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Abstract

1 Introduction

The volatile trend of grain prices during the last decades, aroused much attention on how grain prices are fixed in international markets and how they respond to shocks. The main reason is despite the fact that prices fluctuation affects consumers choices it also affects farmers profit and competitiveness. In any market, prices are determined by supply and demand, and are affected by harvest period, weather, price of inputs, economic growth, inflation, exchange rate, consumption patterns and others. For instance, grain prices rise in response to inflation, but decrease during harvest period because of high supply. To reduce uncertainty related to prices fluctuation, farmers use future contracts on derivative markets (Chicago Board of Trade for corn and soy; Winnipeg stock exchange for canola; Minneapolis stock exchange for wheat, etc.) to secure a minimum spot price for grains. Depending on future prices, farmers make use of hedging strategy to reduce prices losses in local markets (CME Group, 2022).

Future prices are used by market participants to forecast spot prices in real market, because they tend to move together and converge to each other in the long run (Ding and Karali, 2019). In response to exogenous shock, prices may deviate from their equilibrium, either spot prices are greater than future prices or the reverse. Thus, governments or institutes implement price adjustment policies to restore somehow the equilibrium. Based on policy implications of prices adjustment [1], this study aims to examine the dynamic relationship between spot and future prices for corn and soybean in Quebec market.

Extensive literature have investigated the relationship between future and spot prices for agricultural commodities. Findings of most of these studies indicate strong relationship between spot and future prices, and for several agricultural commodities a change in future price has a significant effect on spot price. However, two schools of thought dominate the theory on spot-future relationship, one group of studies assumes linear relationship between spot and future prices and another group assumes a nonlinear relationship. Yan and Reed (2014) used

[1] Correct specification of prices transmission helps producers to assess cost-effectiveness of hedging, to forecast spot prices and to mitigate price risks.

daily data on seven years period to estimate linear cointegration (long-run relationship) and Granger causality between spot and future prices for corn and soybean in China. Their results suggest that Chinese corn futures prices lead the spot prices. For soybeans, imported soybean (GMO) future prices lead spot prices but spot prices lead non imported future prices. In addition to Granger causality, Xu (2019) estimate contemporaneous causality between US corn futures and seven cash prices from major producing states and found in sample Granger causality from future prices to spot. These studies mainly assumed that time series on agricultural commodities are no stationary but their linear combination may be; and also assumed symmetric prices adjustment to shocks. Their main contribution is that they explicitly estimate the direction of causality between spots and futures.

Other studies argued that relationship between prices of agricultural commodities is nonlinear on a long period because it may present one or several structural break(s), a change in their process's behavior over different time intervals. Structural break occurs when there is exogenous shock. Moreover, the existence of "m" structural breaks creates "$m+1$" regimes or time intervals. In this case, prices are cointegrated over each regime, and linear relationship shifts from one regime to another. Based on these arguments, Dawson and Sanjuán (2006) used monthly data for 1974-2001 to show that a long-run relationship between the export prices of Canadian and US hard wheat exists and presents two breaks in late 1985 and early 1995, that coincide with the Export Enhancement Program. They estimated linear cointegration within each of the three regimes defined by the breaks and found that Canada is price leader. Elmarzougui and Larue (2013) identified three breaks in the relationship between monthly international prices of crude oil and corn over 1957-2012. They found that oil and corn prices are not cointegrated in all four regimes, only in the last regime, and oil price shocks systematically affect corn prices. These studies used impulse response function to estimate dynamic bivariate relationship, and measured to what extent a shock in one price impacts the other price. They do not estimate prices adjustment speeds to move back to the equilibrium.

Recent studies used threshold cointegration approach to estimate dynamic relationship and prices adjustment speeds. This approach assumes when a deviation from the equilibrium exceeds a critical threshold, prices adjustment is asymmetric. Depending on the shock, increase or decrease in one price, the adjustment speed of other price is low or high. In contrast to the linear cointegration approach that assumes symmetric price adjustment, threshold cointegration models are related to nonlinear long-run relationship and asymmetric price adjustment. Rasheed et al. (2016) adopted this approach to estimate threshold adjustment between monthly prices of crude oil and soybean. Their results indicate that soybean prices adjust faster to the increase in crude oil prices. In other words, soybeans commodity prices rise faster when crude oil prices increase than its decrease. Kim and Mark (2017) also employed three regimes threshold model with monthly data and found that current Korean beef price is positively affected by increasing in the previous month of Australian beef price in first and second regimes, and also by previous corn price in third regime. Wu et al. (2018) used Wednesday weekly spot and futures closing prices for corn and soybeans in Ontario to show that spot prices of corn adjust more rapidly to an increase in future price than a decrease in future price while spot prices of soybean adjust more rapidly to a decrease in future prices than an increase in future prices. Balke et al. (1998), Ghoshray (2007), Subervie (2011) and Chang et al. (2012) also employed threshold framework to study asymmetric adjustment for agricultural commodities other than corn and soybean subjects in this paper. Empirical evidence using nonlinear cointegration models and different time frequencies indicate mixed results on prices transmission. To identify full adjustment between spot and future prices, Kuiper et al. (2002) propose the use of sufficiently low frequency of data.

Above studies used different frequencies of data within threshold cointegration framework and found mixed results on prices transmission for corn and soybean. Furthermore, prices adjustments found are related to a specific frequency. The main contribution of this paper is that it uses different frequencies of data to investigate the dynamic relationship between spot and future prices for corn and soybean on 1994-2022 period. This study uses four threshold cointegration models and daily data to estimate prices adjustments and check whether adjustments change when estimated with weekly and monthly data. In addition, we estimate the relationship between spot prices in Quebec and Ontario markets to check whether prices adjustments change in a neighbor market. This study extends the literature on price transmission of a small market with positive basis where corn and soybeans are mostly used for animal feeding and industrial transformation. The remainder of the paper is organized as follows. Section 2 describes Quebec grain markets. Section 3 presents the data, section 4 details the empirical framework, section 5 presents and discusses the results and the last section concludes.

2 Overview of Quebec grains Market

Grains are important food crops in Canada as a whole and specifically in Quebec. In Quebec province, grain production is third after milk and pork production in terms of revenue. In 2004, grain production generated two milliards Canadian dollars and created several direct and indirect jobs. There are about 12,500 grain producers in the province for a production volume of 5.1 million tons on 976,200 hectares of land with a total market sales return of 3.7 billion dollars in 2018. The main grains produced in the region are cereals like corn, wheat, barley, oats, and oleaginous (i.e. soybean and canola). More than 80% of produced grains are used for cattle feeding (MAPAQ, 2020). The rest is used either in the production of flours used for bread, cakes, biscuits, pasta, etc., or in the production of beer (barley, corn) and vegetable oils (oleaginous). Market is characterized by high demand of wheat for human food, of corn for animal food, and soybean and canola industrial use (MAPAQ, 2020). Corn is the major crop produced in the region where the main production zones are Monteregie (62 %); Centre-du-Quebec with (15 %); Montreal, Laval and Lanaudiere with (7 %), Capitale-Nationale and Mauricie with (6 %) and Chaudiere-Appalaches with (5 %). Corn and soybean are the grains most produced in Quebec in 2019 with 3,422,600 tons (9.1 t/ha) and 1,051,000 tons (2.9 t/ha) respectively in 2019 (Gouvernement du Canada, 2022).

