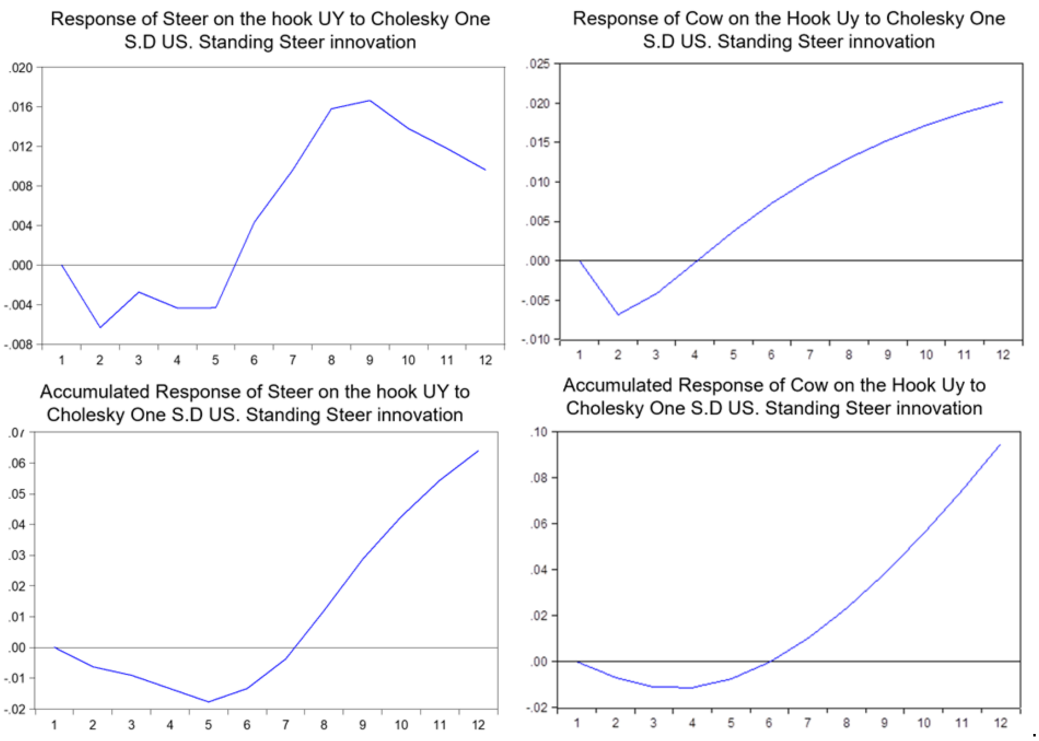
When the Steer on the Hook experiences a shock from the FAO price index, the reaction is symmetric: it's positive from the very first month and hits its peak on the fifth month. Afterwards, it diminishes in intensity and stabilizes up to the twelfth month. In this scenario, a positive shock of one standard deviation results in an accumulated increase of 0.25 SD over 12 months (pass-through). This shock exhibits the greatest magnitude concerning the transmission of international market shocks to the Uruguayan market.

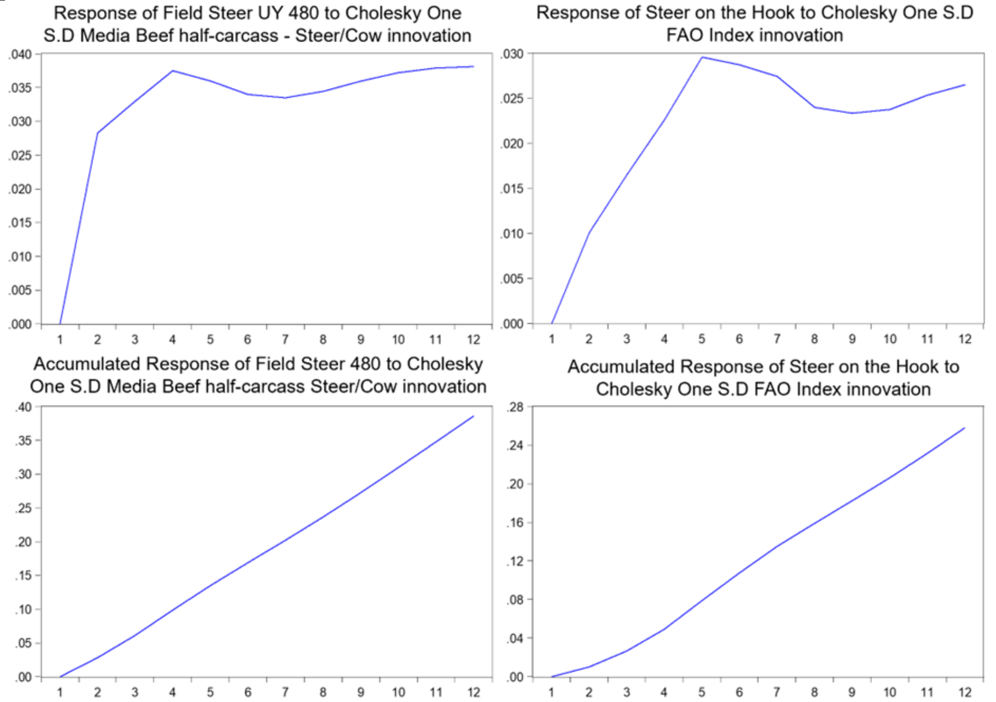
Regarding the pair Field Steer 480kg-Average Cow/Steer Meat, in response to a shock in the average meat category, the Field Steer 480kg responds after the initial period, reaching its peak intensity in the fourth. It then stabilizes and persists beyond 12 months. The pass-through coefficient at 12 months is approximately 0.39. This displays a swifter transmission between different links of the domestic meat chain than between it and international prices.

