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Seasonal Soybean Price Transmission between the U.S. and Brazil Using the Seasonal Regime-Dependent Vector Error Correction Model

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Abstract: Soybean production and trade in the U.S. and Brazil are seasonal. Our research question is whether the seasonal tendencies cause the price relationship between U.S. and Brazilian soybean prices. Therefore, the objective is to test for seasonality in the price transmission between the U.S. and Brazil soybean prices using the seasonal regime-dependent vector error correction model (VECM). Our results show that the speed of the adjustment for the U.S. soybean price in the first half of the year is greater than the speed of the adjustment for the Brazilian soybean price. However, the pattern of their responses becomes the reverse in the second half of the year. The component share calculated by the result of the VECM with seasonal effects indicates that the U.S. dominates the world soybean market during the second half of the year while Brazil is dominant in the soybean market in the first half of the year. These results give us an important finding that we could not find using the VECM without seasonal effects. Finally, our results imply that the seasonal pattern of production in the U.S. and Brazil could cause the sustainability of the supply chain in the world soybean market.

Keywords: component share; seasonality; seasonal regime-dependent VECM; soybeans; soybean products

1. Introduction

The seasonal patterns of soybean production in the U.S. and Brazil play an important role in international soybean trade flows and the sustainability of the global soybean supply chain. The U.S soybean harvest season is from September to February, which is a second half year and Brazil harvests soybeans from March to August which is a first half year. Hence, Figure 1 shows that the main soybean export season in the two countries is relied on the harvest season [1]. On an eight-year average, the share of U.S. soybean exports in the first half of the marketing year is 0.22 but the share of U.S. soybean exports in the second half is 0.80 (https://www.fas.usda.gov/databases/ global-agricultural-trade-system-gats). On the other hand, the share of Brazil soybean exports in the first half of the year is 0.78 while 0.20 is the share of Brazil soybean exports in the second half (https://comtrade.un.org/).

The seasonal tendencies of soybean production and trade affect seasonal price patterns in the U.S. and Brazil soybean market [2]. Margarido et al. [3] find that the "Law of the One Price" holds between U.S. and Brazil soybean prices in the long run, indicating that two prices are integrated. However, the relationship between the U.S. and Brazil soybean prices in the first half and the second half of the marketing year could be different [4]. For instance, U.S. soybean exports to importing countries such as China in the second half lead to the rise in the U.S. soybean price while the Brazil soybean price falls. On the contrary, the U.S. soybean price fall in the first half of the marketing year as the Brazil soybean price rises.