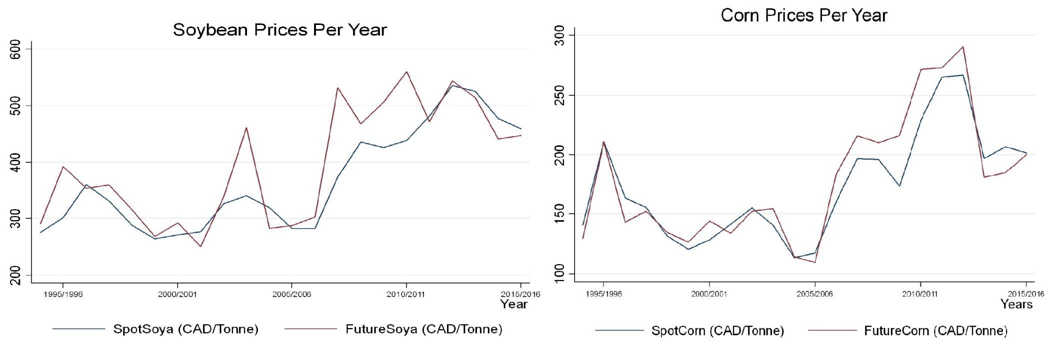
Quebec grain industry has improved in terms of commercial production, even though historically Quebec was known to be depending on import of grains. Globally, Quebec province exports grain corn, oats as well as soybeans, and imports barley, wheat and canola. Quebec exports mainly corn to United States of America (57 %), Ireland (23 %), and Spain (20 %); and soybeans to Italy (25%) and Japan (11%).

Figure 1 shows that yearly adjusted future price is greater than yearly spot price, for corn and soybean in Quebec [2]. From 2014 to 2016, Yearly spot prices of soybean and corn are greater than their corresponding future prices. Between 1995 and 2016, yearly spot price of soybean has saw-tooth trend. Its higher value is 535.80 CAD in 2012 and its lower value is 282,68 CAD in 2006. However yearly spot price of corn has decreasing trend between 1997 and 2005 and increasing trend between 2006 and 2012. Its higher value is 266.76 CAD in 2012 and its lower value is 113.56 CAD in 2004.

Figure 1: Trend of spot and future prices of corn and soybean (Quebec)

Many studies investigated price dynamics in Canadian grain market, but none focused on price dynamics in Quebec grain market. McKnight et al. (2021) used weekly data from July 2008

[2] Data on spot prices are from Statistics Canada; Data on future prices are from CME group website; and data on exchange rate are from historical exchange rate website.



to April 2018 to investigate time-varying relationships between Canadian wheat prices and US corn, ethanol, and gasoline prices. Their results indicated positive relationships between wheat and corn, ethanol and corn, and wheat and ethanol markets; and also price volatility in each market in response to shock. Dawson and Sanjuán (2006) examined the long-term relationship in presence of structural breaks between the hard wheat monthly prices of Canadian Western Red Spring (CWRS) and US Dark Northern Spring (DNS) exported from Atlantic ports from 1974 to 2001. They found that a long-term relationship exists, and Canada is price leader. Bessler et al. (2003) and Mohanty and Langley (2003) reached the same conclusion. The major gap of recent literature is that most studies are on oil and wheat Canadian markets and they examined price relationship between Canada and others high income countries (United States or European countries). Few studies considered price dynamics in grain market other than wheat. Wu et al. (2018) investigated a nonlinear dynamic relationship between spot and futures prices of corn and soybean in Ontario. The present study extends literature on prices relationship in grain market by the fact that it assesses how corn and soybean prices perform in Quebec market on 28 years period over the long and short runs and whether their performance are consistent with different time-frequency.

3 Data

Data used in this analysis are uninterrupted price series, spot and future for corn and soybean, from september 1994 to may 2022. The sample period covers 10,105 days, 1443 weeks and 333 months. The daily spot prices in Canadian Dollars (CAD) per ton are obtained from la Financière Agricole du Quebec, and the monthly spot are from Statistics Canada. The corresponding daily future prices in US Dollars (USD) per bushel are from CME group (CBOT) and they are used to compute the average monthly future prices. The weekly data are based on Wednesday price series in the sample period. For analysis, spot and future prices are converted into CAD per bushel and transformed into natural logarithm. In this regard, spot prices in CAD per ton are divided by 39.368 bushels for corn and by 36.744 bushels for soybean [3] Future prices in USD per bushel are multiplied by the exogenous US-Canada exchange rate [4].

Descriptive statistics in table 1 show that on average, corn spot price in Quebec market is greater than the adjusted future price at daily, weekly or monthly level. In contrast average soybean spot price in Quebec market is lower than the adjusted future price. Moreover, average monthly spot prices of corn and soybean in Ontario market are the smallest, compared to their

[3] One ton of grain corn is equal to 39.368 bushels whereas one ton of soybean is equal to 36.744 bushels. Grain measures are obtained from Alberta Government website in the sector of agriculture, forestry and rural economic development.

[4] https://fxtop.com/en/historical-exchange-rates.php?A=1&C1=USD&C2=CAD&MA=1&DD1=01&MM1=01&YYYY1=1994&B=1&P=&I=1&DD2=30&MM2=06&YYYY2=2022&btnOK=Go%21, last access April 4th, 2023

corresponding spot prices in Quebec market and future prices. Standard deviations suggest that all price series have same variability, monthly spot prices of corn and soybean fluctuate more in Quebec than in Ontario (Table 11 in Annex).

Table 1: Summary statistics of Quebec spot and future prices for corn and soybean

(1) Variables	(2) N	(3) Mean	(4) Standard deviation	(5) Min.	(6) Max.
Daily prices					
Corn spot in Quebec market	10105	4.748	1.365	2.259	9.815
Corn adjusted future	10105	4.488	1.395	2.257	10.462
Soybean spot in Quebec market	10105	10.688	2.825	5.579	21.288
Soybean adjusted future	10105	10.894	3.043	6.008	22.064
Weekly prices					
Corn spot in Quebec market	1443	4.754	1.364	2.511	9.562
Corn adjusted future	1443	4.489	1.396	2.257	10.295
Soybean spot in Quebec market	1443	10.671	2.803	5.869	20.537
Soybean adjusted future	1443	10.9	3.052	6.03	22.045
Monthly prices					
Corn spot in Quebec market	333	4.777	1.367	2.605	9.322
Corn adjusted future	333	4.503	1.422	2.299	10.07
Soybean spot in Quebec market	333	11.132	3.011	6.34	21.1
Soybean adjusted future	333	10.926	3.082	6.113	21.303