Pertaining to the shock transmission between the U.S. Steer price and Brazil's Fattened Steer, the response is almost instantaneous from the second period, swiftly attaining its maximum intensity, experiencing a minor decline in the third month. Then, it gradually increases and remains consistent throughout the observed period, with a pass-through coefficient of 30% by its conclusion. As for the shock transmission between the Canadian Steer and the U.S. Steer, there's a swift response from the second period, and the impulse intensity keeps growing with diminishing increments without halting until the end of the evaluated period, reaching an approximate pass-through coefficient of 32% after 12 months.

In summary, Uruguayan categories exhibit a pass-through coefficient (see Table 6) concerning the American Steer, which is significantly lower than that presented by Brazil (30%) or Canada (32%), highlighting an incomplete price transmission. When gauging this shock transmission with the FAO index, the pass-through coefficient rises to 26%, a figure considerably higher than that observed for the U.S. Steer but still below the other analyzed countries.

Figure 1. IRF for VECMs




Response of Field Steer UY 480 to Cholesky One S.D Media Beef half-carcass - Steer/Cow innovation
Response of Steer on the Hook to Cholesky One S.D FAO Index innovation
Accumulated Response of Field Steer 480 to Cholesky One S.D Media Beef half-carcass Steer/Cow innovation
Accumulated Response of Steer on the Hook to Cholesky One S.D FAO Index innovation

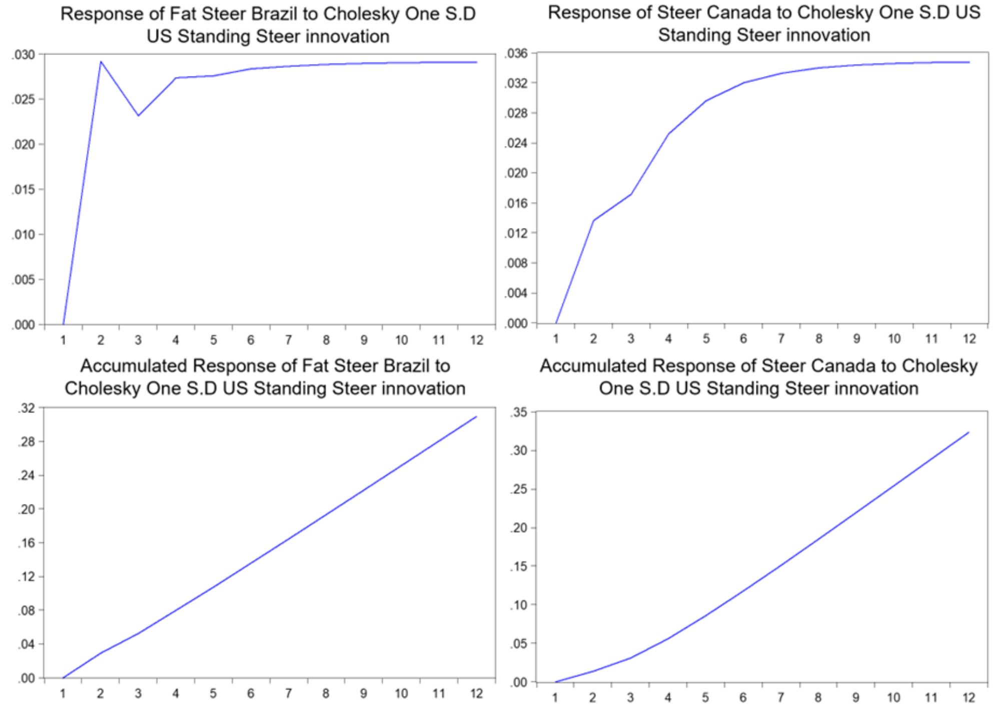

Response of Fat Steer Brazil to Cholesky One S.D US Standing Steer innovation
Response of Steer Canada to Cholesky One S.D US Standing Steer innovation
Accumulated Response of Fat Steer Brazil to Cholesky One S.D US Standing Steer innovation
Accumulated Response of Steer Canada to Cholesky One S.D US Standing Steer innovation

Table 5. Impulse-Response Function (IRF)

Period o	Cholesky Ordering: US.Standing Steer Fat Steer Brazil	Accumalated	Cholesky Ordering: US.Standing Steer Standing Steer Canada	Accumalated	Cholesky Ordering: Beef half-carcass - Steer/Cow Field Steer 480 UY	Accumalated
1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.029212	0.029212	0.013649	0.013649	0.028276	0.028276
3	0.023158	0.052370	0.017150	0.030798	0.032993	0.061269
4	0.027380	0.079749	0.025226	0.056024	0.037521	0.098790
5	0.027606	0.107356	0.029639	0.085663	0.035998	0.134788
6	0.028379	0.135735	0.032032	0.117695	0.033997	0.168785
7	0.028660	0.164395	0.033290	0.150985	0.033495	0.202280
8	0.028876	0.193272	0.034002	0.184987	0.034443	0.236723
9	0.028990	0.222262	0.034390	0.219377	0.035955	0.272677
10	0.029062	0.251324	0.034601	0.253978	0.037222	0.309899
11	0.029103	0.280427	0.034716	0.288693	0.037901	0.347800
12	0.029128	0.309555	0.034778	0.323471	0.038120	0.385920

