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Asymmetric Price Transmission Analysis of the International Soybean Market

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Abstract

This study analyzed the asymmetric price transmission in the international soybean market, using data from the US (Chicago Futures), European (Rotterdam), Brazilian (Paranaguá), Argentinian (Rosario Futures and Rosario Spot), and Chinese (Spot and Futures) markets. The study looked at the price transmission between these markets over a period of almost 10 years, from September 2009 to May 2019. The Phillips-Perron unit root test was used to determine the order of integration of the time series. The Engle-Granger cointegration test failed to find any evidence of cointegration between the Chinese and Argentinian markets with any others of the international markets. The lack of cointegration was associated with highly government intervened markets. The cointegration and threshold test proposed by Enders and Siklos, succeeded in rejecting the Null hypothesis and finding cointegration among the series after structural breaks had been taken into account. The BDS test for nonlinearity showed that most of the time series were nonlinear, which prompted the investigation to look into nonlinear modelling. To evaluate asymmetric price transmission, the study used the Threshold autoregressive (TAR) model and the momentum threshold model (MTAR). The Argentine and Chinese markets were primarily suspected of exhibiting asymmetric price transmission due to structural government intervention. However, the test results failed to reject the null hypothesis and revealed asymmetric price transmission between these markets and the international market. As expected, the results found no evidence of asymmetric price transmission in the Paranaguá, Rotterdam, and Chicago markets. Hence, it can be concluded that symmetric price transmission is more prevalent in the global soybean market than asymmetric price transmission.

Keywords

Agricultural Economics, Econometrics, Price Transmission, Soybean Market, Asymmetric Price Transmission, TAR, MTAR, BDS

1. Introduction

The international soybean market is one of the most important in the world, as it represents a key source of protein for animal consumption [1] and the fourth largest agriculture market in terms of volume. There are many actors in this commodity market, but few have relative importance in terms of production, consumption, and price leadership. Brazil is the main producer of soybean, accounting for 121.8 million tonnes (2020), closely followed by the United States with 112.55 million tonnes (2020). Thirdly, Argentina produced 48.80 million tonnes (2020) [2]. Together, they represent the main supply of raw and crushed soybean. On the other hand, on the demand side, China clearly consumes the most soybean (14.07 billion U$S by 2020), followed by the European Union (1.91 billion U$S) [3].

In terms of price leadership, several authors have identified the US-Chicago Market and the European Port of Rotterdam as the price leaders of the market [4] [5]. This market is characterized as cointegrated and highly efficient, where the Law of One Price (LOOP) has already been validated. The free market status of the international soybean market has not always been the rule, with different market actors having intervened within the market several times. For example, in the case of Argentina with its export tariff known as "retentions" [4], or its fixing of exchange rates limiting production and trade, and promoting stockpiling of production in anticipation of a better political scenario. Similarly, China has intervened within the domestic market via the introduction of price support policies, such as imposing a "floor price" or increasing import tariffs to protect the domestic market [6], or applying a selective tariff on US soybean exports. The researcher [7] argues that these types of policies and market interventions can generate asymmetric price transmission (APT). It is widely agreed that intervention generates a loss of market efficiency and asymmetry of price [8]. Given the structure of the global soybean market and the interventions imposed some players, the question remains as to what degree have the interventions generated APT across the international market. This research focuses on and addresses this gap, trying to understand the implications in terms of APT in a highly efficient and cointegrated market.

APT can be caused by various factors, the main literature suggests that non-competitive markets and adjustment costs can play a role [8]. However, since the soybean market is highly efficient and competitive, this may not be a problem. There are several other factors that might generate APT such as inventory management, asymmetric information, asymmetric costs, market power, and political intervention [9]. The latter two factors were suggested by [5], for the previously mentioned case of government-intervened markets such as in the case of Argentina [4] and China [6]. The researchers [10] suggest that APT in the spatial dimension can also be generated by differences in transportation costs. Some trade channels might be more developed in terms of infrastructure, storage facilities, capabilities, and transportation.

The Threshold Autoregressive (TAR) and Momentum Threshold autoregressive models (MTAR), alongside Engle and Granger's (1987) methodology, have been widely used for studies of APT. The researcher [11] was the first researcher to study APT in the international soybean market. He examined US domestic and export prices using the sub-sampling methodology of [12] and repeated the TAR model to avoid sample selection problems. The researcher [11] conclusion was that from 1967 to 1977, the PT was positively asymmetric and then became symmetrical and asymmetrically negative after 1977 until 1988. During the next period until halfway through the 1990s, APT shifted to negative. This result can be attributed to the rise of Brazil and Argentina as world leaders in soybean export. Later on [13] successfully found evidence of APT in the soybean complex of the Chicago Board of Trade, between soybean futures prices and the prices of soymeal and soybean oil. The authors used an innovative methodology, a multi-variate quartile approach by a Vector Autoregressive Quantile Model (VARQ). The authors demonstrated the superiority of quantile regression over OLS regression, as the VARQ model provides a more detailed view for identifying the sources and patterns of APT between downstream and upstream markets. The authors found evidence of APT in the soybean complex, with a negative response from soybean products to shocks in input prices. The researchers [13] have studied the APT in the vertical dimension from futures prices or across different linked commodities, such as raw soybeans, soybean oil, and soymeal. This research opens up a gap in the study of horizontal APT across the same commodity in different spatial markets. It remains unclear if APT is the rule rather than the exception in the international market. Previous authors who have studied APT in soybeans have solely focused on the US market, which is already considered to be the most efficient market in terms of PT. Therefore, if the US market has presented structural APT during different periods, it is likely that other markets, such as the Argentinian and Chinese markets, which have structural market intervention and lower degrees of market efficiency, also present APT. The aim of this research is to address this gap and understand the dynamics of the international soybean market in terms of PT. This question remains whether the intervened markets with decreased market efficiency present APT, which can be associated with intervention policies, market power, asymmetric information, or other factors.