4 Modeling prices adjustment within cointegration framework

Relationship between future and spot prices is established by either no arbitrage or arbitrage price theories. Arbitrage theory defines future price as the sum of spot price and cost of carry. The last measures storage cost (u_t) plus interest rate (r_t) minus the carry return (y_t) or income earned (Fernandez, 2016). Arbitrage refers to the strategy used by agent to purchase a commodity in long future contract and sell it at the end of contract at higher price. In contrast, the non-arbitrage theory establishes a non nonlinear relationship as follows:

$$F_{t,T} = S_t.e^{(u_t+r_t-y_t)(T-t)} \tag{1}$$

$F_{t,T}$ is future price negotiated at time t for delivery at T, and S_t is spot price. The expression $(T-t)$ is future contract period. The cost of carry is $u_t+r_t-y_t$. In terms of logarithm, equation (1) becomes:

$$f_{t,T} = s_t + (u_t + r_t - y_t)(T-t) \Longrightarrow s_t - f_{t,T} = -(u_t + r_t - y_t)(T-t)$$
$$\Longrightarrow s_t - f_{t,T} = z_t$$

where z_t represents the basis. At equilibrium, the basis is equal to zero meaning that future and spot prices move together through a linear long-run relationship. In case of disequilibrium, the basis is different from zero, that is spot price and its corresponding future price deviate from each other. Since spot and future prices for corn and soybean fluctuate over the sample period, the main purpose is to assess whether they are cointegrated and how they go back to their long run equilibrium in presence of temporary shock. The empirical analysis is performed into several steps. At first step, stationarity tests are implemented to check for all price series, the presence of unit roots with or without structural breaks. Stationary test verifies whether a variable's properties (mean and variance) change with time. This test is justified by the fact that linear regression with nonstationary variables may violate the OLS assumptions leading to a time-varying heteroscedastic residuals. To take the structural breaks into account, Gregory and Hansen residual-based test is performed at the second step, to estimate the most possible break date in long-run relationship. Thereafter, the break date is used at the third step to estimate long run-relationship with linear cointegration model proposed by Engle and Granger (1987) and nonlinear or threshold cointegration models proposed by Enders and Siklos (2001). Once results indicate that prices are cointegrated, the final step estimate error correction models to assess how prices adjust from disequilibrium. Cointegration and error correction models are related because cointegration of variables implies that they automatically adjust to prevent larger errors in the long-run relationship (Phung Thanh Binh, 2013).

4.1 Unit root and structural break tests

The well known stationarity tests are Dickey Fuller test and Philips Perron test. Dickey fuller test is a basic stationarity test that uses first auto regressive model AR (1) to test the presence of unit root. Its main limit is that it does not capture high order autocorrelation. Augmented Dickey Fuller test (ADF) is a modified Dickey Fuller test, a parametric method that uses high number of lags of differentiated series to correct residuals autocorrelation. Philips Perron test also corrects residuals autocorrelation but with non-parametric method. Another unit root test is the Dickey-Fuller Generalised Least Squares (DF-GLS) test proposed by Elliott et al. (1996), that uses Generalised Least Squares (GLS) approach to modify ADF test statistic. This author proved that DF-GLS test has the best overall performance in terms of small sample size and optimal lag selection. It uses the modified Akaike Information Criterion to select the optimal lag (Ng and Perron, 2001). Based on these arguments DF-GLS is used in this study to test for unit root.

In presence of structural break, unit root test assumptions, stating that mean and variance of series do not change over time, do not hold. As consequence, standard tests of Dickey-Fuller, Phillips-Person and DF-GLS are not valid, and lead to misspecification. Structural break is a change in time series in a response to an economic policy or economic shock (Glynn et al., 2007). Methods used to test unit roots and structural breaks, depend on the number of breaks assumed, and the presence of trend. There are Zivot and Andrews (1992) method and Clemente Lopez et al. (1998) method that test the null hypothesis of presence of unit root with structural break but differ with the alternative hypothesis. Zivot and Andrews (1992) proposed three models to test the alternative hypothesis of unit root with one-time structural break. A first model allows one break in intercept. A second model allows one break in trend, and a third model allows one break in both intercept and trend. Clemente Lopez et al. (1998) tests the alternative hypothesis of one or two structural breaks. This approach proposes an additive outlier (AO) model to test a presence of sudden break (a change that occurs instantaneously and disappears), and an innovative outlier (IO) model to test a presence of gradual change. Zivot and Andrews unit root test is based on innovative model and identifies one break even if more than one exists. As Wu et al. (2018), one gradual change is assumed in Quebec grain prices to perform Zivot and Andrews test.

4.2 Linear and nonlinear cointegration tests

In time series literature, it is important to verify that variables are cointegrated. Cointegrated variables means that there exists long run relationship between nonstationary variables at level, or integrated variables of order p. Standard cointegration tests are bivariate Engle Granger and multivariate Johansen-Juselius cointegration tests when series are integrated at same level; and autoregressive distributed lag (ARDL) model when series are integrated at different levels. Based on diagnosis tests, spot and future prices of corn and soybean in this study are integrated at order one. Then Engle and Granger method is used to test cointegration between spot and future prices.

Engle and Granger (1987) cointegration test is a two steps linear model. At first step, it uses the following equation to estimate long run relationship between spot and future prices for both corn and soybean and predicted residuals Z_t:

$$S_t = \beta_0 + \beta_1 F_t + Z_t \tag{2}$$

where S_t and F_t are respectively log of spot price and log of adjusted future price. β_0 and β_1 are parameters to be estimated. β_1 is the long run relationship or price adjustment. Predicted residuals represent the basis, or the unobserved transaction and storage costs. At the second step, residuals stationarity is verified with ADF test, through the equation below.

$$\Delta Z_t = \rho Z_{t-1} + \sum_{i=1}^{k} (\sigma_i \Delta Z_{t-i} + v_t) \tag{3}$$

The parameter ρ represents price adjustment speed, and σ_i is used to correct errors serial correlation. There is a long relationship between log of spot price and log of adjusted future price if ρ is significantly lower than one, leading to stationarity of residual at level. Engle and Granger (1987) cointegration test is then a stationary test of residual. It is a static model based on symmetric price adjustment for temporary deviation from long run equilibrium and is not valid in presence of structural breaks or when there is nonlinear relationship between prices.

Nonlinear relationship in time series analysis is explained by structural change (Giordani et al., 2007) or when a larger shock (greater than a threshold) causes response different to smaller shock (Goodwin and Holt, 1999). Gregory and Hansen (1996) proposed a method to test the null hypothesis against the alternative of cointegration with a single unknown break in time. They assumed that in presence of nonlinear cointegration, cointegration holds over some period and shifts to a new long-run relationship. Based on structural break test, nonlinear cointegration with shift in constant and trend is tested as follows [5]:

$$S_t = \gamma_0 + \gamma_1 D_t + \gamma_2 t + \gamma_3 F_t + Z_t \tag{4}$$

D_t is a dummy variable defined by: $D_t = \begin{cases} 0 & \text{if } t \leq T \\ 1 & \text{if } t > T \end{cases}$ for a given time T of structural break. S_t and F_t are I(1). γ_0 is the intercept before the shift; γ_1 is the estimated change in the intercept at the time of the shift; γ_2 denotes the change in the trend and γ_3 denotes the cointegrating slope coefficient before the regime shift. Nonlinear cointegration test predicts residual from this regression and perform ADF test.