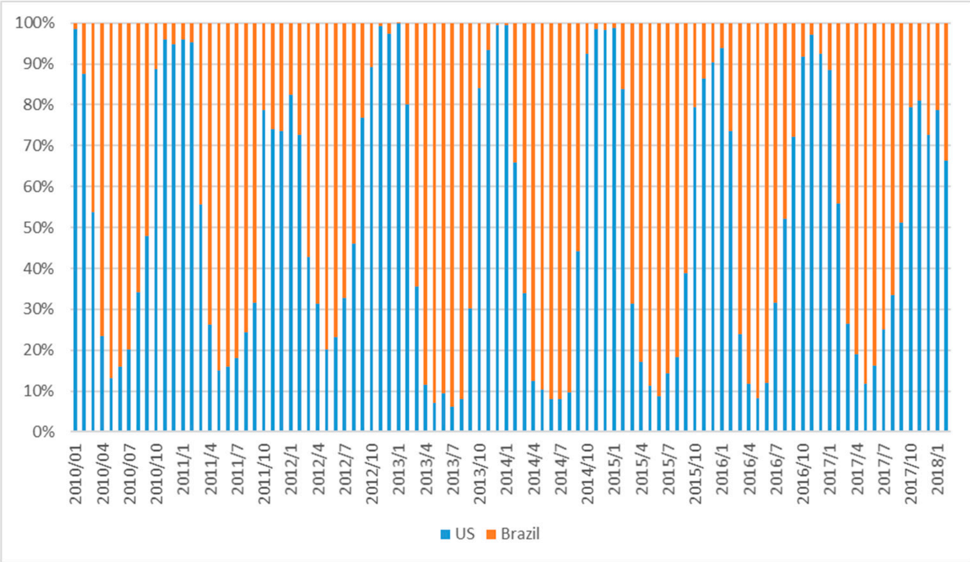

Figure 1. Export patterns in the U.S. and Brazil, Source: USDA-GATS (https://www.fas.usda.gov/databases/global-agricultural-trade-system-gats) and UN COMTRADE (https://comtrade.un.org/).

The price pattern in the world soybean market is subject to changes in trade relations [2]. In 2010/11, the U.S. produced 90 million metric tons and exported 41 million metric tons of soybeans. These amounts were larger than Brazil's soybean production and exports. In 2017/18, the roles were reversed as the U.S. produced 120 million metric tons and exported 61 million metric tons while Brazil produced 124 million metric tons and exported 78 million metric tons. Part of this reversal could be explained, in part, by the current trade tensions between the U.S. and China, which has reduced its purchases of U.S. soybeans. Instead, Brazil and Argentina have helped fill Chinese demand for soybeans. In terms of global sustainability, the U.S. is expected to plant fewer soybeans at the time of writing [5], while there is evidence that Brazil increased its clearance of Amazonian rainforest in 2019.

These changes of trade pattern should also be considered with the price pattern. Figure 2 shows the price pattern in the first and second half years using a price ratio of U.S. price to Brazil price for soybeans, soybean products. When Brazil's soybean exports are high, the price ratio is also high, implying that Brazilian soybean prices are lower than U.S. soybean price. Meanwhile, the price ratio in the second half of the year has become lower since U.S. soybean exports increased relative to Brazil's exports. These price patterns imply that there might be seasonality. Therefore, finding evidence of the seasonal soybean price relationship is important to analyze the impact of trade policy on soybean exporting or importing countries.

Many studies consider seasonality in agricultural commodities using various methods. Miranda and Glauber [6] explore the intra-seasonal pattern of demand for fall potatoes using stochastic dynamic programming and maximum likelihood methods. The authors use seven periods of the marketing year to take seasonality into account. Sun et al. [7] estimate the impact of seasonal price incentive on U.S. milk production using a quarterly dynamic supply response model. Muhammad [8] employs an Almost Ideal Demand System (AIDS) to estimate fresh apple demand in the UK. Taking seasonality into account, the author provides chock prices at which imports are zero because trade is seasonal.

