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Conference Article

Vertical and spatial analysis of the Uruguayan beef chain: Asymmetry in price transmission, and Risk of Spillover

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Abstract: The objective of this study is to examine the potential asymmetric price transmission and the risk of spillover effects between the Uruguayan beef sector and the international market. This analysis is conducted both spatially and vertically for the time frame spanning January 2000 to December 2020. In this context, the international market is depicted through the prices of the US Steer and the FAO Bovine Price Index, while the Uruguayan market is represented by prices at the farmer and industrial levels. Additionally, to provide comparative insights, prices of fat steer from Canada and Brazil were included. Employing cointegration analysis techniques and examining price transmission via the Law of One Price, this research delves into the dynamics of the Uruguayan beef chain. Through connectedness analysis based on VAR models (Diebold and Yilmaz, 2012) it was determined that the average dynamic connectedness for the domestic market system stood at 85%. This indicates a highly volatile system with a strong propensity for spillover risks, akin to a domino effect. The findings show that within the national market, the "Standing Steer UY" category and the industrial price for "Steer Half carcass" are the primary drivers, acting as net transmitters. Further analysis using TAR models revealed that cointegration in the price series, both domestic and international, was evident only after correcting for structural breaks. These adjustments unveiled a nonlinear price transmission that is predominantly symmetrical. However, an alternative model (MTAR) identified an asymmetry in price transmission between the international and Uruguayan markets. It showed that domestic prices tended to decrease more steeply in response to international price increases. In comparison, the Brazilian and Canadian markets displayed a higher degree of cointegration without the necessity for adjustments due to structural breaks, and they did not exhibit any asymmetry in price transmission. This asymmetry in the Uruguayan market may be partially attributed to imperfect market structures, tariff, and quotas.

Keywords: Price Transmission; Asymmetric Price Transmission; Connectedness Index; Risk of Spillover; MTAR; TAR

1. Introduction

The beef industry in Uruguay is a cornerstone of the nation's agricultural sector, engaging over 44,000 farmers and spanning upwards of 13 million hectares, according to the 2022 DIEA Yearbook. Its impact extends internationally, as evidenced by meat exports surpassing USD 3.2 billion in 2022—making up 3% of the worldwide meat trade, as reported by INAC in the same year. The sale of three Marfrig facilities (Slaughterhouses) to Brazil's Minerva Foods has sparked renewed concerns over market concentration in Uruguay's beef industry, raising questions about competitive practices both from a political and productive standpoint. In this scenario Minerva Foods will have a 42% market share of the slaughtering capacity, dwarfing its closest competitor at 10%, potentially distorting the competitive landscape.

Analyzing how prices are transmitted throughout the market is a key method for understanding competitive dynamics, and in Uruguay's beef industry, it's especially useful for assessing competition and its price effects. Price signals are conveyed horizontally across different geographical markets and vertically through the supply chain, influencing business decisions, resource distribution, and overall market movement. Discerning the ripple effect of price fluctuations across various regions and their temporal impact offers insights into the market's operational efficiency.

In a fully competitive market, local prices should align with international standards (Law of One Price). Yet, this ideal is often complicated by factors such as transport costs, currency value shifts, trade tariffs, regulations, and quality and domestic distinctions like weather and seasonal impacts. Furthermore, market control and non-competitive practices, including monopolistic and oligopolistic behaviors, and transaction costs can introduce an asymmetric price transmission resulting in global loss of market efficiency and economic welfare.

In order to study a potential asymmetric price transmission, the application of threshold autoregressive models (TAR) and momentum-threshold autoregressive models (MTAR) has provided significant insights into the 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, *et al.,* (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.

1.1. Price Transmission in the Uruguayan Beef Market

Research on the Uruguayan beef market has delved into elements that may impact the flow of price information, overall market efficiency, and the balance of market power. In their study, Picerno & Mayid (2001) applied Vector Autoregression (VAR) and Johansen Cointegration techniques to assess connections between the levels of wholesale, producer, and retail beef prices, deducing that the market exhibits considerable efficiency as evidenced by the strong elastic response in prices. Fossati and Rodriguez (2002), when examining the integration of local and global markets for assorted commodities, observed that, specifically, the beef market shows signs of incomplete integration, largely due to persisting inefficiencies in the handling of byproducts.

Investigating export pricing for beef, Alfaro *et al*., (2003) noted a persistent link between the prices of Uruguayan exports and those of pivotal international players, including Argentina, Australia, Brazil, and the United States. Meanwhile, Bedat and Ois (2005) scrutinized the factors influencing price formation in Uruguay's cattle trade market using LOGIT models, pinpointing several influential factors, yet not extending their research to aspects of price transmission or market power.

The examination of price transmission and market influence within Uruguay's beef sector by Alfaro and Olivera (2009) revealed a high elasticity between steer prices and slaughtering costs, pegged at 0.99. However, the link between steer prices and average export returns was weaker, with an elasticity of 0.69. The researchers proposed the existence of imperfect market structures (oligopolistic) leverage by slaughterhouses but also acknowledged the counteracting forces of climatic variations and the size of the domestic market, which accounts for approximately 30% of total slaughters. Freiria (2018) used Johansen cointegration tests and Vector Error Correction Models (VECM) to investigate the relationship between export prices and producer prices, noting a moderate to slow adjustment speed toward long-term equilibrium, taking about 7.2 months for complete adjustment. The study also reviewed the price relay from the industry to the producer, being this a slightly faster, yet still within the moderate speed thresholds, (adjustment pace of 6 months to return to equilibrium).

Barboza Martignone et al., (2023) examined the dynamics and efficacy of the Uruguayan beef sector with regard price transmission, market integration with the international market, scrutinizing both spatial and vertical interactions from January 2000 through December 2020. Employing techniques such as cointegration and price transmission analysis based in the Law of One Price. The authors applied the Johansen cointegration test, modified to account for structural breaks identified by the Bai-Perron and Augmented Dickey-Fuller tests (with breaks), this work assesses the extent of cointegration linking the Uruguayan beef sector with the international cattle market. The Granger Causality test, showed a general lack of short term price causality from the international market (exemplified by the US Standing steer) with those in the domestic setting. When a causal linkage did surface, the authors used Vector Error Correction Models (VECM) to analyse the market efficiency and measure the speed of adjustment of the domestic prices with international benchmarks, evaluating both short and long-term adjustments.