4.3 Nonlinear or threshold cointegration models

In the standard cointegration test proposed by Engle and Granger (1987), error terms are autoregressive process and prices adjustment are symmetric. However, price adjustment to long run equilibrium may be asymmetric when cointegration is not linear, that is response to a shock is dynamic. Enders and Siklos (2001) introduced a two-regime model in which residual

[5] Gregory and Hansen (1996) proposed four models to test nonlinear cointegration: a model with cointegration with a level shift, a model with a cointegration with a trend shift, a model with a cointegration with a regime shift and a model with cointegration with a regime shift and trend.

deviation from the long run equilibrium behaves as Threshold Autoregressive process. This Threshold Autoregressive model (TAR) is defined as follows:

$$\Delta Z_t = I_t \rho_1 Z_{t-1} + (1 - I_t)\rho_2 Z_{t-1} + \sum_{i=1}^{k}(\sigma_i \Delta Z_{t-i} + v_t) \tag{5}$$

It is the Heaviside indicator that takes the value of one when the first lag of residual ($Z_{(t-1)}$) is greater than the threshold (τ). It equals to zero if $Z_{(t-i)}$ is lower or equal to threshold.

$$I_t = \begin{cases} 0 & \text{if } Z_{t-1} \geq \tau \\ 1 & \text{if } Z_{t-1} < \tau \end{cases}$$

Condition $Z_{(t-1)} \geq \tau$ refers to positive deviation from the threshold and then decrease in future price; while $Z_{(t-1)} < \tau$ refers to negative deviation from the threshold increase in future price (Subervie, 2011). Estimated parameters ρ_1 and ρ_2 represent prices asymmetric adjustment. Predicted residual is stationary if ρ_1 and ρ_2 are both lower than 0: $\rho_1 < 0$, $\rho_2 < 0$ and $(1 + \rho_1)(1 + \rho_2) < 1$ (Enders and Siklos, 2001). Stationary of residual with asymmetric adjustment indicate that spot and future prices are cointegrated at a given threshold. It means that adjustment occurs when spot price deviation from future price exceeds some critical threshold, and adjustment to positive deviation is different to negative deviation.

Modified Fisher test of Enders and Siklos (2001) are usually used to test the null hypothesis of no cointegration ($\rho_1 = \rho_2 = 0$) against the alternative hypothesis of cointegration ($\rho_1 \neq \rho_2 \neq 0$). Joint Fisher test is computed ($\rho_1 = \rho_2 = 0$) and compare statistics to critical values given by Enders and Siklos (2001). If there is cointegration, standard Fisher test is used to check whether prices adjustment is symmetric ($\rho_1 = \rho_2$) or asymmetric ($\rho_1 \neq \rho_2$). In case wher $\rho_1 \neq \rho_2$, there are two situations $|\rho_1| > |\rho_2|$ or $|\rho_1| < |\rho_2|$.

If $|\rho_1| < |\rho_2|$ negative deviation from equilibrium adjusts more rapidly than positive deviation. That is spot prices adjust more rapidly to increase in future prices than a decrease in future prices (Wu et al., 2018). However if $|\rho_1| > |\rho_2|$, spot prices adjust more rapidly to positive deviation, than a decrease in future prices. TAR model is estimated with threshold $\tau = 0$ and $\tau \neq 0$. When threshold is different from zero, its value is estimated by grid search such that it minimizes the sum of squared errors (Chan, 1993). In this case asymmetric adjustment model is called consistent TAR. Momentum threshold autoregressive (M-TAR) model and consistent M-TAR models with $\Delta_{(t-1)}$ threshold variable instead of $Z_{(t-1)}$ are also estimated. In these models, first lag of residual and its first difference are sorted and trimmed to 15% smallest and largest before threshold that minimizes the SSR is settled. M-TAR model is estimated when there is asymmetric adjustment and more deviation to one direction. For example, when there is more positive deviation of basis than negative deviation. Heaviside indicator of M-TAR model is defined as follow:

$$I_t = \begin{cases} 0 & \text{if } \Delta Z_{t-1} \geq \tau \\ 1 & \text{if } \Delta Z_{t-1} < \tau \end{cases}$$

4.4 Symmetric and asymmetric error correction models (ECM)

Preliminary results indicate that Spot and future prices are integrated of order one and cointegrated for both corn and soybean market in Quebec and that the price series have a long run relationship. Consequently, an error correction model (ECM) can be used to test whether spot price causes future price adjustment or adjusts to its deviation (Engle and Granger, 1987). As a rule of practice, ECM can be estimated in one or two steps. In case of asymmetric adjustment, first step of ECM estimates long run relationship and test if estimated residual is stationary. The second step regresses first difference of spot price (ΔS_t) on first difference of future price

(ΔF_t) and first lag of residual estimated at first step (Z_{t-1}) with additional constant term. Estimated coefficient of ΔF_t measures the short run effect of a change in future price on a change in spot price. Z_{t-1} represents error correction term, short run fluctuations from long run relationship estimated at the first step. Its estimated coefficient is the error correction coefficient or adjustment effect. This coefficient should be negative and significant. In this study, bidirectional symmetric ECM equations are estimated as follows:

$$\Delta S_t = \beta^S + \sum_{i=1}^{k} \sigma_{i,F}^S \Delta F_{t-i} + \sum_{i=1}^{k} \sigma_{i,s}^S \Delta S_{t-i} + \delta^S Z_{t-i} + \varepsilon_t^S \quad (6)$$

$$\Delta F_t = \beta^F + \sum_{i=1}^{k} \sigma_{i,F}^F \Delta F_{t-i} + \sum_{i=1}^{k} \sigma_{i,s}^F \Delta S_{t-i} + \delta^F Z_{t-i} + \varepsilon_t^F \quad (7)$$

The term $\sum_{i=1}^{k} \sigma_{i,s}^S \Delta S_{t-i}$ is included to correct serial correlation error. $\sigma_{i,F}^S$ is the short run effect of a change in future price on change in spot price. δ^S is the error correction term and represents how cointegrated spot and future prices move back to long run equilibrium when there is deviation. Threshold ECM is also estimated to examine price adjustment to short run positive and negative deviation and asymmetric error correction coefficients in the long run.

5 Results

5.1 Price series diagnosis

This study tests the presence of unit root in prices series of corn and soybean for the three frequency time data: daily spot price in Quebec market, daily future prices, monthly spot prices in Quebec and Ontario markets. Table 2 presents results of DF-GLS unit root test and Zivot-Andrew test for spot prices in Quebec and future prices (see Table 12 in Annex for Ontario market). In table 2, the DF-GLS statistics are compared to Elliott-Rothenberg-Stock critical values. With no linear trend, all price series present unit root at level and are integrated of order 1, that is I(1) at conventional significance level. With linear trend, all prices except daily soybean spot price in Quebec market are stationary at level, and all prices except daily corn spot in Quebec market are I(1). In columns 6 and 7 of table 2, Zivot Andrew test results show that all price series daily and monthly are I(1) with break in trend and intercept.

Before cointegration analysis, Gregory and Hansen test is performed for eight bivariate prices relationships: corn spot in Quebec market and future, soybean spot in Quebec market and future corn spots in Quebec and Ontario markets, soybean spots in Quebec and Ontario markets. Gregory and Hansen test predicts residuals from nonlinear relationship and computes ADF statistics and Phillips test statistics for all estimated breakpoints. The results presented in table 3, indicate that each paired price series move together with one time regime shift. Estimated breakpoints retained are from the smallest statistics values, except the one retained from ADF test for soybean monthly spot in Quebec market and future. The estimated breakpoints are October 21st 1998 and September 27th 2008, respectively for Quebec daily corn spot-future and soybean spot-future. These periods are close to the ones estimated with weekly and monthly data. Structural change between soybean spot and future prices in September 2008, can be explained by the 2008 food crisis that mostly affected grains and oilseeds prices (FAO, 2022). Moreover, structural break for corn in October 1998 is explained by the huge decrease of hog price in Quebec market/North America. The time of regime shift between monthly spot prices in Quebec and Ontario markets are December 2000 and August 2004 respectively for corn and soybean (Table 13 in Annex).