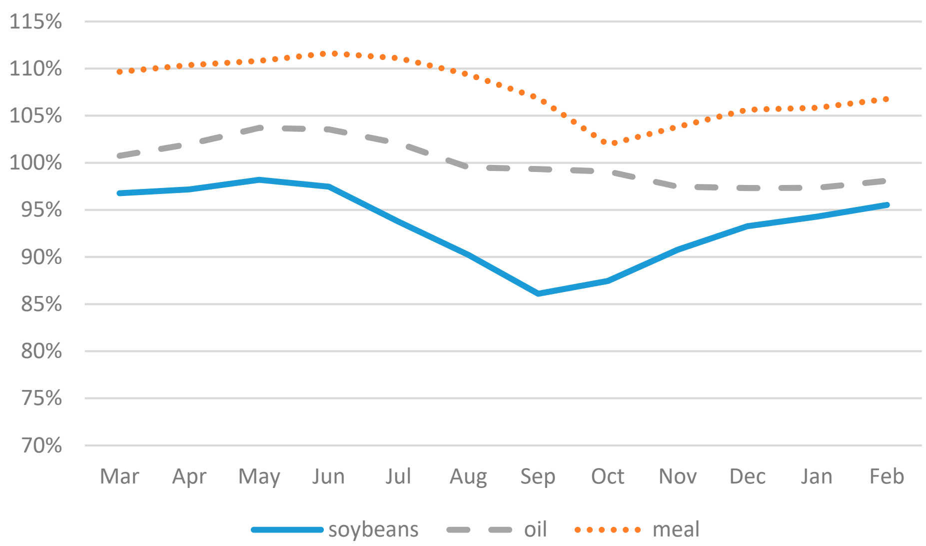

Figure 2. Price ratio of U.S. to Brazilian soybeans and soybean products. Note: The ratio is divided U.S. price by Brazil price. Average prices of each month from 2000 to 2018, Source: USDA, Foreign Agricultural Service. Oilseed: World Markets and Trade (https://www.fas.usda.gov/data/oilseeds-world-markets-and-trade).

Some studies use time series techniques to examine seasonality in commodities. Goodwin et al. [9] examine seasonal fluctuations in butter prices before and after the adoption of mechanical refrigeration using the threshold vector error correction model. The results show that the adoption of refrigeration leads to reducing the seasonal variations of prices. Amikuzuno and von Cramon-Taubadel [4] test that tomato markets in Ghana are seasonally regime dependent. The authors incorporate regime-dependent behavior into the VECM to find seasonal patterns between the producers and consumers in Ghana. Bittmann and Anders [10] show the evidence of seasonal asymmetries in wholesale-retail cost pass-through using a panel two-regime error correction model.

Seasonality in the soybeans market has been examined before. Glauber and Miranda [2] indicate how seasonal pattern in soybean production affects trade, stocks and price integration between the southern and northern hemispheres. The results imply that seasonality in production and trade influences a seasonal pattern of price integration. Margarido et al. [3] also examine the price transmission between the U.S. and Brazil using the error correction model. Based on the adjustment speed coefficients, Brazil responds to shocks faster than the U.S. Machdo and Margarido [11] estimate the seasonal pattern of soybeans between the U.S. and Brazil using the autoregressive integrated moving average (ARIMA) X-11 method. These previous studies point out that soybean markets are seasonal. To the best of our knowledge, our study is the first time a seasonal regime-dependent VECM has been applied to the analysis of soybean markets in the U.S. and Brazil.

Price discovery analysis provides which country dominates price discovery in the market. Usually, price discovery has been studied in the agricultural futures markets [12–14]. Gonzalo and Granger [15] introduce the component share to explore price discovery with the adjustment speed coefficients estimated by the VECM. Arnade and Hoffman [12] and Janzen and Adjemian [14] estimate the information share and the component share using the VECM framework.

The objective of this study is to test the seasonality in the price transmission between the U.S. and Brazil soybean prices. The seasonal regime-dependent vector error correction model (VECM) is used to test the seasonality in the soybean, soybean oil and meal prices between the U.S. and Brazil. For example, the VECM of price transmission between the U.S. and Brazil prices estimates the seasonal speed of adjustment so that we can find the different seasonal speed of adjustment of the U.S. and Brazil soybean prices. The change in the speed of adjustment between two soybean prices represents how the markets are integrated. Following Gonzalo and Granger [15], we then use the relative ratio of the adjustment coefficient with the seasonal regime-dependent VECM to examine the seasonal price discovery and whether the U.S. or Brazil dominates the world soybean market in different seasons.

The paper is organized as follows. Section 2 explains the seasonal regime-dependent VECM model. Section 3 introduces data and cointegration test results and Section 4 reports the empirical results. The conclusions are in Section 5.