According to the before mentioned authors the Uruguayan meat industry suffers from slow speed and incomplete price transmission, which in turn undermines market efficiency. The speed of adjustment from the domestic prices to their international counterparts was noted to range from 3% to 7.8%, with a return to long-term equilibrium occurring within 14 to 22 months. The impulse response function (IRF) showed an unsymmetrical reaction from the domestic market to shifts in international prices, characterized by delayed response and a minimal pass-through rate (ranging from 6-26%).

The authors utilized the Forecast Error Variance Decomposition and its generalized form (FEVD & GFEVD) found that international market disturbances could only account for a marginal proportion (0.4-13% for FEVD and 0.6%-28% for GFEVD) of the fluctuation in Uruguayan prices in the six months post-shock, with a peak influence ranging from 3.5 to 20% (FEVD) and 4.6 to 36% (GFEVD) a year after the shock. In a turn away from expected outcomes, the study suggests that the price variance within Uruguay’s meat industry is more closely tied to internal shocks than to external influences from the international market. This contrasts with findings from Brazil and Canada, where international price movements accounted for a more substantial portion of domestic price variations. These markets showed significantly greater efficiency in price transmission, with about 30 to 36% efficiency and a restoration to long-term equilibrium occurring within merely 3 months. FEVD & GFEVD results indicated that international prices accounted for 34%-54% of the price variance in the Brazilian and Canadian markets, a stark contrast to the Uruguayan scenario.

Barboza Martignone et al., (2023), pointed that lack of causality (Granger), slow and incomplete price transmission (IRF & VECM), uneven responses to price impulses (IRF), and minimal impact of international prices on Uruguay's market (FEVD & GFEVD) relative to other scrutinized nations point to inefficiencies within the Uruguayan beef industry. Suggesting that the presence of oligopsonistic market configurations might partially elucidate this inefficiency.

1.2. Objectives of the Work.

The central purpose of this research is to carry out a detailed diagnosis of any potential asymmetries in price transmission y vertical and horizontal dimension for the Uruguayan market, supply chain and for the Brazilian and Canadian markets.

In a vertical dimension, the objective is to analyze any trace of asymmetry at any point in the Uruguayan supply chain. In a spatial (horizontal) dimension, the aim is to examine potential asymmetrical price transmission from the international market to the Uruguayan market. Concurrently, the same methodology will be applied to the cases of Canada and Brazil

In a complementary dimension, this research aims to integrate fundamental concepts such as connectedness and the risk of 'spillover'. This integration will allow for a deeper understanding of the interconnection and dynamics existing between different market categories. Moreover, we aspire to identify which national categories are leaders, i.e., transmitters of volatility, and which ones act more as price market followers or receptors.

Ultimately, this study aims to highlight the potential effects that a concentration of purchasers and the development of flawed market frameworks, such as oligopsony's, may have on the performance of the meat distribution network, considering the trends currently observed in the market.

2. Methodology

This study is an essential component of a broader series of investigations conducted by the same authors. The initial chapter, "Vertical and Spatial Price Transmission Analysis of the Uruguayan Beef Chain" (Barboza Martignone et al., 2023), primarily explored price transmission and market efficiency employing the Johansen cointegration technique. It also utilized Granger causality to identify directional influences among variables and proposed various Vector Error Correction Models (VECM) to measure the rate of adjustment to long-term equilibria and assess market efficiency. Impulse Response Functions (IRF) were applied to analyse the effects of changes in international prices and calculate the pass-through coefficient. Furthermore, the study leveraged Forecast Variance Error Decomposition (FVED) and Generalized Forecast Error Variance Decomposition (GFEVD) to determine the extent to which international prices can explain the dynamics of beef prices in Uruguay, Brazil, and Canada.

In conjunction with the frameworks suggested by the authors, this research proposed the study of potential asymmetries through Momentum Threshold Autoregressive (MTAR) and Threshold Autoregressive (TAR) models. The assumptions of stationarity and cointegration have already been validated by the prior research.

The first step is to identify and assess non-linearity and the possibility of asymmetric adjustments in price transmission. Threshold Autoregressive (TAR) and Momentum Threshold Autoregressive (MTAR) models were used, and cointegration under asymmetry by Enders and Siklos (2001). To ensure robustness and result interpretation, the Connectedness index or risk spillover by Diebold and Yilmaz (2012), based on generalized forecast errors (GFVED) derived from a Vector Autoregressive model (VAR), was used.

To support the findings of this study, secondary data were collected from a range of sources. These included the INAC (Uruguayan National Meat Institute), IPCV (Institute for the Promotion of Argentine Beef), and the FAO (Food and Agriculture Organization of the United Nations). The data were categorized into several segments: retail prices (butcher shops), wholesale prices for halves of beef carcasses from steers and cows, and the relative prices of cow and beef carcasses in Uruguay. On the production side, prices were examined for various categories of cattle, such as field steers 480 kg, prime and regular steers, fat and standard cows, premium cows, 310 kg heifers, and half carcass of cows and steers in Uruguay. Internationally, prices were considered for steers in Canada and the USA, and for fat steers in Brazil, along with the FAO's beef price index.

All the data series underwent a logarithmic transformation and first-difference processing to eliminate sources of variability, streamline their patterns, and improve the precision of our model. Structural breaks from Barboza Martignone *et al.*, (2023) were used as dummy variables for correcting the cointegration under asymmetry by Enders and Siklos (2001).

2.1. TAR

The TAR (Threshold Autoregressive) model is a nonlinear model type used to describe a time series. It's an extension of the AR (autoregressive) model that allows for the capture of nonlinear dynamics in the data. The basic idea behind the TAR model is that the process generating a time series may vary depending on whether a variable, termed the "threshold variable", exceeds a certain "threshold" value. In other words, the model exhibits different behaviors or regimes based on whether the threshold variable is above or below this value. This model can be employed to capture asymmetries in price transmission. Such asymmetries are particularly prevalent in financial and commodity markets, where prices might respond differently to positive and negative shocks or varying market conditions. Asymmetry in price transmission refers to situations where prices react more intensely or rapidly to shocks in one direction than the other. A commonly cited example in economic literature is the "stairs and elevator" phenomenon: commodity prices may slowly rise over an extended period (like climbing stairs) but can rapidly drop in response to bad news (as if taking an elevator down).