Table 2: Stationnary test results of Quebec spot and future prices for corn and soybean

(1) Variables	(2) DF-GLS Linear trend	(3)	(4) DF-GLS No linear trend	(5)	(6) Zivot-Andrew	(7))
	Level	First difference	Level	First difference	Level	First difference
Daily prices						
Corn spot in Quebec market	-2.742*	-0.922	-0.411	-1.667*	-3.287	-54.410***
Corn adjusted future	-2.796*	-11.946***	-0.447	-16.954***	-4.019	-38.763***
Soybean spot in Quebec market	-2.022	-20.816***	0.642	-20.761***	-4.924	-45.803***
Soybean adjusted future	-2.999**	-10.370***	-0.557	-10.176***	-4.167	-39.008***
Weekly prices						
Corn spot in Quebec market	-2.750*	-2.142	-0.543	-1.725*	-4.205	-16.474***
Corn adjusted future	-3.012**	-7.317***	-0.565	-4.709***	-4.276	-20.832***
Soybean spot in Quebec market	-2.654**	-26.725***	0.107	-16.258***	-3.462	-17.904***
Soybean adjusted future	-3.261**	-5.577***	-0.533	-2.978***	-4.616	-14.732***
Monthly prices						
Corn spot in Quebec market	-2.917**	-7.008***	-1.071	-3.621***	-4.658	-11.684***
Corn adjusted future	-2.771**	-10.617***	-0.193	-9.686***	-4.852*	-9.314***
Soybean spot in Quebec market	-3.264**	-10.378***	-0.136	-7.982***	-4.174	-9.156***
Soybean adjusted future	-2.848**	-10.001***	-0.229	-7.926***	-5.177	-9.240***

Note: The optimal lag length was determined based on the minimum modified Akaike Information Criterion. ***, **, * indicate respectively significance at the 1%, 5% and 10%. DF-GLS test, with linear trend or not, performed in this study compares statistic values to Elliott-Rothenberg-Stock critical values: -3.48, -2.89, and -2.57 respectively for 1%, 5%, and 10% significance levels. Zivot–Andrews test allows for one single break at an unknown point in both the intercept and the linear trend; with -5.57, -5.08, and -4.82 as critical values at 1%, 5%, and 10% levels.

Table 3: Gregory and Hansen test results of Quebec spot and future prices for corn and soybean

(1) Cointegration relationships [a]	(2) t-statistics	(3) Estimated break points
Spot in Quebec market and adjusted future for corn [b]		
Daily corn prices: spot - future	-854.17***	October 21^{st}, 1998
Weekly corn prices: spot - future	-117.60***	October 21^{st}, 1998
Monthly corn prices: spot - future	-90.06***	October 1998
Spot in Quebec market and adjusted future for soybean		
Daily soybean prices: spot - future	-2225.18***	September 27th, 2008
Weekly soybean prices: spot - future	-579.05***	August 13th, 2008
Monthly soybean prices: spot - future	-83.80***[c]	August 2008

Note: a: Gregory and Hansen test performed in this study, estimated cointegration model with break in constant and trend.
b: Model estimated is $S_t = \gamma_0 + \gamma_1 D_t + \gamma_2 t + \gamma_3 F_t + Z_t$ with daily, weekly or monthly prices of corn and soybean. D_t is a dummy variable that equals to 0 for the period before estimated break point, and equals to 1 from the break point to the period after. γ_0 is the intercept, t is time variable, γ_2 is the coefficient related to the trend and γ_3 is the coefficient related to the future price at time t.
c: Break point estimated for this relationship is from ADF test. The other estimated breakpoints are from the smallest statistic test value (za statistic). ***, **, * indicate respectively significance at the 1%, 5% and 10%.

5.2 Cointegration and asymmetry tests

This section presents results of Engle-Granger cointegration test and threshold cointegration analysis based on the Enders and Siklos (2001) procedure. To estimate long run relationship between spot and future prices (equation 2), daily, weekly or monthly spot price is regressed on its corresponding future price, a dummy variable to take account periode of structural change and a time variable. Predicted residual from each linear relationship is used to estimate Engle-Granger cointegration model and threshold cointegration models. Results in tables 4 and 5 indicate that for both corn and soybean, there is long-run relationship between spot and future prices. Estimates of ρ related to the lag of residuals in columns (2), (3) and (4) in tables 4 and 5 reject the null hypothesis of no cointegration at 1% significance level. Therefore, spot and future prices are cointegrated at any time frequency level for corn and soybean.

Table 4: Results of Engle-Granger cointegration for corn

	Daily corn spot - future[a]	Weekly corn spot - future	Monthly corn spot - future	Monthly corn spot Quebec - spot Ontario[b]
ρ^c	-0,083***	-0,082***	-0,262***	-0,298***
	(0,005)	(0,011)	(0,036)	(0,042)
σ^c	-0,418***	-0,118***	0.202***	0.028
	(0,009)	(0,026)	(0.054)	(0.055)
$Q(4)^d$	709.60***	1.92	2.486	7.046

Note: a: Long-run relationship estimated at first step is $S_t = \beta_0 + \beta_1 F_t + Z_t$ and at second step residual stationnarity is verified with $\Delta Z_t = \rho Z_{t-1} + \sum_{i=1}^{k}(\sigma_i \Delta Z_{t-i} + v_t)$.
b: Long-run relationship estimated at first step is $S_{t,Quebec} = \beta_0 + \beta_1 S_{t,Ontario} + Z_t$.
c: ρ and σ are parameters from residual stationnarity. Entries are point estimates with t-statistics in parentheses.
d: Q(4) denotes the Ljung-Box statistic to test the hypothesis that the first four residuals are not autocorrelated (jointly equal to zero).
***, **, * indicate respectively significance at 1%, 5% and 10% levels.