Period o	Cholesky Ordering: US.Standing Steer Cow in the Hook UY	Accumalated	Cholesky Ordering: US.Standing Steer Steer on the Hook UY	Accumalated	Cholesky Ordering: FAO Index Steer on the Hook UY	Accumalated
1	0.00000	0.00000	0.000000	0.000000	0.000000	0.000000
2	-0.00685	-0.00685	-0.006329	-0.006329	0.010096	0.010096
3	-0.00415	-0.01100	-0.002734	-0.009062	0.016515	0.026611
4	-0.00022	-0.01121	-0.004344	-0.013407	0.022621	0.049233
5	0.00376	-0.00746	-0.004319	-0.017725	0.029595	0.078828
6	0.00732	-0.00014	0.004335	-0.013390	0.028741	0.107568
7	0.01041	0.01027	0.009638	-0.003752	0.027450	0.135019
8	0.01304	0.02331	0.015811	0.012058	0.024008	0.159027
9	0.01529	0.03860	0.016661	0.028720	0.023361	0.182388
10	0.01720	0.05580	0.013818	0.042538	0.023775	0.206163
11	0.01882	0.07462	0.011810	0.054348	0.025361	0.231524
12	0.02019	0.09481	0.009627	0.063975	0.026507	0.258031

Table 6. Pass-through coefficient

Impulse	Pass-through coefficient (12m)	Response
US.Standing Steer	9%	Cow in the Hook UY
US.Standing Steer	6%	Steer on the Hook UY
FAO Index	26%	Steer on the Hook UY
Beef half-carcass - Steer/Cow	39%	Field Steer 480 UY
US.Standing Steer	30%	Fat Steer Brazil
US.Standing Steer	32%	Standing Steer Canada

3.6. Forecast Error Variance Decomposition (FEVD & GFEVD)

3.6.1 Forecast Error Variance Decomposition

The Forecast Error Variance Decomposition (FEVD) is a tool used in the analysis of VAR (Vector Autoregressive) and VECM (Vector Error Correction) models. FEVD allows for the decomposition of the forecast error variance of an endogenous variable into proportions attributable to shocks (or innovations) in each of the system's endogenous variables. In other words, FEVD measures the proportion of forecast variability (forward-looking) of a variable resulting from shocks to other variables in the VECM models (Figure 2 and Table 7).

FEVD can be complemented with Impulse-Response Functions to provide a comprehensive perspective on how shocks to a specific variable affect all other variables in the system over time. On the other hand, GFEVD (Generalized Forecast Error Variance Decomposition) is an extension of the traditional FEVD. While traditional FEVD depends on the order in which variables are placed in the VAR or VECM model (i.e., the Cholesky ordering), GFEVD is order-invariant. This makes it a useful tool when there is no clear theoretical basis regarding the correct order of variables, offering a more generalized perspective.

Cow on the Hook (UY) / U.S. Steer Pair: In the short term (initial periods), shocks in the Cow Hook price are almost solely responsible for fluctuations in its variance prediction. However, as longer periods are considered, the impact of U.S. Steer price shocks on the Cow Hook price becomes increasingly significant, though remaining relatively small even after 12 months, accounting for only 3.5% of the variation. This suggests that while U.S. Steer has some impact on the Cow Hook price, this influence is limited compared to the internal shocks of the Cow on the Hook price.

Steer on the / U.S. Steer Pair: In the short term, internal shocks in Steer on the Hook mainly account for fluctuations in its prediction. Over time, the impact of U.S. Steer price shocks (4.2%) on Steer on the Hook becomes more notable, but remains minor compared to Steer Hook 's own shocks (95.8%). This suggests that while the U.S. Steer price, being an international benchmark, has some influence on the local Hook Steer price, its effect is limited, especially compared to the internal shocks of Steer on the Hook.

In summary, the local price of Steer on the Hook is predominantly influenced by its own shocks in the short and medium term. However, as longer terms are considered, the reference or international price (U.S. Steer) starts having a more significant impact, yet it's still relatively minor compared to internal shocks. This may indicate that the local market is largely autonomous but is not entirely isolated from international price dynamics.

Steer on the Hook / FAO Index: Initially, the Steer on the Hook price is quite autonomous, with most of its variance explained by its own shocks. Yet over time, its internal impact lessens, and the FAO beef index begins to exert a growing influence. By the end of the period, the FAO price index accounts for 20% of the Steer on the Hook variance.

Brazilian Fat Steer / U.S. Steer Pair: Initially, the variance in Brazilian cattle prices is almost entirely determined by its own shocks. However, as time progresses, shocks in the U.S. meat market start explaining an increasing portion of this variance. By the 12th period, over a third (34.05%) of the variance in Brazilian cattle prices is attributed to shocks in the U.S. Steer market. This suggests that while the Brazilian cattle market has strong internal influences, it's also significantly affected by movements in the U.S. meat market as the time horizon extends. This might reflect trade relationships, competition, or simply the globalization of meat markets.