This is how the TAR model captures such asymmetries: Threshold definition: In the context of price transmission, the "threshold" in a TAR model usually represents a specific level of price change or a particular margin. If the price change exceeds this threshold, one regime is activated, and if not, another one is.

Differentiated regimes: The asymmetries arise because price behavior differs between these regimes. For instance, there might be one regime where prices respond rapidly to rises in a reference price (e.g., an international price) and another where prices react slowly to reductions in the same price. In our case, it's to determine whether domestic prices perceived by agricultural producers adjust more rapidly to international price declines than to their increases.

Using TAR models to analyze price transmission is advantageous because they can identify and quantify these asymmetries, which traditional linear models do not capture. Such insights can be invaluable for crafting economic policies, understanding market dynamics, and making more accurate forecasts. For instance, comprehending the asymmetry in price transmission can be vital for producers seeking to hedge against price risks or regulators aiming to ensure fair play in the market.

The MTAR (Momentum Threshold Autoregressive model) is an extension of the TAR (Threshold Autoregressive model). While the TAR focuses on nonlinearity based on a threshold value, the MTAR captures asymmetries in adjustments towards the long-term equilibrium based on the sign of the equilibrium deviation. The MTAR is primarily used in the context of cointegration to model nonlinear relationships that might have asymmetric adjustments. These models are beneficial when it is suspected that the variables in a cointegrated relationship adjust differently depending on whether the equilibrium deviation is positive or negative, and especially in situations where it is anticipated that the variables adjust more swiftly in one direction than another. For instance, there might be situations where the variables adjust quickly when they are above their equilibrium relationship, but more slowly when they are below. This can have significant implications for economic policy. For example, if it's found that a particular market adjusts swiftly to negative shocks but slowly to positive shocks, it might suggest the need for policies that specifically address asymmetries in economic adjustment. This methodology also requires performing the cointegration test on asymmetry, as proposed by Enders and Silko (2001), considering the possibility of asymmetries in error correction.

Before elaborating on TAR and MTAR models, it's essential to validate cointegration under asymmetry. Enders and Siklos (2001) introduced an extension of Engle and Granger's cointegration test to consider the potential for asymmetries in error correction. Traditional cointegration tests assume adjustments to long-term imbalances (i.e., deviations from the cointegrating equilibrium) are linear. However, in many economic contexts, this adjustment can be asymmetric. For example, slaughterhouses might react more swiftly to a decline in international prices than to their increase.

2.2. Connectedness Index or Risk of Spillover

Diebold and Yilmaz (2012) introduced "spillover" measures in a volatility context, linking the idea to the interconnection between economic variables or financial assets. The term "spillover" denotes the effect one variable or system might have on another. In the financial realm, the concern often revolves around how a shock in one market or asset can influence other markets or assets. Specifically, in our context, we're interested in how the price of one category of cattle might affect another. The Connectivity Index provides a numerical representation of how much shocks "spillover" between different variables in a market. A high connectivity index suggests strong interlinkages between the variables or assets under consideration, indicating that a shock in one could significantly impact others. The average dynamic connectivity between variables or assets is not static; it can shift over time, especially in response to major economic events or policy changes.

By observing dynamic connectivity, we gain a nuanced understanding of how interrelationships among variables or assets evolve over time. The technique by Diebold and Yilmaz (2012) offers tools to quantify and visualize the interconnections between different variables or assets within a system. These tools are particularly valuable in risk management, as they assist in identifying potential sources of instability in a financial or economic system. In this specific case, our focus will be on determining connectivity among different categories in the domestic market.

3. Results

3.1 TAR (Threshold Autoregressive)

3.1.1. TAR Cow on the Hook UY/US. Steer

For the Cow Hook/US. Steer pair, cointegration regarding asymmetry required the use of several structural breaks as dummy variables. This suggests that there were several points in time where significant events or changes affected the relationship between Cow Hook/U.S Steer. The inclusion of these dummy variables increases the model's complexity and the risk of overfitting—a model that may fit the data sample too closely and may not generalize well outside of it. Interpretations become more complex with the inclusion of many terms, which can also reduce the model's degrees of freedom, affecting the efficiency of the estimations. The need to include multiple dummy variables in a cointegration model could indicate problems in the cointegrated relationship between the variables of interest. After correcting for the structural breaks, the T-max and F-joint values suggest the series are cointegrated in an non lineal relation. The F-equal test verifies the equality of coefficients above and below the threshold. The F-statistic value is 0.001217, while the critical value at the 5% level is 2.67. As the F-statistic value is lower than the critical value, the null hypothesis is not rejected, indicating there's no statistically significant evidence of asymmetry in the adjustment towards equilibrium. In other words, the adjustment rate is the same whether Cow on the Hook is above or below its equilibrium level concerning U.S. Steer (Table 8.

3.1.2. TAR Steer on the Hook UY/U.S. Steer

In this case, to find cointegration (previously found in Johansen Cointegration), it was necessary to correct the series for structural breaks. This again suggests cointegration issues between local and international prices. The T-max value of -2.7 is less than the critical value of -2.11. This means we reject the null hypothesis of linearity in favor of a nonlinear alternative. For F-joint (Phi), the value of 12.95 exceeds the critical value of 5.9, rejecting the null hypothesis that there is no cointegration in the presence of nonlinearity. There is evidence that the variables are cointegrated. Lastly, F-equal with a value of 0.94, which is less than the critical value of 2.67, suggests we do not reject the null hypothesis of symmetry. There's not enough statistical evidence to claim an asymmetric relationship between the variables above and below the threshold (Table 1).