Table 5: Results of Engle-Granger cointegration for soybean

	Daily soybean spot - future[a]	Weekly soybean spot - future	Monthly soybean spot - future	Monthly soybean spot Quebec - spot Ontario[b]
ρ^c	-0,197***	-0,337***	-0,247***	-0,536***
	0,007	0,024	(0,039)	(0,059)
σ^c	-0,232***	-0,226***	-0.014	-0.046
	(0,01)	(0,026)	(0.055)	(0.055)
$Q(4)^d$	158.76***	40.62***	3.754	0.493

Note: Refer to table 4 notes

Table 6 presents results of threshold cointegration between corn spot and future prices. Estimates with daily data suggest nonlinear dynamic relationship and asymmetry between corn spot and future prices. In each threshold model, the point estimates for adjustment parameters, ρ_1 and ρ_2, (columns (2), (3), (4) and (5) of table 6) are negative and significant suggesting stationary basis term and convergence. In addition, the phi statistic, the Fisher statistic compared to the critical values given by Enders and Silkos (2001) rejects the null hypothesis of no threshold cointegration ($\rho_1 = \rho_2 = 0$) at 1% significance level. The statistics are greater than the critical value at 1%. Results show that spot and future prices of corn are cointegrated with threshold equals to zero for basis in TAR model and for basis change in MTAR model. Corn price series are also cointegrated with -0.09 as threshold for basis in consistent TAR model and -0.03 as threshold for basis change in consistent MTAR model. The standard Fisher statistic to test price asymmetry ($\rho_1 = \rho_2$) suggests symmetric corn prices adjustment in MTAR model. The null hypothesis of symmetric adjustment cannot be rejected. The sample F-statistics in columns (2), (3) and (5) reject the null hypothesis of symmetric adjustment in TAR model at 10% level, in consistent TAR and consistent MTAR models at 1% level. The results of theses tests imply asymmetric adjustment between corn spot and future prices. The adjustment speed seems to be different for positive and negative deviation from long run equilibrium. Based on AIC and BIC values, the best fitted model with the lowest values is the consistent MTAR model. Moreover in all estimated model, the Ljung-Box statistic for testing residuals autocorrelation reject the null joint hypothesis that the first four residuals autocorrelation are zero. This can be interpreted as corn price adjustment within four days.

In the case of soybean, estimation of threshold models with daily data (columns (2), (3), (4) and (5) of table 7) show that spot and future prices move together in the long run. In each model, adjustment parameters converge, and basis term are stationary. Asymmetric test reveals asymmetric price adjustment in TAR, consistent TAR and consistent MTAR models; and symmetric price adjustment in MTAR model. In addition, the Ljung-Box statistics in all models show autocorrelation of the first four residuals. Among these models, the most fitted with the lowest AIC and BIC values is consistent TAR model.

Estimations with weekly data, columns (6), (7), (8) and (9) in tables 6 and 7, also suggest threshold cointegration and asymmetric price transmission toward long run equilibrium for corn price series as well as for soybean price series. For both grains, the most fitted model is the consistent MTAR estimated. The first fours residuals are not correlated in consistent MTAR model estimated with weekly data of corn prices but correlated in the same model estimated with weekly data of soybean prices. Regarding the other estimated models with corn prices, results indicate threshold cointegration with no convergence of adjustment parameters in TAR and MTAR models, and symmetric adjustment in consistent TAR model. With soybean prices, point estimates of adjustment parameters do not converge in TAR model and adjustment is symmetric and asymmetric respectively in MTAR and consistent TAR models.

Table 6: Results of threshold cointegration between corn spot and future prices[a]

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Daily corn spot and future				**Weekly corn spot and future**				**Monthly corn spot and future**			
	TAR	cTAR	MTAR	cMTAR	TAR	cTAR	MTAR	cMTAR	TAR	cTAR	MTAR	cMTAR
ρ_1^b	-0,006*	-0,406***	-0,01***	-0,129***	0,004	-0,089***	-0,002	-0,115***	-0,013	-0,331***	-0,038	-0,193
	(0,003)	(0,027)	(0,003)	(0,011)	0,012	0,023	0,009	0,017	(0,04)	(0,082)	(0,03)	(0,042)
ρ_2	-0,017***	-0,051***	-0,011***	-0,061***	-0,041***	-0,115***	-0,034***	-0,059***	-0,068	-0,482***	-0,037	-0,447
	(0,004)	(0,006)	(0,003)	(0,005)	0,014	0,031	0,01	0,015	(0,046)	(0,078)	(0,033)	(0,064)
Threshold (τ)	0	-0.09	0	-0.03	0	0.035	0	-0.0034	0	0.0085	0	0.0290
Hypothesis test												
$\rho_1 = \rho_2 = 0^c$	16.57***	146.42***	15.11***	135.52***	4.91***	14.52***	5.61***	30.65***	1.72	54.32***	1.45	34.65***
$\rho_1 = \rho_2^d$	3.08*	160.34***	0.16	29.81***	4.11**	0.46	5.49**	5.98**	0.55	27.16***	0.00	10.96***
$Q(4)^e$	1843.42***	562.09***	1843.51***	551.98***	27.62***	1.81	29.35***	2.068	8.26*	2.56	7.94*	4.70
AIC	-40161,036	-63554,367	-40158,111	-63633,983	-5275,252	-9447,295	-5276,637	-9450,133	-1070,188	-1996,714	-1069,632	-1999,281
BIC	-40133,592	-63511,062	-40130,667	-63590,678	-5255,589	-9415,673	-5256,974	-9418,511	-1056,367	-1973,901	-1055,81	-1976,469

Note: Refer to table 7 notes

Table 7: Results of threshold cointegration between soybean spot and future prices[a]

	Daily soybean spot and future				**Weekly soybean spot and future**				**Monthly soybean spot and future**			
	TAR	cTAR	MTAR	cMTAR	TAR	cTAR	MTAR	cMTAR	TAR	cTAR	MTAR	cMTAR
ρ_1^b	-0,007*	-0,368***	-0,01***	-0,191***	-0,02	-0,598***	-0,0570***	-0,499***	-0,146**	-0,205***	-0,1***	-0,162***
	0,004	0,021	0,004	0,008	0,024	0,08	0,02	0,046	(0,061)	(0,068)	(0,037)	(0,046)
ρ_2	-0,025***	-0,187***	-0,017***	-0,233***	-0,105***	-0,328***	-0,0574***	-0,295***	-0,035	-0,349***	-0,053	-0,589***
	0,005	0,01	0,003	0,015	0,028	0,033	0,02	0,028	(0,045)	(0,094)	(0,041)	(0,088)
Threshold	0	-0.028		0.0265	0	-0.033		-0.038	0	0.0280		0.0363
Hypothesis test												
$\rho_1 = \rho_2 = 0^c$	21.14***	318.22***	18.83***	416.57***	9.85***	77.66***	7.91***	114.00***	4.77***	11.44***	4.35**	28.92***
$\rho_1 = \rho_2^d$	6.79***	59.82***	2.19	6.13**	3.83*	9.77***	0.00	14.36***	1.54	1.55	0.73	18.70***
$Q(4)^e$	1095.64***	144.85***	1096.54***	152.04***	181.19***	37.49***	182.04***	39.29***	18.038***	3.752	18.400***	4.109
AIC	-42293,131	-62135,265	-42288,533	-62089,22	-4724,756	-8287,573	-4720,915	-8290,96	-1171,392	-2116,94	-1170,572	-2131,119
BIC	-42265,675	-62091,941	-42261,077	-62045,896	-4705,085	-8255,934	-4701,244	-8259,321	-1157,588	-2094,128	-1156,767	-2108,307

Note: **a:** Long-run relationship estimated at first step is $S_t = \beta_0 + \beta_1 F_t + Z_t$ and at second step residual stationnarity is verified with $\Delta Z_t = I_t \rho_1 Z_{t-1} + (1 - I_t)\rho_2 Z_{t-1} + \sum_{i=1}^{k}(\sigma_i \Delta Z_{t-i} + v_t)$ with the heaviside indicator depending on the threshold model. TAR, cTAR, MTAR, cMTAR indicate respectively results from Threshold autoregressive model, consistent TAR model, Momentum TAR model, consistent MTAR model. **b:** ρ_1 and ρ_2 are parameters from residual stationnarity. Entries are point estimates with t-statistics in parentheses. ***, **, * indicate respectively significance at 1%, 5% and 10% levels. **c:** Entries in this row are modified Fisher statistics or Φ-statistics to test the null hypothesis $\rho_1 = \rho_2 = 0$. Statistics are compared with critical values given by Enders and Siklos (2001). **d:** Entries in this row are the standard Fisher statistics to test the null hypothesis $\rho_1 = \rho_2$. **e:** Q(4) denotes Ljung-Box statistic to test the null hypothesis that the first four residuals are not autocorrelated (jointly equal to zero).