2. Methodology

This research is based on econometric and statistical procedures and models that use time series analysis of prices (secondary data). The secondary data comes from a variety of sources, such as: Wind Economic, which provided time series data for the China Spot market; The Dalian Commodity Exchange, which provided data for the Dalian Future market; the International Monetary Fund's website, which was the source of data for the Chicago Board of Trade (CBOT) and Rotterdam; the Brazilian Center for Advanced Studies for Applied Economics (CEPEA), which provided data from the Brazilian market of Paranaguá port; and finally, the Rosario Stock Exchange (Bolsa de Rosario), which provided data for the Argentina Spot and Futures market of Rosario. For this type of research, the data has been conditioned and transformed into natural logarithms to decrease variation in the data, simplifying patterns and increasing the robustness of the models, following a standard econometric procedure.

This investigation builds upon previous research from [5]. The same dataset and structural breaks were used, with the starting point being a continuation of the previous results. Using the Augmented Dickey-Fuller test (1979), the previous research found that all the time series are stationary at the first difference, indicating that the integration order is I(1). In this research, the Phillips-Perron unit root test was implemented to complement and confirm the robustness of the framework. The structural breaks were already identified (using Bai-Perron's multiple breakpoint test and ADF with breaks) in the aforementioned research and were used as dummy variables for cointegration under asymmetry test [14]. [5] also found full cointegration among the studied time series using the Johansen Cointegration test. To ensure the validity of the previous results, this investigation performed the Engle-Granger cointegration test using a two-step estimation (**Figure 1**).

First, an ordinary least squares (OLS) regression was created for an overall model that encompasses all time series. Then, the procedure was repeated in paired models for all combinations of time series. For each individual model, the residuals were regressed on intercepts (constant) and a trend to understand their significance, which were later useful for the Augmented Dickey-Fuller (ADF) test specification. The second step was to perform the ADF test on the residuals

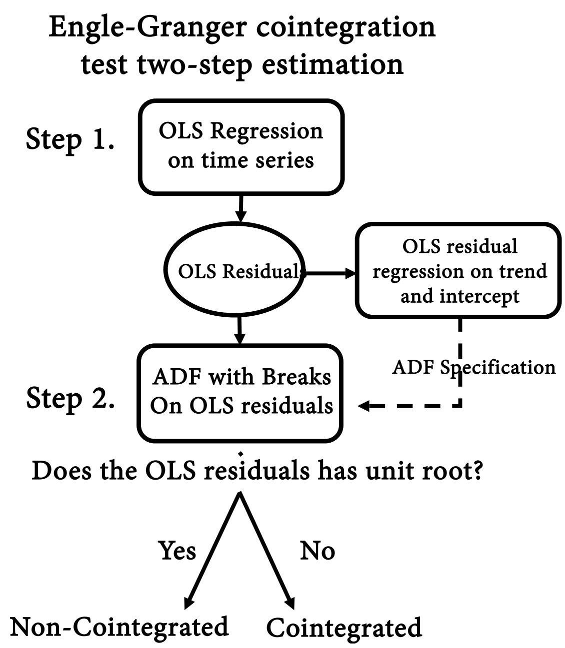

Figure 1. Engle-Granger cointegration test, two-step estimation.

of each OLS model. The modified version of the test, "ADF with breaks," was used in some scenarios where the time series have structural breaks that mislead the results into a false unit root. Cointegration is found if the ADF rejects the Null Hypothesis of Unit root on the residuals of the previously estimated model [15].

The causality of the price series was inferred with the Granger Causality test by [5]. Based on the same integration order, cointegration, and causality among all variables, the relationship among the time series can be represented by an Error Correction Model (VECM) [16]. Following this, [5] built several VECM models to describe the relationship among variables and the market dynamics. Based on the models previously created by the aforementioned authors, this investigation evaluated if the model that accounted for linear and symmetric relationships in PT are valid for non-linear behavior or asymmetric price transmission. Therefore, to switch from linear to nonlinear modeling, it is necessary to check the nature of the time series. To achieve this, the research used the non-parametric BDS test for nonlinearity [17]. The BDS test was originally developed by [17] for detecting serial linear dependence in time series. It is useful for diagnosing nonlinear dependencies in the time series. To correctly perform the test, it is necessary first to increase the statistical power of the test, that's why the series should be transformed into first differences and natural logarithms. The main advantage of the BDS test is that it doesn't require any distribution assumptions. The Null Hypothesis is that the time series are independently and identically distributed, the alternative hypothesis is the opposite of the Null Hypothesis implying nonlinear dependency.