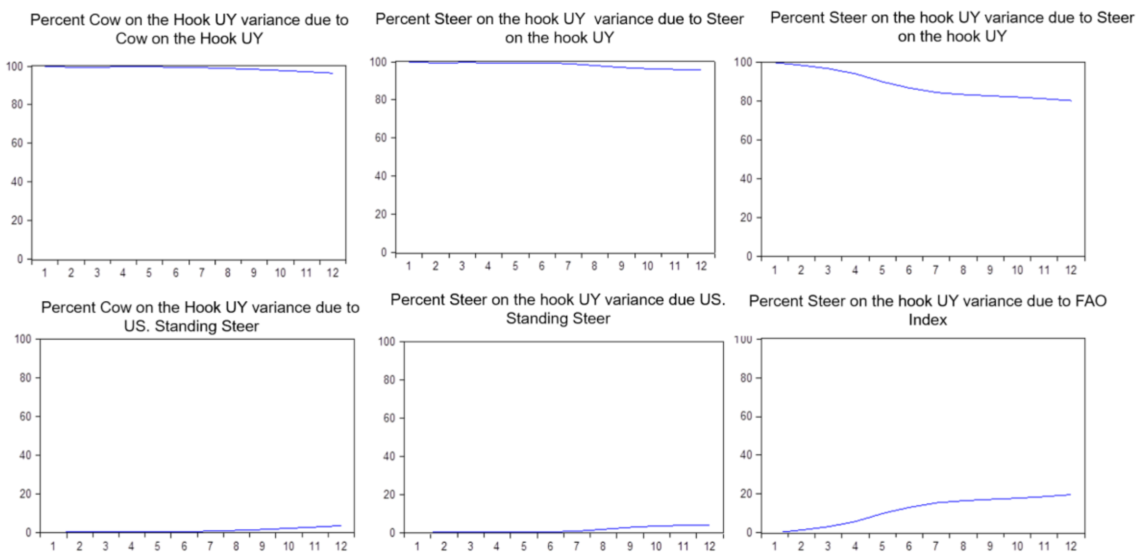
Canadian Steer / U.S. Steer Pair: Initially, the variability in Canadian Steer prices is exclusively influenced by its own shocks. But as time progresses, U.S. Steer market shocks start playing an increasingly significant role. By the 12th period, almost half (45.24%) of the variability in Canadian meat prices is attributed to shocks in the U.S. meat market. This might indicate a strong interdependence between beef markets in Canada and the U.S., which is expected given their geographical proximity and robust trade relations.

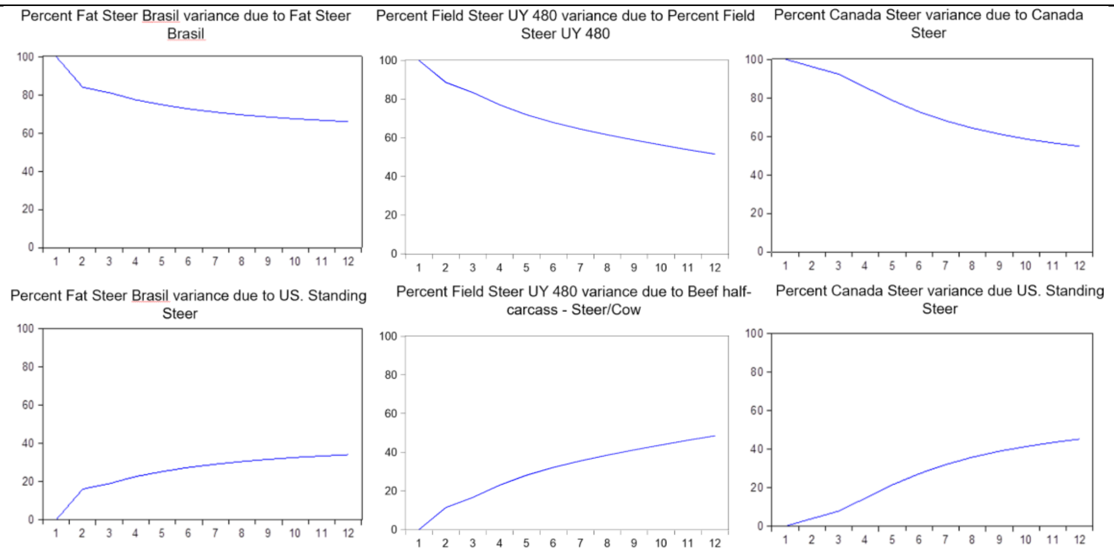
Field Steer 480kg / Behalf Carcass Steer/Cow Pair: At the outset, the variability in the price of Field Steer 480kg is solely determined by its own shocks. However, as time goes by, shocks in the Behalf Carcass Steer/Cow price begin to increasingly influence this variability. By the 12th period, almost half (48.4%) of the Field Steer variability is due to shocks in Behalf Carcass Steer/Cow Carcass. This denotes a strong interaction or dependence between these two variables over time and a high level of connection between the two temporal price series.