With monthly data, results from consistent TAR and consistent MTAR models confirm respectively threshold cointegration and asymmetric adjustment for spot-future corn and spot-future soybean. The four first residuals from these models are not correlated meaning that prices transmission happen within a month. The other models suggest threshold cointegration and symmetric price adjustment, consistent TAR model for spot-future corn; TAR model, consistent TAR model and MTAR model for spot-future soybean.

The main point to keep from these results is that future prices can predict grain prices in Quebec market at any time frequency but the most disregarded frequency estimations are consistent to stress a nonlinear long-run relationship. With daily data the estimated thresholds for corn basis change and soybean basis are respectively -0.03 and -0.028. With monthly data, estimated thresholds in the most fitted models are 0.0085 and 0.0363 for corn and soybean. These results confirm previous findings in the literature (Xu, 2019; Kuiper et al., 2002), showing that future prices are efficient tools for commodities prices prediction in spot market and also the frequency of data is important to detect prices ability. In opposite to Xu (2019) and the present study that used Engle and Granger (1987) cointegration method, Kuiper et al. (2002) used Johansen and Juselius (1990 cointegration procedure for Amsterdam potatoes and U.S. corns. Their findings are twofold. Firstly, spot potato price in Netherlands is orthogonal to future price from Amsterdam Exchange market, meaning cointegration relationship. Secondly, daily and weekly U.S corn prices are related to CBOT future prices in long-run.

5.3 Error correction models (ECM)

Given the fact that there is threshold cointegration in all grain prices pairs estimated with daily, weekly, and monthly data, this study estimates symmetric and asymmetric ECM for both corn and soybean. Spot-future pair and spots Quebec-Ontario pair are used to examine how prices respond to last period basis deviation from long run equilibrium (temporary shock).

Asymmetric ECM estimation used threshold from consistent MTAR for all prices pairs except for daily soybean spot-future pair. The ECM is stable and well specified if the error correction term (Z_{t-1}) is negative and significant. Results of ECM between spot and future prices are presented in tables 9 and 10 for corn and soybean. In bidirectional spot-future symmetric ECM estimated for corn and soybean, the error correction term (ECT) in spot price change equation is negative at 0.1% significance level and at all disaggregated time frequencies. The ECT is negative at 10% level only in future price change equation estimated for corn with weekly data. Point estimates show that, whether a shock in future price is positive or negative, corn spot prices in Quebec drop 8.8% of deviation in a day, 9.9% within a week and 25.8% within a month. For soybean, spot prices eliminate 19.9% of deviation in a day, 35.6% within a week and 24.7% in one month. These results indicate that for soybean, daily, weekly and monthly spot prices react to restore long run equilibrium and not future prices. For corn, daily, weekly and monthly spot prices respond to temporary shock, and both weekly corn spot and future prices react to restore the long-run equilibrium. These results are in line with the findings of Hernandez and Torero (2010) that spot prices of agricultural commodities react mostly to future prices change.

Results from spot-future asymmetric ECM show that corn spot price and soybean spot price react to both positive and negative basis deviation at all period levels. Errors correction terms Z^{+}_{t-1} and Z^{-}_{t-1} are negative and significant in spot equations. Z^{+}_{t-1} and Z^{-}_{t-1} represent adjustment speed toward long run equilibrium respectively for positive and negative basis change. With daily prices of corn, the adjustment coefficients to long-run equilibrium are -0.066 and -0.145 respectively for positive and negative shocks. This means that producer prices in Quebec market adjust to eliminate per day 6.6% of positive deviations due to the decreases in future price, and 14.5% of negative deviations due to the increases in future price. In terms of adjustment speed, positive shocks to corn future prices take 16.66 days to be fully transmitted while negative shocks take 6.89 days. With weekly data, corn spot prices take 12.5 weeks to fully eliminate positive shocks and 8 weeks to fully eliminate negative shocks. For soybean, estimation with daily data in table 10 indicate positive and negative basis take respectively 5.65 and 4.35 days to be fully eliminated. On the other hand, prices transmission take 3.26 weeks and 1.89 weeks for positive and negative shocks. Consequently, daily or weekly prices movements suggest a positive asymmetric price transmission (APT) for both corn and soybean, meaning that the basis adjusts faster backward to long run equilibrium when a shock causes an increase in future price than when it causes a decrease.

The results confirm Li and Chavas (2023) who estimated nonlinear relationship with a quantile vector autoregression (QVAR) model and weekly data over 1980-2019. They mainly found strong positive contemporaneous codependence between future and spot prices in US corn and soybean markets.

Table 8: Results of threshold ECM between corn spot and future prices

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Daily				**Weekly**				**Monthly**			
	Symetric ECM		*Assymetric ECM*		*Symetric ECM*		*Assymetric ECM*		*Symetric ECM*		*Assymetric ECM*	
	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t
z^b_{t-1}	-0.088***	-0.001			-0.099***	-0.021*			-0.258***	-0.054		
	(0.005)	(0.002)			(0.009)	(0.012)			(0.033)	(0.052)		
z^+_{t-1}			-0.066***	-0.002			-0.081***	-0.023			-0.479***	-0.049
			(0.005)	(0.002)			(0.011)	(0.016)			(0.058)	(0.095)
z^-_{t-1}			-0.145***	-0.001			-0.125***	-0.018			-0.166***	-0.055
			(0.011)	(0.004)			(0.013)	(0.018)			(0.038)	(0.063)
Δs_{t-1}	-0.437***	-0.000			-0.158***	-0.007			0.184***	-0.099		
	(0.009)	(0.003)			(0.025)	(0.034)			(0.048)	(0.076)		
Δs^+_{t-1}			-0.611***	0.002			-0.204***	0.005			0.104*	-0.060
			(0.015)	(0.005)			(0.038)	(0.052)			(0.062)	(0.102)
Δs^-_{t-1}			-0.262***	-0.002			-0.104**	-0.020			0.315***	-0.205
			(0.012)	(0.004)			(0.041)	(0.057)			(0.093)	(0.153)
Δf_{t-1}	-0.002	0.036***			0.032	-0.027			0.140***	0.304***		
	(0.031)	(0.010)			(0.020)	(0.028)			(0.043)	(0.069)		
Δf^+_{t-1}			-0.060*	0.040***			-0.009	-0.021			-0.106	0.301**
			(0.034)	(0.011)			(0.032)	(0.044)			(0.072)	(0.118)
Δf^-_{t-1}			0.080	0.023			0.074**	-0.033			0.283***	0.293***
			(0.063)	(0.021)			(0.033)	(0.046)			(0.061)	(0.101)
Q(4)^c	916,266***	3,020	732,328***	3,026	34,897***	1,6970	35,125***	1,7420	4,031	0,240	3,293	0,219