3.1.3. Steer on the Hook UY/FAO Index

For this pair, it was necessary to correct the cointegration for 7 structural breaks, suggesting cointegration issues between the variables. The T-max value of -2.34 is greater (in absolute terms) than the critical value of -2.13, leading to the rejection of the null hypothesis of linearity in favor of a nonlinear alternative. The F-joint (Phi) value of 6.16, which is greater than the critical value (5.91), suggests cointegration between the variables, even accounting for nonlinearity. The F-equal value of 0.106, significantly less than the critical value of 2.86, means we do not reject the null hypothesis of symmetry. There isn't enough statistical evidence to claim an asymmetric relationship between the variables above and below the threshold (Table 1).

3.1.4. TAR Standing Steer Canada/U.S. Steer

For this pair, there was no need to include any exogenous variable in the form of a dummy variable, indicating that the series have no cointegration issues. The T-max value of -4.08, which is less than the critical value of -2.10, means we reject the null hypothesis of linearity in favor of a nonlinear relationship. There's evidence of nonlinearity in the relationship between the variables. The F-joint (Phi) value of 21.37, greater than the critical value of 5.78, implies cointegration between the variables, suggesting a long-term equilibrium relationship between them, even when considering nonlinearity. The F-equal value of 0.76, which is less than the critical value of 2.59, means we do not reject the null hypothesis of symmetry. There isn't enough statistical evidence to claim an asymmetric relationship between the variables above and below the threshold. In conclusion, there's evidence of a nonlinear relationship between the two variables, but not enough evidence to claim the relationship is asymmetric. Moreover, there's evidence that the two variables are cointegrated, indicating a long-term equilibrium relationship between them, accounting for nonlinearity (Table 1).

3.1.5. TAR Fat Steer Brazil/U.S. Steer

For this pair, it was also unnecessary to include exogenous variables to correct the cointegration, suggesting no cointegration issues between the Brazilian and international markets. The F-joint (Phi) value was estimated at 16.4, being greater than the critical value of 5.8, indicating cointegration between the variables and a long-term equilibrium relationship, considering nonlinearity. The T-max value of -4.29, which is less than the critical value of -2.13, suggests rejecting the null hypothesis of linearity in favor of a nonlinear alternative. The F-equal value of 0.098, less than the critical value of 2.69, implies we do not reject the null hypothesis of symmetry. There isn't enough statistical evidence to claim an asymmetric relationship between the variables above and below the threshold. In summary, there's evidence of a nonlinear relationship between the two variables. There's not enough evidence to claim the relationship is asymmetric. Moreover, there's evidence of cointegration between the two variables, suggesting a long-term equilibrium relationship between them, accounting for nonlinearity (Table 1).

3.1.6. TAR Field Steer 480kg UY/Behalf carcass Cow/Steer.

This pair of series did not require correction through exogenous (dummy) variables, indicating that domestic prices are strongly cointegrated. The T-max value of -2.57, less than the critical value of -2.12, indicates rejecting the null hypothesis of linearity in favor of a nonlinear relationship. There's evidence of nonlinearity in the equilibrium relationship between the variables. The F-joint (Phi) value of 9.2, greater than the critical value of 5.83, suggests cointegration between the variables, indicating a long-term equilibrium relationship between them, considering nonlinearity. The F-equal value of 1.25, less than the critical value of 2.78, implies we do not reject the null hypothesis of symmetry. There isn't enough statistical evidence to claim an asymmetric relationship between the variables above and below the threshold. There's evidence of a nonlinear relationship between the two variables, but not enough evidence to claim the relationship is asymmetric (Table 1).

3.1.7. Conclusion

In conclusion, the results showed no evidence of asymmetry in transmission: the transmission is nonlinear and symmetrical. The need to correct Uruguayan series with various combinations of dummy variables suggests cointegration problems between them and international prices. The Uruguayan series were the only ones requiring this technique to show significant cointegration. It's important to note that the presence of dummy variables doesn't necessarily mean the presence of asymmetry; they indicate changes in the series, which can alter cointegration analysis results.

Table 1. TAR

Cow on the Hook UY ← US. Steer
Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01
Method: Threshold
Lags (determined by data): 1

Variable	Coefficient	Std. Error
Above Threshold	-0.119588	0.048144
Below Threshold	-0.121875	0.045797
Differenced Residuals(t-1)	0.109194	0.072832

Threshold value (tau):	0	
F-equal:	0.001217	(2.669123)*
T-max value:	-2.483964	(-2.109788)*
F-joint (Phi):	6.447969	(5.893286)*

**Simulated critical values for 5% significance level.*
Number of simulations: 10000

Steer on the Hook UY ← US. Steer
Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01 B2009M03 B2010M07
Method: Threshold
Lags (determined by data): 2

Variable	Coefficient	Std. Error
Above Threshold	-0.261251	0.057433
Below Threshold	-0.180052	0.066687
Differenced Residuals(t-1)	0.104843	0.072286
Differenced Residuals(t-2)	0.15956	0.072188

Threshold value (tau):	0	
F-equal:	0.93808	(2.667848)*
T-max value:	-2.699958	(-2.113175)*
F-joint (Phi):	12.9541	(5.881446)*

*Simulated critical values for 5% significance level.
Number of simulations: 10000

Standing Steer Canada ← US. Steer
Exogenous variable(s): None
Method: Threshold
Lags (determined by data): 1

Variable	Coefficient	Std. Error
Above Threshold	-0.353936	0.08685
Below Threshold	-0.452223	0.081814
Differenced Residuals(t-1)	-0.037986	0.071536

Threshold value (tau):	0	
F-equal:	0.76172	(2.593925)*
T-max value:	-4.075274	(-2.106066)*
F-joint (Phi):	21.37275	(5.784175)*

**Simulated critical values for 5% significance level.*
Number of simulations: 10000

Fat Steer Brazil ← US. Steer
Exogenous variable(s): None
Method: Threshold
Lags (determined by data): 2

Variable	Coefficient	Std. Error
Above Threshold	-0.533457	0.124291
Below Threshold	-0.577555	0.116218
Differenced Residuals(t-1)	-0.22237	0.093295
Differenced Residuals(t-2)	-0.027842	0.074317

Threshold value (tau):	0	
F-equal:	0.098325	(2.690866)*
T-max value:	-4.292017	(-2.124939)*
F-joint (Phi):	16.44271	(5.847389)*