2. Empirical Method

The VECM is used to test seasonality in price transmission between the U.S. and Brazil soybeans and soybean products markets. According to Engle and Granger [16], if two variables are cointegrated, the VECM adjusts short-run changes in two variables and deviation from equilibrium. We conduct the VECM model with cointegrated two prices of soybeans, soybean meal and soybean oil. The standard VECM representation is as follows:

$$\begin{bmatrix} \Delta P_t^{US} \\ \Delta P_t^{BR} \end{bmatrix} = \beta^0 + \begin{bmatrix} \beta^{US} \\ \beta^{BR} \end{bmatrix} \hat{e}_{t-1} + \sum_h \Gamma_h \begin{bmatrix} \Delta P_{t-h}^{US} \\ \Delta P_{t-h}^{BR} \end{bmatrix} + u_t, \qquad u_t \sim N\left(0, \sum_{2\times2}\right). \tag{1}$$

P_t^{US} and P_t^{BR} are the price in the U.S. and Brazil at time t, respectively. All prices take logarithm. Δ is the first difference operator. Γ_h represents 2 by 2 matrix of short run coefficients and h is the number of lags. β^0 is constant. A vector of disturbance terms, u_t, has mean zero and 2 by 2 covariance matrix, $\sum$. The VECM estimates the speed of the adjustment at which dependent variables returns to equilibrium after other variables has been distorted from equilibrium. For example, if the speed of adjustment coefficient is 0.5, the disequilibrium condition each is corrected in 50% each month. The higher the adjustment coefficient is the faster the market forces. The error correction term, $\hat{e}_{t-1}$, measures deviations from the long-run relationships between prices. We define $\hat{e}_{t-1}$ as $P_t^{US} - P_t^{BR}$. As real value of P_t^{US} is greater than estimated $\hat{P}_t^{US}$, we expect that the adjustment coefficients, called β^{US} and β^{BR}, have different signs. β^{US} is expected to be negative as $\hat{e}_{t-1}$ is positive value, while β^{BR} is positive because of the negative value in $\hat{e}_{t-1}$.

To test seasonality in Equation (1), we add seasonal dummy variables, indicating that two countries have a different seasonal pattern of soybean production and trade. Following Amikuzuno and von Cramon-Taubadel [4], the VECM model with a seasonal dummy is represented as follows:

$$\begin{bmatrix} \Delta P_t^{US} \\ \Delta P_t^{BR} \end{bmatrix} = \beta^0 + \begin{bmatrix} \beta_1^{US} & \beta_2^{US} \\ \beta_1^{BR} & \beta_2^{BR} \end{bmatrix} \begin{bmatrix} D_1 \\ D_2 \end{bmatrix} \hat{e}_{t-1} + \sum_h \Gamma_h \begin{bmatrix} \Delta P_{t-h}^{US} \\ \Delta P_{t-h}^{BR} \end{bmatrix} + u_t \tag{2}$$

We have two adjustment coefficients in Equation (2) using seasonal dummy variables. Based on the fact that the soybean harvest season in Brazil is from March to May while the U.S. harvests soybean from September to November, we assign the dummy variable, D_1 is 1 if the period is from March to August as the first half of the year while D_1 is 0 if the period is from September to February as the second half of the year. D_2 is the opposite as D_2 is 0 if the period is the first half of the year and D_2 is 1 if the period is the second half of the year. Therefore, ${\beta_1}^{\mathrm{i}}$ is adjustment coefficient in the first half of the year in the U.S. and Brazil and ${\beta_2}^{\mathrm{i}}$ is adjustment coefficient in the second half of the year.

We also calculate the component share (CS) by Gonzalo and Granger [15] to measure which country dominates the soybean market in the first and second halves of the year. CS is calculated as the normalized orthogonal of the vector in Equation (2).

$$\mathrm{CS}_1^{US} = \frac{\beta_1^{BR}}{\left(\beta_1^{BR} - \beta_1^{US}\right)} \text{ and } \mathrm{CS}_1^{BR} = \frac{\beta_1^{US}}{\left(\beta_1^{US} - \beta_1^{BR}\right)} \text{ for the first half of the year} \tag{3}$$

$$\mathrm{CS}_2^{US} = \frac{\beta_2^{BR}}{\left(\beta_2^{BR} - \beta_2^{US}\right)} \text{ and } \mathrm{CS}_2^{BR} = \frac{\beta_2^{US}}{\left(\beta_2^{US} - \beta_2^{BR}\right)} \text{ for the sec ond half of the year.} \tag{4}$$