The simplicity and intuitive qualities of linear models have dominated theoretical and applied economics and econometrics for most of the 20th century [18]. However, due to the possibility of nonlinear relationships in time series data, nonlinear models are starting to gain attention. The assumption of linearity in linear models can result in stationary solutions that converge to a point with a tendency towards infinity, and they may fail to explain nonlinear phenomena in natural sciences [18]. The applicability of the Vector Error Correction Model (VECM) assumes linear behavior in time series data. Asymmetrical price transmission suggests a nonlinear relationship among variables.

To account for asymmetrical price transmission (APT), TAR and MTAR models are often used. Both models are classified as bilinear models, and they are popular in econometric literature and have been used in studies of APT in various agricultural markets, such as Wheat in India by [19], Skim Milk Powder International Trade by [20] and Chinese pork and pig market by [21]. The TAR model is a piecewise-linear approximation to a general nonlinear model, an Autoregressive (AR) model with abrupt changes between equations. This type of model can capture deep asymmetry in data. Similarly, the MTAR can capture deep asymmetry in data [22]. To improve the comprehension, the economic procedure and the bounder between this research and [5] study **Figure 2** illustrates the econometric pathway.

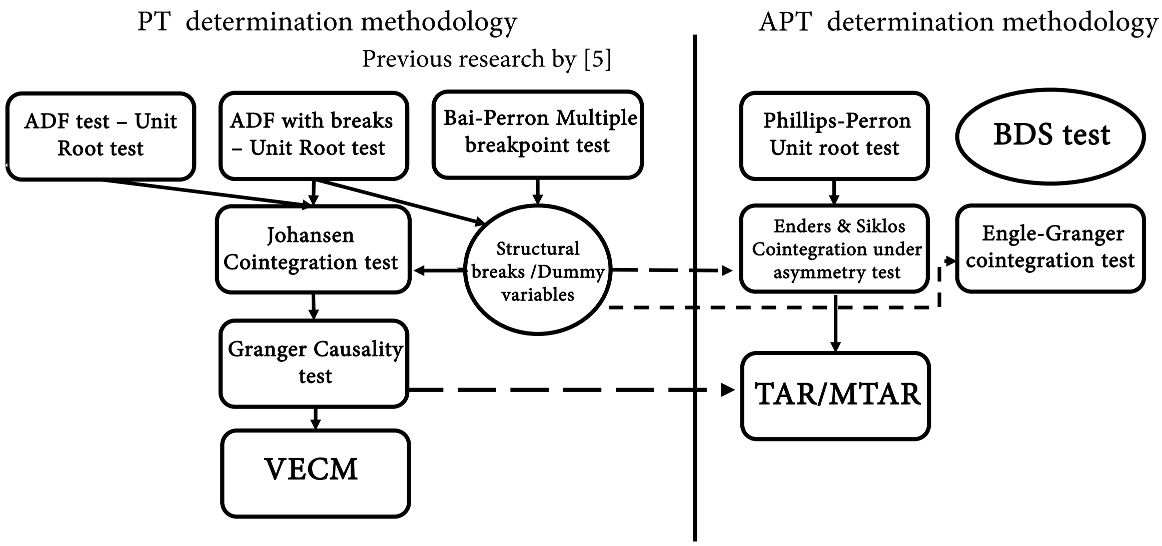

Figure 2. Econometric path way.

2.1. MTAR & TAR Models Specification

As previously mentioned, the series were already detrended (converted into first differences) and the threshold value is set to 0. To filter the series residuals from the long-term equation, a heaside indicator is defined and the series residuals are decomposed into positive (p1) above the threshold, and negative (p2) below the threshold, and the models are estimated. The trimming factor is set at 15%, removing higher values from both ends and using the 75% remaining values to estimate the threshold parameters. A Monte Carlo simulation was used for estimating the critical values. Both the MTAR and TAR models were estimated using the econometric software Eviews.

2.2. Data Summary

As previously mentioned, the secondary data was obtained from a previous investigation [5]. **Table 1** presents the data summary and demonstrates the impact of government intervention on the soybean market. The free markets in Chicago, Paranaguá, and Rotterdam have similar average soybean costs per ton, with any variations in price being attributed to transaction costs. However, the average prices in the markets of China and Argentina deviate significantly from the international market prices. This discrepancy can be attributed to government intervention; China's price support policies have artificially inflated domestic market prices, while Argentina's tariffs and export retention measures have resulted in lower export prices.

3. Results

In this section, the results are explained in the logical sequence in which they were produced. The results were summarized in tables to facilitate comprehension.

Table 1. Soybean data summary.