Price dynamics in livestock and meat markets vary by regions and comparison pairs. In general, a trend is observed where internal shocks dominate local price fluctuations in the short term. However, as the time horizon extends, shocks in foreign markets or related variables start exerting a growing influence.

For the Cow on the Hook compared to the U.S. Steer, the influence of the U.S. market is modest, accounting for only 3.5% of the variation after 12 months. The Steer on the Hook displays similar resistance to external influences, with the U.S. Steer having a growing yet still limited influence over time. The Steer on the Hook also exhibits increasing dependency on the FAO index, with the latter explaining up to 20% of its variation by the end of the period. In contrast, the Brazilian Fat Steer shows a strong susceptibility to U.S. Steer shocks in the long term, with a third of its variability explained by the U.S. market. This emphasizes the potential interconnection and/or competition between these two major beef producers. Similarly, the Canadian Steer reveals a strong interdependence with the U.S. Steer, expected given their geographical and trade relationship. Lastly, the Field Steer 480kg and the Behalf Steer/Cow Carcass showcase a strong dependency, indicating an intrinsic relationship between them in the domestic market.

***Figure 2**. Forecast Error Variance Decomposition*





3.6.2. GFEVD.

GFEVD stands for Generalized Forecast Error Variance Decomposition. This technique is utilized in time series analysis, notably in econometric models such as VAR (Vector Autoregressive) models. The primary aim of GFEVD is to decompose variations in a time series due to "shocks" or innovations across all variables in a system. Unlike the traditional FEVD (Forecast Error Variance Decomposition), GFEVD is not contingent upon a specific ordering of the variables. This becomes especially beneficial when there is no evident basis for selecting a particular order, or when such ordering might influence result interpretation.

Cow on the Hook (UY) series: At the outset (period 1), the Cow on the Hook (UY) price variance is almost entirely accounted for (99.820%) by its intrinsic shocks. A mere 0.18% is attributed to the US. Steer shocks. However, by period 12, its inherent effect has slightly reduced to 95.4%, while the impact of the US. Steer price has risen to 4.6% (FVED 3.5%).

Steer on the Hook UY price series: It initially exhibits a strong influence from its own shocks (98.764%), with only 1.24% attributed to the US. Steer price in the initial period. By period 12, its inherent impact has waned to 93.3%, while the influence from US. Steer price has surged to 6.7% (FVED 4.5%). The Canadian Steer begins with a predominant intrinsic influence of 87.7% and 12.32% from the US. Steer price. By the 12th month, its intrinsic influence has significantly dwindled to 42.3%, whereas the influence of the US Steer price has soared to 57.7% (FEVD 45%). The Brazilian Steer price initiates with an inherent impact of 81.9% and 18.0% from the US. Steer price. In period 12, its inherent impact registers at 46.2%, and the influence from the US. Steer price stands at 53.8% (FEVD 34%).

Steer on the Hook (UY) price vs. FAO beef index: This commences with a dominance of intrinsic shocks, accounting for 91.6%, and merely 8.3% attributed to the FAO index. By period 12, its intrinsic effect has descended to 64.6%, while the FAO index's influence has augmented to 35.7% (FEVD 19%). The decomposition of the Field Steer 480kg (UY) variable begins with a pronounced intrinsic impact of 72.7% and 27% from the Behalf carcass Cow/Steer price. By period 12, its intrinsic effect has tapered to 34.702%, while the Behalf carcass Cow/Steer influence has surged to 65.3% (FEVD 48%).

As time progresses (from periods 1 to 12), the majority of the time series showcase a decrease in variability explained by their own shocks and a rise in the influence from the listed variables. This suggests growing interdependencies among these time series as lengthier temporal horizons are considered. It's particularly evident in the case of the Canadian Steer and the Brazilian Steer prices, where shocks from the US. Steer price become equally or more influential than their intrinsic shocks. This isn't observed in the case of Uruguay, where international price influences are limited (3.5-4.5% to US. Steer and 35.7% to the FAO index). The linkage within the Uruguayan domestic market, represented by Behalf carcass Cow/Steer / Field Steer 480kg, emerged as the most significant among the studied cases, underscoring a high level of dependency and interconnectedness with the domestic market. In conclusion, GFEVD results showcased a higher magnitude of immediate impact and at the period's end across all examined cases when contrasted with the FEVD technique.

Table 7. FEVD

FEVD

Cholesky Ordering:

Periodo	S.E.	**Cow on the hook**	Standing steer U.S	S.E.	**Novillo Gancho UY**	Standing steer U.S	S.E.	**Standing steer Canada**	Standing steer U.S	S.E.	**Fat steer Brasil**	Standing steer U.S	S.E.	**Steer on the hook UY**	Bovine Index FAO	S.E.	**Field steer 480 Uruguay**	Beef half-carcass - Steer/Cow
1	0.059370	100.0000	0.000000	0.052725	100.0000	0.000000	0.051671	100.0000	0.000000	0.053659	100.0000	0.000000	0.053469	100.0000	0.000000	0.053128	100.0000	0.000000
2	0.095140	99.48237	0.517634	0.083015	99.41884	0.581161	0.068862	96.07142	3.928580	0.072921	83.95260	16.04740	0.083356	98.53310	1.466895	0.083799	88.61460	11.38540
3	0.120971	99.56197	0.438029	0.110177	99.60850	0.391497	0.078238	92.15177	7.848228	0.085756	81.10430	18.89570	0.108589	96.82246	3.177539	0.106710	83.41903	16.58097
4	0.140446	99.67479	0.325212	0.124890	99.57430	0.425697	0.087348	85.36331	14.63669	0.097183	77.34907	22.65093	0.123085	94.14907	5.850928	0.119881	77.06674	22.93326
5	0.155825	99.67769	0.322308	0.131656	99.50933	0.490671	0.096443	78.54956	21.45044	0.107158	74.73285	25.26715	0.132886	90.02030	9.979698	0.127849	71.90800	28.09200
6	0.168487	99.53559	0.464409	0.136961	99.44641	0.553588	0.105214	72.70793	27.29207	0.116276	72.58332	27.41668	0.140186	86.82941	13.17059	0.133714	67.85378	32.14622
7	0.179278	99.25296	0.747039	0.143466	99.04415	0.955847	0.113542	67.96810	32.03190	0.124697	70.87870	29.12130	0.146907	84.51531	15.48469	0.139129	64.51140	35.48860
8	0.188736	98.84832	1.151677	0.149808	98.00952	1.990483	0.121434	64.15631	35.84369	0.132576	69.49318	30.50682	0.153793	83.43405	16.56595	0.144788	61.57243	38.42757
9	0.197214	98.34416	1.655840	0.155348	96.99870	3.001297	0.128916	61.07980	38.92020	0.140006	68.35741	31.64259	0.160897	82.75666	17.24334	0.150728	58.85148	41.14852
10	0.204951	97.76273	2.237275	0.159053	96.38212	3.617885	0.136024	58.57067	41.42933	0.147057	67.41378	32.58622	0.167821	82.14307	17.85693	0.156664	56.26608	43.73392
11	0.212115	97.12427	2.875730	0.161953	95.97876	4.021240	0.142798	56.49807	43.50193	0.153784	66.62069	33.37931	0.174141	81.29462	18.70538	0.162352	53.82681	46.17319
12	0.218825	96.44639	3.553614	0.164984	95.78467	4.215335	0.149276	54.76360	45.23640	0.160228	65.94657	34.05343	0.179868	80.29528	19.70472	0.167723	51.57060	48.42940

Table 8. GFEVD

Generalized FEVD (Lanne and Nyberg 2016)
Variance decomposition of

Period	**Cow on the hook UY**	Standing steer U.S.	**Steer on the hook UY**	Standing steer U.S.	**Standing steer Canada**	Standing steer U.S.	**Fat steer Brasil**	Standing steer U.S.	**Steer on the hook UY**	Bovine Index FAO	**Field steer 480 UY**	Beef half-carcass - Steer/Cow
1	99.820	0.180	98.764	1.236	87.676	12.324	81.932	18.068	91.629	8.371	72.680	27.320
2	99.778	0.222	99.484	0.516	78.980	21.020	63.070	36.930	86.315	13.685	58.269	41.731
3	99.856	0.144	99.469	0.531	73.724	26.276	59.224	40.776	82.664	17.336	53.573	46.427
4	99.853	0.147	99.554	0.446	67.069	32.931	55.667	44.333	78.899	21.101	50.433	49.567
5	99.701	0.299	99.598	0.402	61.136	38.864	53.325	46.675	74.473	25.527	47.718	52.282
6	99.392	0.608	99.245	0.755	56.339	43.661	51.514	48.486	71.290	28.710	45.227	54.773
7	98.943	1.057	98.338	1.662	52.561	47.439	50.118	49.882	68.969	31.031	42.980	57.020
8	98.379	1.621	96.692	3.308	49.570	50.430	49.007	50.993	67.732	32.268	40.967	59.033
9	97.725	2.275	95.187	4.813	47.176	52.824	48.108	51.892	66.889	33.111	39.162	60.838
10	97.005	2.995	94.276	5.724	45.232	54.768	47.367	52.633	66.144	33.856	37.533	62.467
11	96.238	3.762	93.668	6.332	43.630	56.370	46.749	53.251	65.241	34.759	36.053	63.947
12	95.443	4.557	93.312	6.688	42.292	57.708	46.226	53.774	64.258	35.742	34.702	65.298

4. Discussion

It is worth noting that not all time series initially demonstrated cointegration. This absence might be explained by interventions resulting from structural breaks in the price series. Such breaks, capable of causing price misalignments and reducing market efficiency, were identified through the ADF tests (with breaks) and the Bai-Perron (Multiple break test). Each structural break was associated with certain exogenous factors. After considering these breaks as exogenous variables in Johansen's cointegration test, the test was recalibrated. Subsequently, the cointegration analysis was repeated, now integrating the structural breaks as dummy variables. This methodology allowed us to confirm complete cointegration among all time series, as evidenced in Table 3. Johansen's test confirmed that all series were cointegrated, suggesting a long-term equilibrium relationship. Short-term deviations may arise, but they eventually converge in the long run. However, in the initial analysis, not all series showed cointegration. International series, by themselves, and domestic market series displayed cointegration without requiring adjustments. However, when trying to jointly analyze domestic and international series, in most cases, it was necessary to incorporate exogenous variables (structural breaks) in the form of dummy variables to reject the null hypothesis of no cointegration.