**Simulated critical values for 5% significance level.*
Number of simulations: 10000

Steer on the Hook UY ← Indice FAO
Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01 B2009M03 B2010M07
Method: Threshold
Lags (determined by data): 6

Variable	Coefficient	Std. Error
Above Threshold	-0.182277	0.059935
Below Threshold	-0.156243	0.066686
Differenced Residuals(t-1)	0.038897	0.078672
Differenced Residuals(t-2)	0.158004	0.078562
Differenced Residuals(t-3)	-0.090773	0.076987

Threshold value (tau):	0	
F-equal:	0.105899	(2.856813)*
T-max value:	-2.342959	(-2.132284)*
F-joint (Phi):	6.167539	(5.916353)*

**Simulated critical values for 5% significance level.*
Number of simulations: 10000

Field Steer 480UY ← Behalf carcass Cow/Steer
Exogenous variable(s): None
Method: Threshold
Lags (determined by data): 4

Variable	Coefficient	Std. Error
Above Threshold	-0.293036	0.075508
Below Threshold	-0.188158	0.073131
Differenced Residuals(t-1)	-0.008103	0.078564
Differenced Residuals(t-2)	0.06507	0.076499
Differenced Residuals(t-3)	0.022082	0.075397

Threshold value (tau):	0	
F-equal:	1.249843	(2.780409)*
T-max value:	-2.5729	(-2.119185)*
F-joint (Phi):	9.18825	(5.833315)*

**Simulated critical values for 5% significance level.*
Number of simulations: 10000

3.2. MTAR (Momentum Threshold Autoregressive model)

3.2.1. MTAR Cow on the Hook / US. Steer

This model did not require the correction of cointegration by including exogenous variables. The F-joint (Phi) value of 22.2 is greater than 6.14 (5% critical value), indicating the rejection of the null hypothesis of no cointegration. Meanwhile, the T-max value of -6.07 is less than -1.95 (5% critical value), suggesting the rejection of the null hypothesis of linearity, implying that the series maintain a nonlinear relationship. The F-equal value of 1.58 does not reject the null hypothesis that the coefficients above the threshold (Above Threshold) and below the threshold (Below Threshold) (with a simulated critical value of 3.7) are statistically different, suggesting that the corrections towards equilibrium are not different when deviations are positive or negative. In other words, the series adjustment is symmetrical.

3.2.2. MTAR Steer on Hook / US Steer

For this pair, there are divergent results stemming from correcting the lack of cointegration through various combinations of structural breaks, resulting in two sub-models.

3.2.2.1. First Sub model:

For this model (Table 2), the F-joint (Phi) value is greater than the critical value, so the null hypothesis of no cointegration is rejected. The T-max value of -2.84 is more negative than the critical value of -1.96, rejecting the null hypothesis in favor of the alternative of nonlinearity, showing the nonlinear relationship between the series. The F-equal value of 0.22 is much less than the critical value of 3.82; therefore, it is not possible to reject the null hypothesis, indicating there is no significant asymmetry between the two regimes. In summary, the series are nonlinearly cointegrated, but there is no evidence of asymmetry in price transmission.

3.2.2.2. Second Sub model:

In the model presented in Table 3, it was tested if the adjustment loads in the regression were the same between two regimes, specifically, above and below a certain threshold. The value found was approximately 4.12, while the reference value to notice a significant difference was 3.82. Since the value found was higher, it was concluded that the adjustment loads were different for the two regimes. This suggests an asymmetry in how international market prices affect the domestic market. Furthermore, by analyzing the coefficients, it was observed that prices adjusted more quickly when they decreased (with a "Below Threshold" coefficient of approximately -0.31) than when they increased (with an "Above Threshold" coefficient of approximately -0.14).

The observed T-max value is -2.31 and the critical value is -1.997; the observed value is more negative than the critical value, meaning we reject the null hypothesis of linearity and conclude there is evidence of asymmetry. The observed F-joint (Phi) value is 14.75 and the critical value is 6.30. Since the observed value is greater than the critical value, we reject the null hypothesis and conclude that the series are cointegrated.

In summary, according to the results, the price series of the Steer on the hook and US Steer have different adjustment loads depending on whether they are above or below the threshold, show evidence of asymmetry, and are cointegrated. This adjustment is greater when prices drop than when they rise. In other words, prices correct more rapidly (in magnitude) when they are below the equilibrium level compared to when they are above it. Therefore, prices for cattle producers effectively "fall faster than they rise" according to this model.

3.2.2.3. Conclusion sub models

- Sub model 1:
  Coefficient for "Above Threshold": -0.142886.
  Coefficient for "Below Threshold": -0.176144.
  F-equal: 0.223544 < 3.828432 (not significant).
  F-joint (Phi): 8.989051 > 6.307636 (significant).

- Sub model 2:
  Additional Exogenous variables: B2010M07.
  Coefficient for "Above Threshold": -0.142295.
  Coefficient for "Below Threshold": -0.308390.
  F-equal: 4.120181 > 3.817080 (significant).
  F-joint (Phi): 14.756550 > 6.307768 (significant).

In Model 2, the difference between the "Above Threshold" and "Below Threshold" coefficients is more pronounced. This indicates a more noticeable asymmetry in price adjustment, as mentioned earlier. This difference in Model 1 is less pronounced. The F-equal value is significant, suggesting there is asymmetry in the adjustment. In Model 1, the F-equal value is not significant, suggesting there's no evidence of adjustment asymmetry. The exogenous variables in Model 2 include an additional exogenous variable (Structural Break, B2010M07). Depending on the economic or market context, this variable might be relevant.

The F-joint values in both models are significant, indicating cointegration in both cases. However, the value is higher in Model 2. This model (2) shows clearer asymmetry in the adjustment, and the F-equal test is significant. Moreover, the higher F-joint value suggests a stronger cointegrated relationship.

The introduction of many dummy variables, especially in time series with a monthly frequency, could generate the risk of multicollinearity. This means that some of these variables might be correlated with each other, which could inflate the variances of the estimators and make some variables appear insignificant when they actually are, and could also affect the degrees of freedom. However, in large samples, this effect may be less concerning. Lastly, if too many variables are included in relation to the number of observations, the model may suffer from overfitting. This means that the model could be too specific for the sample in question and might not generalize well outside of that sample.