	Paranagua Spot U$S/tt	Rotterdam U$S/tt	Chicago futures U$S/tt	Dalian Futures U$S/tt	China Spot U$S/tt	Rosario Futures U$S/tt	Rosario Spot U$S/tt
Mean	438	461	415	630	630	282	288
SD	82.6	78.2	80.6	88.2	82.6	40.6	47.6
Kurtosis	0.58	−0.41	−0.78	−1.23	−1.08	−0.77	0.14
Media	407	432	379	618	607	271	276
Max	714	684	623	786	785	390	429
Min	327	357	306	458	522	225	216
Q1	373	394	354	557	562	248	251
Q2	407	432	379	618	607	271	276
Q3	503	521	497	712	702	319	320

3.1. Phillips-Perron Unit Root Test

The Unit Root test is necessary to open the path to many econometric procedures and models under the assumption that the data is stationary. The results of the Phillips-Perron unit root test (**Table 2**) failed to reject the Null Hypothesis (unit root at level); the probability was higher than the test critical value for all time series. Therefore, there was a high probability of rejecting the Null hypothesis when it is true (Error type I). After transforming the series to the first difference and re-running the test, the Null Hypothesis was rejected. Therefore, the alternative hypothesis was accepted, meaning that all series are stationary at the first difference and with integration 1-I(1) (**Table 2**). These results are in line with [5] where the authors found the same order of integration using the Augmented Dickey Fuller test.

3.2. Engle-Granger Cointegration Test

This cointegration methodology requires two steps. Firstly, it requires estimating an OLS model. In this case, the China Spot market is used as the dependent variable, as previous causality tests performed by [5] revealed that this market was the most Granger-caused by all the studied markets. The linear OLS model showed a high coefficient of determination and all independent variables were statistically significant (**Table 3**).

Secondly, it is necessary to perform the Augmented Dickey-Fuller Unit Root test on the OLS model residuals. If the residuals are stationary, this means that the series are cointegrated. However, it was necessary first to correct the ADF test specification for trend and intercept. Therefore, a regression of trend and constant on the OLS residuals was performed (**Table 4**). The regression showed that the intercept and trend are statically significant, therefore it is necessary to include them in the ADF unit test. The ADF test, including the exogenous constant and trend, rejected the Null Hypothesis of Unit Root, meaning that the

Table 2. Phillis-Perron Unit root test for all-time series.

Phillips-Perron Unit Root Test (level)		Adj. t-Stat	Prob.*
Rotterdam		−1.63	0.47
Rosario Spot		−1.61	0.47
Rosario Futures		−1.62	0.47
Paranaguá Spot		−1.78	0.39
Dalian Futures		−1.70	0.43
China Spot		−1.12	0.71
Chicago Futures		−1.66	0.45
Phillips-Perron Unit Root Test (First Difference)		Adj. t-Stat	Prob.*
Rotterdam		−9.10	0.00*
Rosario Spot		−7.79	0.00*
Rosario Futures		−7.25	0.00*
Paranaguá Spot		−7.28	0.00*
Dalian Futures		−10.58	0.00*
China Spot		−7.87	0.00*
Chicago Futures		−7.83	0.00*
Test critical values:	1% level	−3.485115	
	5% level	−2.88545	
	10% level	−2.579598	

Table 3. OLS regression all-time series.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNCHIGF	0.42	0.11	3.93	0.00*
LNDALIF	0.76	0.05	14.27	0.00*
LNPARANAGUÁSP	0.25	0.10	2.37	0.02*
LNROSFT	−0.53	0.13	−3.99	0.00*
LNROSSP	0.38	0.14	2.75	0.01*
LNUSROTTERDAMCIF	−0.67	0.12	−5.67	0.00*
C	2.50	0.30	8.30	0.00*
R-squared	0.85	Mean dependent var		6.44
Adjusted R-squared	0.84	S.D. dependent var		0.13
S.E. of regression	0.05	Akaike info criterion		−3.04
Sum squared resid	0.31	Schwarz criterion		−2.88
Log likelihood	193.91	Hannan-Quinn criter.		−2.97
F-statistic	106.97	Durbin-Watson stat		0.67
Prob(F-statistic)	0.00			

*Statistically significant at alpha 5%.

Table 4. OLS regression on residuals.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	−0.02	0.01	−2.65	0.01*
@TREND	0.00	0.00	3.07	0.00*
R-squared	0.07	Mean dependent var		0.00
Adjusted R-squared	0.06	S.D. dependent var		0.05
S.E. of regression	0.05	Akaike info criterion		−3.20
Sum squared resid	0.29	Schwarz criterion		−3.15
Log likelihood	198.52	Hannan-Quinn criter.		−3.18
F-statistic	9.41	Durbin-Watson stat		0.72
Prob(F-statistic)	0.00			

*Statistically significant at alpha 5%.

residuals are stationary (**Table 5**). The stationarity of the residuals means that the series are cointegrated. These results are in line with the empirical evidence from previous research, such as that of [5] who arrived at the same conclusion using the Johansen cointegration methodology, as well as many other researchers who have proved cointegration among different soybean markets.