These structural breaks can have multiple causes, such as changes in government policy or regulations, significant economic events like financial crises, recessions, or economic booms. They can also be influenced by technological innovations, introducing new ways of operating, or drastic shifts in consumer preferences reflected as structural breaks. Moreover, in imperfectly competitive market structures, as in the case of oligopsonies where there are few buyers with market power, breaks in time series can manifest as they consolidate their position. Companies with significant power can influence prices and quantities, demonstrating market power. Another cause may be the asymmetry in price transmission, situations where wholesale and retail prices do not adjust proportionally. These asymmetries, stemming from market power, frictions, regulations, and disruptions in the supply chain, might manifest as structural breaks.

A crucial aspect when analyzing the dynamics of the Uruguayan and international meat chain is the Granger causality test to understand price causality. The Uruguayan meat chain mainly exports its production. Given the characteristics of this market (efficient and competitive) and the market share that Uruguay has in this context, Uruguay positions itself as a price taker in the international market and does not have enough market power to influence international prices.

If we assume that international prices influence the Uruguayan domestic price, we can deduce that it is the international price that exerts causality on the Uruguayan market. As references for the international market, the price of the U.S Steer (Choice.) and the FAO beef price index were taken. In an efficient market, these prices should be adequately reflected throughout the Uruguayan meat chain.

However, in practice, this causality is limited: in the case of the US Steer, it only influences three out of the twelve domestic series (Steer on the Hook, Cow on the Hook, and Special Standing Steer). While Granger's causality should not be interpreted in the traditional sense but rather statistically as the ability of one series to predict another, there are nine domestic series that cannot be anticipated by the international price. This means that the US Steer price is not a good indicator of domestic meat prices.

This trend suggests that, in the short term, international prices have minimal influence on domestic ones. This is not the case for Brazil and Canada, where the causality of US prices proved to be significant. Among domestic series, the consumer price leads in terms of causality. This price, primarily set by slaughterhouses, is the main indicator of producer prices. According to Granger causality, producer prices are more influenced by slaughterhouses than by international prices.

The selection of the category "Behalf carcass Steer/ Cow" as the primary transmitter of domestic prices and volatility to the "Field Steer 480 UY" category aligns with the dynamic proposed by both the Granger causality test (where the former causes the latter) and the connectedness index (the former is a net transmitter of volatility, and the latter is a net recipient of the same). This suggests that the Vector Error Correction Model (VECM) might accurately reflect the relationship between the two categories. This model empirically confirmed the existence of a long and short-term relationship between the series, with a moderate adjustment speed and a return time to long-term equilibrium of around 4 months.

The VECM models showing price transmission from the international market (using the "US. Steer" price and the "FAO beef price index" as references) revealed low price transmission (Sharma, 2002), adjusting by 4.5% to 7.8% per period and a total return to long-term equilibrium of 12 to 22 months. This dynamic indicates relatively low market efficiency. If we contrast the efficiency of the Uruguayan market, measured in adjustment speed (α), with markets like Canada (31%) and Brazil (37%), the limited efficiency of the national market becomes evident. While one could argue that Canada, being part of the T-MEC or USMCA (formerly NAFTA), has access to differential meat prices and more efficient price transmission, justifying this high efficiency in the case of Brazil is more complex.

The results of the impulse response function (IRF), which examines how a price series over time reacts to a shock in another within a multivariate system, were revealing. This function, applied to the Vector Error Correction Model (VECM), analyzed how deviations from long-term equilibrium affect short-term dynamics. The findings for shocks in the US market showed a delay asymmetry in the impulse, a persistence in external shocks, but a very low pass-through coefficient (6% to 9% for UY Steer on the Hook and Cow on the Hook respectively). However, the IRF for an impulse in the FAO bovine price index indicates a positive, symmetrical, and persistent response over time (12 months) with a pass-through coefficient of 26%. This might imply that the primary reference for international prices for the Uruguayan market is precisely the FAO index, with moderate transmission efficiency and a pass-through coefficient more in line with other markets. In the Canadian and Brazilian markets, shocks generate more intense short-term responses, persistent over time, with a larger magnitude pass-through coefficient (Canada 32%, Brazil 30%). These figures suggest superior efficiency in these two markets compared to the Uruguayan one and more comprehensive price transmission. Additionally, in the domestic market, a shock in "Average Weight" causes a reaction in "Field Steer 480kg" that persists beyond 12 months, with a pass-through coefficient of 0.39, indicating faster transmission within the domestic meat chain compared to international prices.

The technique known by its acronym as GFEVD (Generalized Forecast Error Variance Decomposition) was employed to discern the relative influence of different prices and shocks on the variance of prices in various markets. Time series analyses suggest that, over time, the variability in their prices is less defined by their shocks and more influenced by external shocks. For instance, in the series of Canadian Steer and Brazilian Steer, the shocks from the US Steer price come to have similar or even superior influence to internal shocks. On the other hand, in Uruguay, the influence of international prices is limited (3.5-4.5% for US Steer and 35.7% for the FAO index). The pair of series Behalf carcass Steer Cow/Field Steer 480 from Uruguay stands out for its high domestic connectivity, with 77% of the variability in the former explained by shocks in the latter, and 67% in reverse. These results highlight the robust domestic integration between these categories, suggesting a domestic market more influenced by internal factors than external ones.