A large value of CS_t^i indicates that small adjustment coefficient in country i. Equations (3) and (4) represent CS for the first and second half of the year, respectively. The sum of CS_t^{US} and CS_t^{BR} should be one. Comparing the size of CS in the same period, we can examine which country dominates the soybean market. For instance, if CS_1^{BR} is larger than CS_1^{US}, it means that the speed of adjustment coefficient in the U.S. soybean market is relatively larger to the value in the Brazilian soybean market, implying that the Brazil soybean market dominates the soybean trade market [14]. Through CS values, we find if there is different seasonal pattern of price discovery between the U.S. and Brazil in the first and second half of the year.

3. Data

Monthly data from January 2000 to December 2018 for the prices of soybeans, soybean meal and soybean oil in the U.S. and Brazil were obtained from USDA-FAS. Table 1 shows a list of soybeans and soybean product prices in the U.S. and Brazil. A dummy variable for the first half of the year, D_1, is equal to 1 in the period from March to August. A dummy variable for the second half of the year is, $1 - D_1$, which is from September to February of the next year.

Table 1. Data.

Commodity	Country	Source	Unit	Mean	Max	Min
Soybeans	U.S.	U.S. NO. 1 yellow cash central Illinois	$ per MT	332	628	152
	Brazil	Rio Grande, Brazil FOB	$ per MT	356	713	158
Soybean Meal	U.S.	Average wholesale 48% protein	$ per MT	323	622	169
	Brazil	Rio Grande, Brazil FOB	$ per MT	303	621	152
Soybean Oil	U.S.	Average wholesale tank crude	$ per MT	710	1376	273
	Brazil	Brazil FOB	$ per MT	719	1382	266

Source: USDA, Foreign Agricultural Service (https://www.fas.usda.gov/data).

Table 2 represents the unit root test results. There are the Augmented Dickey-Fuller (ADF) test and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test to confirm stationarity for each price [17,18]. The test results show that the ADF test fails to reject the null hypothesis of a unit root for each price in levels and the first differences of each price generate stationarity as the ADF test rejects the null hypothesis. The KPSS test provides that the results reject the null hypothesis of stationarity for each price in levels and fail to reject the null hypothesis using the first differences of each price. Therefore, the results imply that all soybeans and soybean product prices in the U.S. and Brazil are integrated of order one, which is non-stationary.

Table 2. Unit Root Tests.

	US			Brazil		
	Soybeans	**Meal**	**Oil**	**Soybeans**	**Meal**	**Oil**
ADF in Levels	−2.11	−0.89	−2.15	−1.88	−1.83	−2.03
ADF in First Differences	−10.23 ***	−13.2 ***	−10.95 ***	−12.03 ***	−12.86 ***	−11.74 ***
KPSS in Levels	1.28 ***	1.49 ***	1.02 ***	1.42 ***	1.49 ***	1.13 ***
KPSS in First Differences	0.11	0.06	0.15	0.15	0.08	0.16

Note: *, ** and *** denote significant at the 10%, 5% and 1% levels.

The Johansen cointegration test is used to detect if two non-stationary prices in the U.S. and Brazil move together in the long-run [19]. In Table 3, the cointegration test result provides a choice of the time-series method. If two prices are not cointegrated, we allow using the Vector Autoregressive (VAR) model. If two prices are cointegrated, we use the Vector Error Correction Model (VECM) is used with error correction term. All of commodities except for soybean meal have at least one cointegration relation. Hence, we conclude that since all pair prices of soybeans and soybean oil are cointegrated, we use the VECM for our study.