Despite the previous procedure having confirmed a long-term relationship among the markets (time-price series), to understand the price transmission dynamic between two markets, it is necessary to check for cointegration in pairs. The previous methodology was applied in pairs for all combinations of time series. However, the large number of results generated can compromise the readability of this research. Therefore, for all pairs of models, the results have been removed from the paper and summarized in **Table 6** (the results are available upon request). Pairwise OLS models were created for all different combinations of time series. For each individual model, the residuals were regressed on an intercept and trend in order to correctly specify the ADF. The residuals were then tested with the ADF unit root test with correct specification (trend and constant). In some cases, the ADF test failed to reject the Null hypothesis of Unit Root. In this scenario, the modified test "ADF with breaks" was applied. This test finds structural breaks in the time series and uses them as exogenous variables, avoiding false unit roots.

In the scenario where the Null hypothesis cannot be rejected, the selected structural breaks from [5] found with the Bay-Perron methodology were introduced as exogenous variables. After following the previously mentioned procedure, the results showed that not all time-price series were cointegrated in pairs. This result is in contrast with the results of the previously mentioned researchers. Empirical evidence suggests that the Johansen cointegration test performs better than single equation and alternative multivariate methods and dominates cointegration analysis [15]. Among the series that did not present cointegration among their pairs, China Spot stands out as the least cointegrated. China Spot

Table 5. OLS regression on residuals.

Augmented Dickey-Fuller		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		−5.12	0.00*
Test critical values:	1% level	−4.03	
	5% level	−3.45	
	10% level	−3.15	

*MacKinnon (1996) one-sided p-values. Null Hypothesis: Residual OLS model has a unit root. Exogenous: Constant, Linear Trend. *Statistically significant at alpha 5%.

Table 6. Engle-Granger cointegration matrix.

	Chicago Futures	Dalian	China Spot	Rosario Futures	Rosario Spot	Rotterdam	Paranaguá
Chicago Futures	X	√	X	X	√	√	√
Dalian	√	X	√	√	√	√	√
China Spot	X	√	X	X	√	X	X
Rosario Futures	X	√	X	X	√	X	√
Rosario Spot	√	√	√	√	X	√	√
Rotterdam	√	√	X	X	√	X	√
Paranaguá	√	√	X	√	√	√	X

presented cointegration only with Dalian Futures and Rosario Spot. Rosario Futures exhibit the second-place in lack of cointegration among pairs, being only cointegrated with Rosario Spot, Dalian and Paranaguá. However, the number of cointegrated pairs increases if the alpha is set at 10%, suggesting a fading effect of the Cointegration vectors or a lack of statistical power from Engle-Granger.

The evidence suggests that the lack of statistical power of the Engle-Granger test, in addition to a high number of structural breaks and government intervention in the previously mentioned markets (Argentina and China), can lead to Error Type II (failure to reject the Null hypothesis when it is true) and spurious results.

3.3. BDS

The investigation of the presence of non-linearity in the time series is considered a standard procedure before modeling MTAR and TAR asymmetry models, which are considered close approximations of non-linear models. Firstly, in order to perform the BDS test, the series must be detrended, and autocorrelation needs to be eliminated. Therefore, all series must be in natural logarithm and differentiated (first difference). The Null Hypothesis is that the series are identical and identically distributed. The alternative hypothesis is that the data is not linearly dependent. The results of the BDS test are reported in Table 7. The results show that most of the series were non-linearly dependent in nature, with the exception of Rotterdam and Dalian futures.

Table 7. BDS results.

	Dimension	BDS Statistic	Std. Error	z-Statistic	Normal Prob.	Bootstrap Prob.
Chicago Futures	2	0.021	0.008	2.736	0.006	0.017*
	3	0.042	0.012	3.427	0.001	0.006*
Paranaguá	2	0.023	0.006	3.521	0.000	0.004*
	3	0.028	0.010	2.728	0.006	0.022*
China Spot	2	0.028	0.009	3.190	0.001	0.010*
	3	0.039	0.014	2.792	0.005	0.018*
Rosario Futures	2	0.016	0.007	2.441	0.015	0.040*
	3	0.023	0.011	2.157	0.031	0.054
Dalian Futures	2	0.003	0.007	0.423	0.672	0.624
	3	0.000	0.011	−0.029	0.977	0.899
Rosario Spot	2	0.015	0.006	2.364	0.018	0.045*
	3	0.017	0.010	1.741	0.082	0.117
Rotterdam	2	0.012	0.007	1.648	0.099	0.136
	3	0.012	0.012	1.013	0.311	0.312
	Dimension	Epsilon (1)	$c(m, n)$	Epsilon (2)	$c(1, n-(m-1))$	$c(1, n-(m-1))^k$
Chicago Futures	2	3705	0.510	5079	0.700	0.489
	3	2715	0.380	4976	0.697	0.338
Paranaguá	2	3729	0.514	5087	0.701	0.491
	3	2630	0.368	4985	0.698	0.340
China Spot	2	3767	0.519	5089	0.701	0.491
	3	2714	0.380	4991	0.699	0.342
Rosario Futures	2	3703	0.510	5102	0.703	0.494
	3	2615	0.366	5000	0.700	0.343
Dalian Futures	2	3575	0.492	5080	0.700	0.490
	3	2466	0.345	5011	0.702	0.346
Rosario Spot	2	3696	0.509	5105	0.703	0.494
	3	2591	0.363	5011	0.702	0.346
Rotterdam	2	3664	0.505	5095	0.702	0.493
	3	2530	0.354	4995	0.700	0.342

3.4. TAR

Several TAR models were estimated following the combination from VECM models previously proposed by [5]. The previously mentioned authors used the model accounting for Granger causality of the prices, first in pairs, and then using all series that were independent and cointegrated with the dependent Granger-caused series "target series." **Table 8** shows different pair combinations of TAR models for the China Spot market, and in the last column, an overall model that uses all series that Granger-cause the China Spot market.