3.2.3. MTAR Steer on the Hook / FAO Index

In the Steer on the Hook / FAO Index pair, it was necessary to use dummy variables to correct for cointegration. However, cointegration between the series could not be found. As the observed F-joint (Phi) value (6.11) is lower across all combinations with different exogenous variables than the critical value (6.24) at a 5% significance level, we cannot reject the null hypothesis. This suggests the series might not be cointegrated. The observed F-equal value (0.00024) is much smaller than the critical value (3.69); therefore, we cannot reject the null hypothesis of symmetry at a 5% significance level. Comparing the observed T-max value (-2.7) to the critical value (-1.97), we reject the null hypothesis, suggesting the series is non-linear (Table 9).

3.2.4. Standing Steer Canada / US. Steer

For this model, there was no need to use exogenous variables to correct the cointegration test, indicating a more significant and stable relationship between Canadian cattle and the international reference price. This is reflected as the observed F-joint (Phi) value (20.9) is much higher than the critical value (6.45) at a 5% significance level, meaning we reject the null hypothesis and conclude that the series are strongly cointegrated. The observed T-max value is -4.69, greater than the critical value (-1.98), so we can reject the null hypothesis, indicating the series is non-linear. The observed F-equal value (0.0015) is much smaller than the critical value (3.788340); therefore, we cannot reject the null hypothesis of symmetry at a 5% significance level. The transmission between the international reference price and the Canadian price is symmetrical (Table 9).

3.2.5. Fat Steer Brazil / US Steer

For this pair, there was no need to use exogenous variables to correct for cointegration. The T-max value is more extreme than the critical value (-1.99), suggesting the series is non-linear. The observed F-joint (Phi) value (16.42) exceeds the critical value (6.29) at a 5% significance level, leading us to reject the null hypothesis and conclude that the series are strongly cointegrated. The observed F-equal value (0.062) is well below the critical value (3.89), indicating that we cannot reject the null hypothesis of equality at a 5% significance level. Therefore, no asymmetry was observed in the price transmission from the US. Cattle to the Brazilian Fat Cattle (Table 2).

3.2.6. Field Cattle 480kg (UY) / Behalf carcass Cow/Steer

This domestic pair did not require cointegration correction via exogenous variables, implying a stable long-term cointegration relationship. The observed F-joint (Phi) value of 9.4 exceeds the critical value of 6.23, leading us to reject the null hypothesis and conclude that the series are cointegrated. The T-max value of -2.18, being more extreme than the critical value of -1.97, suggests a non-linear relationship between the two series. The F-equal value of 1.65 is below the critical value of 3.73, meaning we cannot reject the null hypothesis of symmetry at a 5% significance level. We conclude that price transmission in the domestic market is symmetrical (Table 2).

Table 2. MTAR

Cow on the Hook UY ← **US. Steer**

Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01

Method: Momentum (tau is defined by user)

Lags (determined by data): 1

Variable	Coefficient	Std. Error
Above Threshold	-0.103553	0.046072
Below Threshold	-0.139584	0.048062
Differenced Residuals(t-1)	0.11408	0.07332
Threshold value (tau):	0	
F-equal:	0.299261	(3.898974)*
T-max value:	-2.247632	(-1.986022)*
F-joint (Phi):	6.607158	(6.386339)*

**Simulated critical values for 5% significance level.*

Number of simulations: 10000

Steer on the Hook UY ← **US. Steer**

Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01 B2009M03

Method: Momentum (tau is defined by user)

Lags (determined by data): 2

Variable	Coefficient	Std. Error
Above Threshold	-0.142886	0.050292
Below Threshold	-0.176144	0.052788
Differenced Residuals(t-1)	0.114686	0.07251
Differenced Residuals(t-2)	0.122245	0.072908
Threshold value (tau):	0	
F-equal:	0.223544	(3.828432)*
T-max value:	-2.841134	(-1.966531)*
F-joint (Phi):	8.989051	(6.307636)*

**Simulated critical values for 5% significance level.*

Number of simulations: 10000

Novillo Canada ← **US. Steer**

Exogenous variable(s): None

Method: Momentum (tau is defined by user)

Lags (determined by data): 1

Variable	Coefficient	Std. Error
Above Threshold	-0.404342	0.081946
Below Threshold	-0.408695	0.087059
Differenced Residuals(t-1)	-0.034531	0.071677
Threshold value (tau):	0	
F-equal:	0.001488	(3.788340)*
T-max value:	-4.694461	(-1.982846)*
F-joint (Phi):	20.90854	(6.452710)*

**Simulated critical values for 5% significance level.*

Number of simulations: 10000

Fat Steer Brazil ← **US. Steer**

Exogenous variable(s): None

Method: Momentum (tau is defined by user)

Lags (determined by data): 2

Variable	Coefficient	Std. Error
Above Threshold	-0.578846	0.129002
Below Threshold	-0.54314	0.113385
Differenced Residuals(t-1)	-0.226134	0.093162
Differenced Residuals(t-2)	-0.031239	0.074326
Threshold value (tau):	0	
F-equal:	0.062673	(3.891429)*
T-max value:	-4.487107	(-1.992995)*
F-joint (Phi):	16.42176	(6.292512)*

**Simulated critical values for 5% significance level.*

Number of simulations: 10000

Steer on the Hook UY ← **FAO Index**

Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01 B2009M03 B2010M07

Method: Momentum (tau is defined by user)

Lags (determined by data): 6

Variable	Coefficient	Std. Error
Above Threshold	-0.171609	0.062921
Below Threshold	-0.170388	0.062917
Differenced Residuals(t-1)	0.039093	0.078748
Differenced Residuals(t-2)	0.15739	0.078582
Differenced Residuals(t-3)	-0.091057	0.077057
Threshold value (tau):	0	
F-equal:	0.000238	(3.697251)*
T-max value:	-2.708162	(-1.968010)*
F-joint (Phi):	6.111101	(6.239004)*