In summary, while international prices, especially the US Steer, serve as a reference for the sector, their actual influence on domestic prices is limited. The Uruguayan beef market is characterized by high interconnectivity between cattle categories. Shocks in one category can influence many others. This dynamic underscores the importance of viewing the system holistically. Domestic prices, particularly those set by slaughterhouses, play a significant role in influencing producer prices. The results also indicate that the efficiency of the Uruguayan market is lower than that of Brazil and Canada in terms of price transmission. Future studies might further explore these dynamics and their implications for traders, producers, and policy makers.

Freiria (2018) empirically demonstrated price cointegration from export to producer prices (Johansen cointegration). He studied price transmission from the export price to the price perceived by the producer (VECM), finding a moderate to slow adjustment speed of 14% (7.2 months) to return to long-term equilibrium. Contrary to Freiria (2018), this research found transmission speeds ranging from 4.5% to 7.8% from the Novillo US price and the FAO index to national prices. This trend makes sense as the closer the measurement of price transmission is to the supply chain, the greater the efficiency. For instance, considering vertical transmission between the industry and the producer, Freiria (2018) achieved a moderate adjustment speed of 16%, while our research confirms 24%, within the range considered a moderate adjustment speed. However, when measuring price transmission on a horizontal scale from the international market, we lose efficiency. Freiria (2018) estimated an efficiency of 14% for the export price, while this research confirmed even lower efficiency at a more distant market level (4.5%-7.8%), such as the prices of Novillo US or the FAO index.

Globally, there exists a system of trade blocs, bilateral agreements, and trade barriers (tariffs, quotas) that could affect this price transmission between the international reference price and the Uruguayan producer price. In other words, price transmission could also be impacted by the number and quality of trade agreements each country reaches. Economic liberalism tends to increase market efficiency; hence this could be crucial in enhancing market efficiency.

5. Policy Implications

Analysis of the Dynamics of the Uruguayan Meat Market and International Comparative.

Policy and Regulatory Management: Given that structural breaks can arise from changes in policy or regulation, policymakers should tread carefully and anticipate the long-term consequences of any changes that might affect market co-integration and efficiency. The limited efficiency of the Uruguayan market, in comparison to markets like Canada and Brazil, suggests a need to revisit trade policies and economic strategies that could bolster the competitiveness and efficiency of the Uruguayan meat market. If market power or oligopsony is behind structural breaks or potential asymmetries in price transmission from the international market to producers and consumers, it is crucial to introduce regulatory measures to ensure fair competition and prevent price manipulation. There should be an allowance for the export of live cattle, linking domestic prices with international ones. This would incentivize the meatpacking industry to enhance its efficiency and competitiveness, aligning with the prices acknowledged in international markets. This would enhance market efficiency, speed up price transmission, and eliminate possible asymmetries in transmission.

Findings and Recommendations: The results suggest that the Uruguayan meat market has relatively low efficiency, which might necessitate policy interventions to enhance transparency, minimize frictions, and speed up the rate at which prices adjust. Developing a composite price transmission indicator could be viable for monitoring overall market efficiency and transparency within the meat supply chain. Given that Uruguay predominantly operates as a price-taker in the international market, the country should diversify its export markets, seek to negotiate free trade agreements or other types of bilateral agreements to improve its connection with the international market, strengthen trade ties, and enhance its integration with other markets.

6. Conclusion

The present research provides a detailed look into the complexity and intricacies of time series related to the Uruguayan meat market and its relationship with international markets. Initially, not all the series studied using the Johansen Cointegration method showed cointegration. This situation could be due to interventions arising from structural breaks, many of which are linked to exogenous factors. By adapting the methodology to account for these breaks, full cointegration between series was identified. However, when contrasting the domestic series with international ones, clear differences emerge, especially in how the Uruguayan series react to international price changes. While some domestic series display strong interdependence, their response to price shocks in international markets is limited in terms of slow adjustment speed to long-term equilibrium (VECM). Notably, they highlight how prices in Uruguay are more influenced by internal factors than by international price shocks, unlike markets such as the Canadian and Brazilian ones.. Additionally, the impulse response function shows how the Uruguayan market reacts to specific shocks, revealing persistent latency and asymmetry in its response to international price shocks. Moreover, only between 6-26% of the impulse is effectively transmitted within a 12-month period. This reduced efficiency of the Uruguayan market, compared to markets like the Canadian or Brazilian, poses challenges and opportunities to enhance its reactivity and efficiency. The Forecast Error Variance Decomposition (FEVD) and the Generalized Forecast Error Variance Decomposition (GFVED) indicate that, over time, price variability is less influenced by own shocks and more by external shocks from benchmark international markets. For instance, in the Canada Steer and Brazil Steer series, price shocks from the US Steer have as much or more influence than internal shocks. Yet, in Uruguay, the influence of international prices is minimal.

The derived policy implications suggest allowing livestock export to enhance market efficiency, cointegration, and competitiveness of the meatpacking industry. Understanding these mechanisms and dynamics is vital for informed decision-making in the sector, especially in a globalized context where market interconnection is constant. This study significantly contributes to that understanding, offering essential tools and insights for managers, investors, and policymakers in the Uruguayan meat sector. The challenge lies in leveraging these findings to optimize market performance and bolster Uruguay's position on the international stage.

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