Table 8. TAR model for China Spot.

China Spot	Chicago futures		Rotterdam		Paranaguá		Dalian Futures		Overall model	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Above Threshold P1	−0.05	0.04	−0.04	0.04	−0.04	0.04	−0.34	0.09	−0.35	0.08
Below Threshold P2	−0.08	0.05	−0.06	0.04	−0.09	0.05	−0.21	0.08	−0.41	0.08
Differenced Residuals (t − 1)	0.17	0.09	0.13	0.09	0.24	0.09	0.15	0.09	0.39	0.08
Differenced Residuals (t − 2)	−0.03	0.09	−0.02	0.09	−0.05	0.09			0.27	0.09
Threshold value (tau):	0.00		0.00		0.00		0.00		0.00	
F-equal:	0.27	2.81	0.08	2.68	0.67	2.88	1.30	2.09	0.36	1.76
T-max value:	−1.23	−2.13	−1.21	−2.12	−1.07	−2.10	−2.45	−2.43	−4.64	−3.01
F-joint (Phi):	2.05	5.93	1.57	5.92	2.32	5.76	10.07	7.36	20.94	10.15

From **Table 8**, it is possible to observe the lack of cointegration under asymmetry from the T-Max value and the F-joint (phil) were lower than the critical value. This is in contrast with previous findings of [5] and in line with the Engle-Granger test. Even though all previous breaks found from the ADF with breaks and Bai-Perron multiple break test were used as dummy variables in the cointegration test, the results failed to find cointegration between the China-Spot and Chicago-Futures and China-Rotterdam. The different cointegration methodologies with differing statistical power can partially explain the mixed results. For the China Spot-Dalian and the overall model, both T-Max and F-joint t-static were higher than the critical value, finding cointegration among the time series. However, the test did not show asymmetry under cointegration. Therefore, it is possible to assure that there is a symmetric price transmission among the time series cointegrated series.

The TAR models for Paranaguá as the dependent variable paired with Chicago and Rotterdam as dependent variables and the combined model (**Table 9**) showed a clear cointegration under asymmetry. The T-statistic was higher than the critical value for all three models (T-max and F-Joint (Phi)). However, the model failed to find any trace of asymmetry (F-equal). Therefore, the null hypothesis of symmetric price transmission is accepted. This finding is in line with the empirical evidence that presents those markets as highly efficient in terms of price transmission and has a high degree of market freedom [5].

The Rosario Spot TAR models (**Table 10**) all presented cointegration among the time series. However, there is mixed results regarding cointegration between Rosario Spot and Rosario Futures, where the F-joint (Phi) t-statistics were higher than the critical value, therefore rejecting the null hypothesis of non-cointegration among the time series. However, for the T-max, the t-statistic was lower than the critical value, failing to reject the non-cointegration null hypothesis. Despite many attempts to incorporate structural breaks as dummy variables, full cointegration was not successful. Previous results have shown clear cointegration between the Rosario Futures and Rosario Spot time series.

Table 9. TAR model for Paranaguá.

Paranaguá Spot	Chicago futures		Rotterdam		Overall model	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Above Threshold	−0.35	0.07	−0.27	0.09	−0.30	0.07
Below Threshold	−0.33	0.09	−0.37	0.10	−0.38	0.08
Differenced Residuals (t − 1)	0.43	0.08	0.14	0.09	0.41	0.08
Differenced Residuals (t − 2)	0.16	0.09	0.03	0.09	0.24	0.09
Threshold value (tau):	0.00		0.00		0.00	
F-equal:	0.04	2.88	0.54	2.83	0.7	2.22
T-max value:	−3.57	−2.11	−3.03	−2.12	−4.53	−2.43
F-joint (Phi):	17.21	5.83	9.68	5.99	19.29	7.24

Table 10. TAR model for Rosario Spot.