Table 3. Johansen cointegration test results.

Commodities	Trace Statistics		Max-Eigen Statistics	
	$\lambda_{\mathbf{trace}}$		$\lambda_{\mathbf{max}}$	
Soybeans				
$H_0: r = 0$	44.58	(0.00)	40.92	(0.00)
$H_0: r \leq 1$	3.66	(0.05)	3.66	(0.05)
Soybean Meal				
$H_0: r = 0$	26.67	(0.11)	23.52	(0.00)
$H_0: r \leq 1$	3.14	(0.07)	3.14	(0.07)
Soybean Oil				
$H_0: r = 0$	27.64	(0.00)	23.86	(0.11)
$H_0: r \leq 1$	3.772	(0.05)	3.77	(0.05)

Note: Parentheses are *p*-values.

4. Results

The estimation results for the seasonal regime-dependent VECM in Equation (2) are presented in Table 4. The results compare the speed of the adjustment coefficients of the VECM with and without seasonal regime-dependent. The first two columns represent the speed of the adjustment in the first and second half of the year. The last column shows the speed of the adjustment using the standard VECM.

Table 4. The results of adjustment coefficients of the Vector Error Correction Model (VECM) with and without seasonal dummy variables.

Dependent Variable	VECM with Seasonal Effects				VECM without Seasonal Effects	
	First Half Year		Second Half Year			
Soybeans						
P^{US}	−0.22	(0.01)	−0.15	(0.02)	−0.18	(0.00)
P^{BR}	0.02	(0.07)	0.17	(0.01)	0.11	(0.07)
Soybean Meal						
P^{US}	−0.17	(0.03)	−0.36	(0.00)	−0.25	(0.00)
P^{BR}	0.04	(0.56)	0.04	(0.70)	0.04	(0.50)
Soybean Oil						
P^{US}	−0.26	(0.00)	−0.22	(0.02)	−0.24	(0.00)
P^{BR}	0.15	(0.05)	0.06	(0.52)	0.12	(0.06)

Note: Parentheses are *p*-values.

The U.S. soybeans and soybean products markets respond to unpredicted shocks such as a change in other variables in the system. For the U.S. soybean market, the speed of adjustment coefficients are −0.22 and −0.15 in the first and second half of the year, respectively. These coefficients mean that the U.S. soybean market gets back to equilibrium at 22% and 15% each month when there is a shock. The size of the speed of the adjustment is relatively smaller in the second half of the year when the U.S. mainly harvests soybeans to the first half of the year. Therefore, the U.S. soybean price slowly responds to unpredicted shocks in the U.S. soybean harvest season. For the U.S. soybean oil market, the change in the size of the speed of the adjustment is similar to the U.S. soybean and statistically significant. On the other hand, the U.S. soybean meal market returns more quickly to equilibrium and the size of the speed of adjustment in the second half of the year is larger than in the first half of the year.

The Brazilian soybean products markets do not respond well to a shock, whereas the Brazilian soybeans market responds to a shock generating disequilibrium in the system. The Brazilian soybean meal market has a statistically insignificant value at 10% level. One of the reasons could be the low soybean meal exports. U.S. soybean meal exports in 2017/18 market year were 10 thousand metric tons but Brazil exports of soybean meal were less than 0.1 thousand metric tons. The small share of soybean meal exports results in no adjustment between the U.S. and Brazilian soybean meal prices. Moreover, the results of the VECM with seasonal effects for soybean meal prices are consistent with the result of the VECM without seasonal effect. Also, the Johansen cointegration test in Table 3 shows that the soybean meal prices in the U.S. and Brazil are not cointegrated. Therefore, the Brazilian soybean meal does not respond well. The Brazilian soybean oil has a statistically significant adjustment coefficient in the first half of the year when Brazil harvests soybeans but in the second half of the year, Brazilian soybean oil does not adjust quickly back to equilibrium from a shock.