**Simulated critical values for 5% significance level.*

Number of simulations: 10000

Field Steer 480UY ← **Behalf carcass Cow/Steer**

Exogenous variable(s): None

Method: Momentum

Lags (determined by data): 4

Variable	Coefficient	Std. Error
Above Threshold	-0.291366	0.070739
Below Threshold	-0.170568	0.078123
Differenced Residuals(t-1)	-0.01475	0.078142
Differenced Residuals(t-2)	0.060097	0.076256
Differenced Residuals(t-3)	0.016412	0.075137
Threshold value (tau):	0	
F-equal:	1.653998	(3.734300)*
T-max value:	-2.183341	(-1.971510)*
F-joint (Phi):	9.409112	(6.234663)*

**Simulated critical values for 5% significance level.*

Number of simulations: 10000

Table 3. MTAR Sub model

Steer on the Hook UY ← US. Steer
Exogenous variable(s): B2007M06 B2008M10 B2008M11 B2009M01 B2009M03 B2010M07

Method: Momentum (tau is defined by user)

Lags (determined by data): 2

e	Coefficient	Std. Error
bove Threshold	-0.142295	0.061543
elow Threshold	-0.30839	0.060257
enced Residuals(t-1)	0.105279	0.071671
enced Residuals(t-2)	0.152608	0.071533
old value (tau):	0	
l:	4.120181	(3.817080)*
value:	-2.312107	(-1.997341)*
(Phi):	14.75655	(6.307768)*

**Simulated critical values for 5% significance level.*
Number of simulations: 10000

3.3. Connectedness Index or Risk of Spillover.

Table 4, "Average Dynamic Connectivity," portrays interactions among various variables associated with domestic cattle category prices and industry prices. Specifically, it illustrates how shocks "spillover" from one category to another and how much each category receives from the others.

The main diagonal (highlighted in gray) represents each category's contribution to its own volatility. For instance, the Behalf carcass Cow has a value of 17.3, meaning this category contributes 17.3% to its own volatility. Values outside the diagonal represent the spillover from one category to another. For instance, the interaction between the Behalf carcass Cow and Behalf carcass Cow/Steer stands at 15.7, indicating the Behalf carcass Cow contributes 15.7% to the volatility of Behalf carcass Cow/Steer.

The "From Others" column shows how much of a category's total volatility comes from other categories. It's the horizontal sum of spillovers from all other categories to a specific one. For example, the Behalf carcass Cow derives 82.7% of its volatility from other categories.

The "Contribution to Others" row indicates how much a particular category contributes to the volatility of other categories. It's the vertical sum of spillovers from one category to all others. For instance, the Behalf carcass Cow contributes 89.6% to the volatility of other categories. The “Contribution including own” row adds a category's contribution to others and itself.

The "NET" row signifies the difference between what one category contributes to others and what it receives from others. A positive value implies the category is a "net source" of volatility transmission. Conversely, a negative value suggests the category is a "net recipient" of volatility.

The categories Behalf carcass Steer and Standing Steer' are the primary net transmitters of spillover or volatility within the system, given their net positive values. These categories could be regarded as the domestic price benchmarks. Behalf carcass Cow Steer follows them in magnitude, ranking third in terms of volatility transmission. On the other hand, the categories 'Field Steer 480kg' and 'Special Standing' are the main net recipients of volatility, with net negative values. They are the primary categories affected by price changes or market shocks. The 'Standing Steer' is the principal source of volatility for other categories, with a value of 101%. This suggests that price leadership in the domestic market is shared between the industry price and producer price (Behalf carcass Steer and 'Standing Steer'), with the most susceptible categories being 'Field Steer 480kg' and 'Special Standing Steer'. This technique offers a different perspective compared to the Granger Causality test on price leadership in the domestic market. However, the choice to use the 'Behalf carcass Cow /Steer' as an independent variable and 'Field Steer 480kg' as the dependent variable is justified by these results.

The Total Connectedness of 85.5% in the context of the "Average Dynamic Connectness" table provides a general idea of how interconnected the different cattle categories are with one another. This high connectivity implies a strong interdependence among the cattle categories, meaning a shock or disturbance in one category has a high likelihood of affecting others. There's no isolation in the domestic market, as the connectivity is high, nearing 100%. No category is entirely isolated. Even if a category itself had a low volatility level, it would still be significantly influenced by the others. From a risk management perspective, high connectivity suggests that market participants should consider the system as a whole rather than analyzing each category separately. A systematic approach to assess and manage risk might be more suitable than an individualized approach.

High connectivity may also hint that a shock in one category could trigger a domino effect in others, amplifying the initial impact. From an investment or marketing perspective, diversifying among different categories might not be as effective for mitigating specific risks, as high connectivity indicates categories tend to move together in response to shocks.

In summary, a Total Connectivity of 85.5% suggests that the different cattle categories in this system are strongly interconnected in terms of volatility. This high interconnection can have significant implications for both risk management and investment or marketing decisions in the cattle sector.

Table 4. Connectedness Index; Average Dynamic Connectedness

Avarage Dynamic connectedness	Beef half-carcass - Steer (UY)	Beef half-carcass - Cow (UY)	Beef half-carcass - Steer (UY)	Field steer 480 UY	Special standing steer UY	Steer on the hook UY	Novillo en Pie UY	Cow on the hook UY	Standing cow UY (Fat)	Standing cow UY	From Others
Beef half-carcass - Steer (UY)	17.3	16.3	16.2	5.5	6	7.1	8.6	7	8.9	7	82.7
Beef half-carcass - Cow (UY)	15.7	16.5	16.4	5.9	6.6	7.4	8.8	7.1	8.9	6.8	83.5
Beef half-carcass - Steer (UY)	14.9	15.7	16.3	6.1	6.6	7.8	9	7.5	9	7	83.7
Field steer 480 UY	7.8	8.6	9.1	14.3	10.9	10.9	11.1	9.3	9.9	8.2	85.7
Special standing steer UY	8	8.8	9.3	10.3	13.7	10	12.3	8.5	10	9.1	86.3
Steer on the hook UY	8.3	8.9	9.6	8.7	8.2	12.8	12.1	11.3	10.8	9.1	87.2
Novillo en Pie UY	8.5	8.8	9.6	7.6	7.9	10.3	14.6	9.2	12.1	11.4	85.4
Cow on the hook UY	8.7	9.1	9.8	8	7.7	11.7	11.8	12.2	11.7	9.4	87.8
Standing cow UY (Fat)	9.1	9.3	9.9	7.4	7.5	9.9	13.2	9.7	13.8	10.3	86.2
Standing cow UY	8.6	8.7	9.3	7.3	7.2	9.8	14.1	9.2	12	13.8	86.2
Contribution to others	89.6	94.2	99.1	66.9	68.6	84.8	101	78.9	93.3	78.4	854.7
Contribution including own	106.9	110.7	115.4	81.2	82.3	97.6	115.5	91.1	107.1	92.2	85.50%
NET	6.9	10.7	15.4	-18.8	-17.7	-2.4	15.6	-8.9	7.1	-7.8	