Rosario Spot	Chicago Futures		Rotterdam		Paranaguá		Rosario Futures		Overall model	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Above Threshold	−0.21	0.07	−0.31	0.10	−0.36	0.09	−0.25	0.07	−0.31	0.07
Below Threshold	−0.30	0.07	−0.27	0.10	−0.35	0.09	−0.14	0.09	−0.35	0.09
Differenced Residuals (t − 1)	0.32	0.09	0.04	0.09	0.27	0.09	0.25	0.09	0.30	0.09
Differenced Residuals (t − 2)	0.16	0.09	0.04	0.09	0.11	0.09	−0.08	0.09	0.23	0.09
Threshold value (tau):	0.00		0.00		0.00		0.00		0.00	
F-equal:	1.02	2.83	0.11	2.19	0.01	2.91	0.99	2.80	0.15	1.70
T-max value:	−3.10	−2.11	−2.77	−2.44	−3.70	−2.11	−1.53	−2.13	−3.95	−2.99
F-joint (Phi):	11.91	5.79	7.96	7.26	13.04	5.85	6.81	5.92	15.15	10.00

3.5. MTAR

In contrast with TAR models, the MTAR models using the [14] cointegration test under asymmetry and corrected by structural breaks as dummy variables all-time series presented cointegration, following the line of previous empirical evidence. The China Spot market has historically presented structural government intervention, protecting the market from exogenous shocks in prices and international price fluctuation. Therefore, the presence of APT was likely to happen according to [5]. In contrast to the previous suggestion, all test results for all the time series and the overall model (**Table 11**) failed to reject the null hypothesis of symmetry of price transmission. These results seem counterintuitive given the market is intervened and non-efficient common source of APT. The TAR model showed the same result, failing to reject the null hypothesis. Therefore, it is possible to conclude that the price transmission from the international soybean market to the Chinese Spot domestic market is symmetrical.

Following the TAR model, the MTAR models results for Paranaguá in pairs with Rotterdam, Chicago Futures and overall combined are represented in **Table 12**.

Table 11. MTAR model for China.

China Spot	Chicago Futures		Rotterdam		Paranaguá		Dalian Futures		Overall model	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Above Threshold	−0.17	0.08	−0.15	0.07	−0.18	0.06	−0.35	0.12	−0.39	0.08
Below Threshold	−0.28	0.07	−0.27	0.07	−0.19	0.06	−0.40	0.10	−0.37	0.08
Differenced Residuals (t − 1)	0.26	0.09	0.15	0.09	0.35	0.09	0.19	0.09	0.39	0.08
Differenced Residuals (t − 2)	0.11	0.09	0.05	0.09	0.01	0.09	−0.11	0.10	0.27	0.09
Threshold value (tau):	0.00		0.00		0.00		0.00		0.00	
F-equal:	1.40	3.78	1.58	3.89	0.04	3.88	0.14	3.92	0.03	3.77
T-max value:	−2.11	−1.98	−2.00	−1.97	−2.90	−1.98	−2.92	−2.00	−4.65	−2.80
F-joint (Phi):	10.80	6.33	9.09	6.33	8.06	6.30	10.64	6.48	20.72	10.66

Table 12. MTAR model for Paranaguá.

Paranaguá Spot	Chicago		Rotterdam		Overall model	
Variable	Coeff.	Std. Error	Coeffi.	Std. Error	Coeff.	Std. Error
Above Threshold	−0.37	0.08	−0.23	0.09	−0.36	0.07
Below Threshold	−0.32	0.08	−0.43	0.10	−0.31	0.07
Differenced Residuals (t − 1)	0.40	0.09	0.13	0.09	0.41	0.08
Differenced Residuals (t − 2)	0.16	0.09	0.07	0.09	0.25	0.09
Threshold value (tau):	0.00		0.00		0.00	
F-equal:	0.19	3.80	2.37	3.89	0.37	3.76
T-max value:	−4.28	−1.97	−2.50	−1.97	−4.14	2.30
F-joint (Phi):	16.70	6.31	10.74	6.35	19.06	7.80

All the models for the same market combination showed cointegration under asymmetry, again confirming the long-term relationship of the series. However, all the tests failed to reject the symmetry null hypothesis. In other words, the price transmission is symmetric among the different time series. This is in perfect agreement with the empirical evidence, especially for this market that presents highly efficient price transmission. Therefore, the result can be classified as expected according to economic theory.

The MTAR model for the Rosario Spot in pairs with Chicago futures, Paranaguá, Rosario Futures, and the overall model, presented a very similar pattern to the TAR model. Both failed to reject the null hypothesis, indicating that the price transmission is symmetric. The only observed difference between the TAR and MTAR model is in the cointegration test under asymmetry. The TAR model failed to reject the null hypothesis of non-cointegration between the Rosario Spot and Rosario Futures markets. However, the MTAR model with the cointegration test of [14] rejected the null hypothesis and found cointegration between these markets, in line with the empirical results [5]. This result is consistent with

Table 13. MTAR model for Rosario Spot.

Rosario Spot	Chicago		Rotterdam		Paranaguá		Rosario Futures		Overall model	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Above Threshold	−0.23	0.07	−0.23	0.09	−0.34	0.09	−0.18	0.07	−0.40	0.08
Below Threshold	−0.22	0.07	−0.21	0.08	−0.32	0.09	−0.28	0.10	−0.25	0.08
Differenced Residuals (t − 1)	0.30	0.09	0.03	0.09	0.26	0.09	0.24	0.09	0.31	0.09
Differenced Residuals (t − 2)	0.15	0.09	0.03	0.09	0.10	0.09	−0.08	0.09	0.21	0.09
Threshold value (tau):	0.00		0.00		0.00		0.00		0.00	
F-equal:	0.03	3.89	0.03	2.78	0.04	3.73	0.70	3.85	2.22	3.90
T-max value:	−3.28	−1.98	−2.54	−2.10	−3.67	−2.00	−2.56	−1.97	−3.11	−2.83
F-joint (Phi):	9.92	6.34	6.04	5.85	11.87	6.39	6.65	6.34	16.45	10.58

empirical evidence. In terms of asymmetric price transmission, against intuition and expectation due to government intervention, the Rosario spot market did not present any evidence of APT (Table 13).