These two different adjustments, using seasonal regime-dependent VECM, imply that the seasonal pattern of soybean production in the U.S. and Brazil represents changes in the adjustment, while the VECM without seasonal effect does not take into account. As for comparing the speed of the adjustment between the U.S. and Brazil in the same period, we find that the soybeans market has different responses to shocks in the first and second half of the year. The speed of the adjustment for the U.S. soybean price in the first half of the year is greater than the speed of the adjustment for the Brazilian soybean price. However, the pattern of their responses becomes the reverse in the second half of the year. These results give us important finding that we could not find the seasonal patterns using the VECM without seasonal effect.

Table 5 shows the value of the CS identifies price discovery. Based on the CS in the results of the VECM without seasonal effects, the Brazilian soybeans dominate the soybean market against the U.S. soybean market. However, the results of VECM with seasonal effects show that the U.S. soybeans dominate the soybean market in the second half of the year because the value of CS for the U.S. is greater than the value of CS for Brazil in the second half of the year. Then, the Brazilian soybeans lead to the soybean market in the first half of the year since the value of CS for Brazil becomes larger than the value of CS for the U.S. For the soybean products market, the Brazilian soybean products dominate the market because of the large value of CS in both VECM with and without seasonal effects. However, because the speed of adjustment coefficients of the Brazilian soybean meal in both first and second half of the year and the Brazilian soybean oil in the second half of the year are insignificant, the CV in the first half of the year for soybean oil could be only interpreted. The value of CS for the Brazilian soybean oil market is the price discovery reference market.

Table 5. Comparisons of component share.

	VECM with Seasonal Effects		VECM without Seasonal Effects
	First Half Year	**Second Half Year**	
Soybeans			
CS^{BR}	0.91	0.47	0.63
CS^{US}	0.09	0.53	0.37
Soybean Meal			
CS^{BR}	0.80	0.91	0.86
CS^{US}	0.20	0.09	0.14
Soybean Oil			
CS^{BR}	0.64	0.78	0.68
CS^{US}	0.36	0.22	0.32

Source: Authors' calculations.

5. Conclusions

The seasonal tendencies of soybean production and trade in the U.S. and Brazil cause changes in the price relationships between two major soybean exporting countries. Our study uses the seasonal regime-dependent VECM to test whether soybeans and soybean products in the U.S. and Brazil are seasonal. The value of the CS calculated by the speed of adjustment coefficient from the seasonal regime-dependent VECM finds which country dominates the world soybean market in the first and second halves of the year.

Our results show that the U.S. soybeans and soybean products markets respond differently to unpredicted shocks in the system. The U.S. soybeans and soybean meal prices seem to respond more slowly to unpredicted shocks in the U.S. soybean harvest season. While the U.S. soybean meal prices return to equilibrium somewhat quickly, the size of the speed of adjustment in the first half of the year is larger than in the second half of the year. The Brazilian soybean products markets do not respond well to a shock, whereas the Brazilian soybeans market responds relatively quickly to a shock generating disequilibrium in the system.

The seasonal pattern of soybean production in the U.S. and Brazil generates price discovery in different season. Based on the CS in the results of the VECM without seasonal effects, the Brazilian soybeans dominate the soybean market against the U.S. soybean market. However, the results of VECM with seasonal effects show that, while Brazil dominates the market in the first half of the year, the U.S. is more dominant in the soybean market during the second half of the year.

Our results imply that the seasonal pattern of soybean production and trade leads to changes in the speed of adjustment, which is not captured by the VECM without seasonal effect. The study emphasizes that soybean producers and traders should react to the seasonal tendency of soybean production. Moreover, a change in the seasonal pattern of soybean production could be an indicator of a change in the sustainability of world soybean production. Lastly, our study can help traders and policy markets understand that there is a seasonal price pattern in the soybeans and soybean product market.

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