4. Discussion

The connectedness or " risk of spillover" index, based on GFEVD and a VAR model, provided additional insight. Diebold and Yilmaz (2012) introduced "Risk of spillover" measures to understand how shocks in one variable affect others in terms of volatility. Under this approach, the categories "Behalf carcass Steer" and "Standing Steer" are the primary sources of volatility, while "Field Steer 480kg" and "Special Standing Steer" are the most influenced by shocks in other categories. This technique offers a complementary view to the Granger test on how leading prices operate in the domestic market. With an overall connectedness of 85.5%, it's clear that cattle categories are deeply interconnected, especially in the domestic market. A shock in one category could reverberate across many others. This high interconnection implies that market players should view the system holistically, not just focusing on specific categories. This interrelation also has implications for risk management and investments due to the potential domino effect in the market.

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 Models (VECM) proposed by Barboza Martignone *et al*., (2023) 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.

This study aims to understand the market dynamics of both the Uruguayan beef market and international markets. The findings suggest a low market efficiency, incomplete price transmission, and even co-integration issues with international markets. These issues became more pronounced in the cointegration test under Enders and Siklos (2001) asymmetry, in which Uruguayan series required adjustments for structural breaks, mirroring observations from the Johansen test. TAR/MTAR (Threshold Autoregressive & Momentum Threshold Autoregressive) models were employed to discern potential asymmetric transmissions from international prices to Uruguayan prices and from industry prices to producers. The results highlight that cointegration and the nonlinear nature of the relationships are consistent across most studied pairs. However, not all pairs exhibited the same symmetry in price transmission. For instance, the MTAR Steer on the Hook / US.Steer (sub-model 2) showed an asymmetric transmission of prices from the international to the domestic market. Such asymmetry may be attributed to market factors such as entry barriers, transaction costs, market power, and oligopsonies. The need for exogenous variables to correct cointegration differs by pair, suggesting disparities in market structures or historical events that unevenly impact each pair. Notably, both international and domestic series did not necessitate exogenous variables for cointegration correction, indicating that most relationships were nonlinear but with symmetric price transmission.

The Enders & Siklos's (2001) test suggest integration issues between domestic and international markets. This outcome aligns with findings from Fossati and Rodriguez (2002), who determined that the bovine market is not fully integrated, attributing this situation to unresolved inefficiencies. Correcting the cointegration for structural breaks enables the identification of a long-term relationship between the domestic market and international markers, represented by Novillo US and the FAO meat index. Alfaro, Salazar, and Troncoso (2003) had previously identified a long-term relationship between Uruguay's export prices and standard prices in international markets, encompassing countries like Argentina, Australia, Brazil, and the United States. In this context, while there is an integration between international markets and the Uruguayan market, this relationship tends to be less stable and enduring, with a trend toward decoupling in the face of external shocks.

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. In contrast with the findings of Freiria

(2018), Barboza Martignone et al. (2023) identified that the speed of price transmission fluctuated between 4.5% and 7.8% when tracking the movement from the US Novillo price and the FAO index to domestic prices. This observation aligns with the expectation that price transmission accuracy improves when analyzed closer to the supply chain's core, reflecting heightened efficiency. For example, Freiria's study in 2018 pinpointed an adjustment speed of 16% in the vertical transmission context between industry and producers, whereas Barboza Martignone et al. (2023) corroborates a higher rate of 24%, which still falls within what's typically deemed moderate. Nevertheless, the efficiency of price transmission appears to diminish when assessed on a horizontal plane in relation to the international market. Freiria's earlier estimate stood at 14% efficiency concerning the export price, in stark contrast to the diminished efficiency uncovered by Barboza Martignone et al. (2023) at a mere 4.5% to 7.8% for more remotely connected market levels, such as the US Novillo prices or the FAO index.

Worldwide, a network of trading blocs, individual country agreements, and various trade impediments, such as tariffs and quotas, potentially influences the price transmission from the global benchmark price to the price received by Uruguayan producers. In essence, the extent and effectiveness of trade agreements that a nation secures can also shape how prices are transmitted. The principles of economic liberalism are often associated with heightened market efficiency, suggesting that these trade agreements could play a pivotal role in optimizing market performance.

6. Conclusion

The connectedness index of the Uruguayan domestic market reaches 85%, suggesting a high interconnection and potential for domino effects on prices. The MTAR and TAR models were applied to identify possible asymmetries in price transmission, for Uruguay as well as for Canada and Brazil, and the possible asymmetry between the industry price and the producer price. In the Canadian and Brazilian markets, perfect cointegration with the international market was evident, showing non-linear adjustments but without asymmetry in price transmission. On the other hand, for models representing Uruguayan and international prices, it was necessary to correct for structural breaks to observe significant cointegration. In most cases, adjustments were non-linear, and in a specific case, an asymmetry in price transmission was detected, showing quicker adjustments to drops in international prices than to increases. The MTAR/TAR model for the domestic price pair showed significant cointegration without the need to include exogenous variables, with non-linear but symmetrical adjustments. The policy recommendations inferred from this research advocate for the deregulation of livestock exports as a means to improve market efficiency, integration and boost the competitiveness of the meatpacking industry. Grasping these processes and their interplay is critical for strategic decision-making within the industry, particularly given the incessant interlinkages of markets in today's globalized economy. The insights and analytical tools provided by this study are of substantial value to executives, investors, and policy architects in the Uruguayan meat industry. The key challenge moving forward is to apply these insights effectively to enhance market functioning and strengthen Uruguay's competitive stance globally.

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