4. Discussion

This study was conducted as an extension of previous research on market integration, efficiency, and price transmission in the soybean market by the same authors. The aim of the study was to investigate the possible asymmetry of price transmission in soybean markets that are subject to government intervention. The methodology was designed to complement the previous results and provide a more comprehensive understanding of the topic.

The BDS test results suggested a non-linear nature of the majority of the time series, which calls into question the applicability of linear models such as the Vector Error Correction Model (VECM) and opens up the possibility of using non-linear approximation models such as TAR and MTAR. The Phillips-Perron unit root test indicated that the series were stationary at first difference and integrated at order I(1), which is consistent with the previous research by [5] using the same data set but a different methodology (the Augmented Dickey-Fuller unit root test).

The mixed results from the Engle-Granger cointegration test and both the cointegration and threshold test proposed by [14] and the Johansen cointegration test raise questions about the statistical power of the first test. Empirical evidence supports that Johansen cointegration test is superior in terms of cointegration analysis. This test overcomes the limitations of the Engle-Granger methodology by estimating and testing for the presence of multiple cointegration vectors through canonical correlation. Monte Carlo simulation studies have provided evidence of better performance from the Johansen methodology [15].

The results of this study revealed a clear association between government intervention, structural breaks, and a lack of cointegration vectors. The Johansen test performed better in correcting for structural breaks and finding cointegration equations, as was seen in the study by [5]. The cointegration and threshold test proposed by [14] for the MTAR model showed similar results to the Johansen methodology. However, the same test applied to the TAR model showed a lack of cointegration in intervened markets. This suggests that the Johansen cointegration test has greater statistical power to detect cointegration vectors. Furthermore, when market interventions generate exogenous shocks that affect the market, the cointegration gradually fades over time, and the Engle-Granger test starts to give mixed or inconclusive results.

In conclusion, despite some cointegration tests (Engle-Granger) failing to find cointegration in some cases, the [14] test for the MTAR and the empirical evidence from the Johansen cointegration test indicate that the market is highly cointegrated, showing long-term relationships among and between the series.

The MTAR and TAR models failed to find any evidence of asymmetric price transmission among and between the time series. This contradicts the suggestion of asymmetric price transmission from the international market to Argentina and the Chinese spot market made by previous researchers [5]. One limitation of using the TAR model is the arbitrary selection of sample periods. The choice of sample period can affect the TAR model's parameters, making it necessary to test different sample sizes [12].

Ignoring these limitations, the research results suggest that instead of asymmetric price transmission, the transmission is symmetric, and market intervention might be associated with a lack or fade of cointegration equations or temporary APT in intervened markets. Many of these interventions generated structural breaks in the market when converted as dummy variables and used as exogenous variables to correct the cointegration model. This raises questions about whether these interventions temporarily dislocate the market and if the arbitrage process efficiently returns to symmetrical long-term equilibrium. [5] failed to prove this in the case of market dislocation caused by the US-China trade war, but their methodology might have overestimated the impact of the trade war in terms of generating structural breaks in different international markets.

Further Research & Policy Implications

Despite the conclusive results regarding APT, further research is needed to address the limitations of the TAR/MTAR methodology [12] and explore alternative methods. One such approach could be to adopt a multivariate quantile approach, such as the Vector Autoregressive Quantile Model (VARQ), which is considered superior to conventional OLS regression as it is not influenced by extreme values [13].

The nature of the results, indicating symmetrical price transmission in all markets, despite consistent structural market intervention, may lead to the conclusion that there is no association between market intervention and APT in this case. However, the researchers believe that this is not the case, and therefore, caution is advised when drawing policy implications until further research clarifies the mixed results.

5. Conclusions

The non-linear nature of the time series raises doubts about the applicability of autoregressive models and opens the possibility of investigating non-linear models. The results of the Engle-Granger cointegration methodology for highly government-intervened markets showed a lack of cointegration vectors. However, the cointegration and threshold adjustment test proposed by [14] for the MTAR model showed that the market is fully cointegrated after the series were corrected for structural breaks. In other words, this result reflects the presence of a long-run equilibrium that converges over time.

Contrary to previous researchers' suggestions of APT, the TAR and MTAR models did not show any signs of asymmetric price transmission. Instead, all models showed symmetric price transmission. This suggests that the international soybean market is highly cointegrated, efficient, and symmetrical, capable of circumventing market interventions through arbitrage and converging to long-term equilibrium. Government interventions in some markets (China and Argentina) have caused structural breaks, temporal loss of cointegration vectors, and a loss of market efficiency, instead of generating asymmetric price transmission.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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