Note: **a:** Entries are point estimates with t-statistics in parentheses. ***, **, * indicate respectively significance at 1%, 5% and 10% levels.
b: z_{t-1} denotes the estimated error correction term (ECT) related to symmetric adjustment from the long-run. z^+_{t-1} and z^-_{t-1} are ECT showing adjustment to positive and negative deviations from the long-run.
The estimated coefficients of lagged differenced spot Δs_{t-1}; Δs^+_{t-1} and Δs^-_{t-1} indicate respectively the short-run symmetric adjustment, the short-run adjustments to positive and negative deviations.
The estimated coefficients of lagged differenced future Δf_{t-1}; Δf^+_{t-1} and Δf^-_{t-1} indicate respectively the short-run symmetric adjustment, the short-run adjustments to positive and negative deviations.
c: Q(4) denotes the Ljung-Box statistic to test the null hypothesis that the first four residuals are not autocorrelated (jointly equal to zero.

Positive asymmetric price transmission found for corn is in harmony with Wu et al. (2018) who applied threshold approach with Wednesday weekly prices in Ontario grain market. But the rapid adjustment of soybean for negative shocks contradicts Wu et al. (2018) results suggesting rapid adjustment to the decrease in future prices. The estimated prices transmission with daily and weekly data are also in line with studies on other commodities. Lin and Liang (2010) used consistent MTAR model to estimate dynamic movement between daily spot prices and one-month futures prices for the Brent petroleum market. Their results indicate spot prices in London petroleum market adjust strongly to a negative basis from a long-run equilibrium and moderately to a positive basis over five years period. This study found additionally that future prices adjust to a negative basis, but not to a positive basis.

Full price transmission with monthly data, change direction and take more time. In fact, asymmetric ECM with monthly data suggest negative APT for both corn and soybean. Monthly spot prices of corn fully eliminate positive deviation in 2.08 months and negative deviation in 6.02 months, while monthly spot prices of soybean eliminate positive and negative deviations respectively in 3.05 months and 5.23 months, respectively. In brief, monthly spot prices of corn and soybean rapidly adjust to future prices decrease than it increase. However, Balke et al. (1998) findings do not confirm this conclusion. They also estimated threshold ECM but found that monthly prices of soybean react quickly to the increase of crude oil prices that are volatile in international market. Consistent price transmission with daily and weekly data suggest that price transmission with aggregated monthly data are estimated with bias. These result confirm Kuiper et al. (2002) assumption, and imply daily adjustment analysis.

5.4 What happens between Quebec and Ontario markets

To examine the dynamic relationship between spot price in Quebec market and spot price in Ontario market, this study estimates for corn and soybean a linear regression of monthly spot price in Quebec market on monthly spot price in Ontario market and break dummy time variable, and uses the residuals to threshold models. Results from cointegration models estimation (Table 14 in Annex) show that paired spot prices Quebec-Ontario move together in the long run, specifically when threshold equals to zero or is non-zero. Symmetric ECM indicate adjustment from Quebec market to Ontario market, not the reverse. ECT in spot equations are negative and significant. A past change of corn price in Ontario market imply 15.2% adjustment of deviation to the long-run equilibrium. A previous deviation of corn price in Quebec has significant effect on the current variation of corn price in the same market. For soybean, estimated coefficient show 24.9% of symmetric adjustment.

In asymmetric ECM the ECT (Z^-_{t-1}) in Quebec spot price is negative at 0.1% meaning that corn spot price in Quebec market responds only to the increase of corn spot price in Ontario market. Regarding soybean, the negative and significant ECT (Z^+_{t-1}) indicate that spot prices in Quebec market react faster to the decrease of spot price in Ontario market. These adjustments show market integration of Quebec and Ontario. In sum, grain prices flow from Ontario market to Quebec market. Ontario is therefore a price leader. This may be explained by the fact that Ontario is net exporter of corn and soybean (Goodwin and Holt, 1999).

Table 9: Results of threshold ECM between soybean spot and future prices

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Daily				**Weekly**				**Monthly**			
	Symetric ECM		*Assymetric ECM*		*Symetric ECM*		*Assymetric ECM*		*Symetric ECM*		*Assymetric ECM*	
	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t	Δs_t	Δf_t
z^b_{t-1}	-0.199***	0.000			-0.356***	-0.001			-0.247***	0.048		
	(0.007)	(0.002)			(0.023)	(0.014)			(0.036)	(0.056)		
z^+_{t-1}			-0.177***	-0.006**			-0.307***	0.006			-0.285***	0.115
			(0.010)	(0.003)			(0.027)	(0.016)			(0.060)	(0.094)
z^-_{t-1}			-0.230***	0.009***			-0.528***	-0.020			-0.191***	0.016
			(0.013)	(0.004)			(0.044)	(0.026)			(0.056)	(0.089)
Δs_{t-1}	-0.242***	-0.002			-0.263***	-0.031**			-0.056	0.018		
	(0.010)	(0.003)			(0.025)	(0.015)			(0.050)	(0.079)		
Δs^-_{t-1}			-0.223***	-0.007**			-0.184***	-0.038*			-0.183**	0.042
			(0.012)	(0.003)			(0.037)	(0.022)			(0.085)	(0.135)
Δs^+_{t-1}			-0.268***	0.005			-0.301***	-0.021			0.025	0.019
			(0.016)	(0.004)			(0.038)	(0.023)			(0.063)	(0.099)
Δf_{t-1}	-0.058	-0.001			0.014	0.006			0.233***	0.388***		
	(0.037)	(0.010)			(0.048)	(0.028)			(0.043)	(0.068)		
Δf^+_{t-1}			-0.083*	0.007			-0.025	0.010			0.264***	0.507***
			(0.046)	(0.012)			(0.057)	(0.034)			(0.081)	(0.128)
Δf^-_{t-1}			-0.015	-0.016			0.128	0.006			0.197***	0.348***
			(0.063)	(0.017)			(0.089)	(0.053)			(0.052)	(0.082)
Q(4)	190,429***	3,018	183,898	2,652	39,071***	1,754	39,981	1,607	0.986	3.025	0.628	2.968

Note: Refer to table 8 note

Table 10: Results of threshold ECM between monthly spot in Quebec and Ontario markets

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Monthly corn spots				**Monthly soybean spots**			
	Symetric ECM		*Assymetric ECM*		*Symetric ECM*		*Assymetric ECM*	
	ΔS_t	ΔO_t	ΔS_t	ΔO_t	ΔS_t	ΔO_t	ΔS_t	ΔO_t
z^b_{t-1}	-0.152***	0.073			-0.249***	0.324***		
	(0.058)	(0.059)			(0.078)	(0.088)		
z^+_{t-1}			-0.069	0.251**			-0.313**	-0.024
			(0.107)	(0.108)			(0.134)	(0.150)
z^-_{t-1}			-0.196***	-0.019			-0.143	0.593***
			(0.070)	(0.071)			(0.110)	(0.124)
Δs_{t-1}	0.357***	0.362***			-0.044	-0.012		
	(0.091)	(0.092)			(0.077)	(0.086)		
Δs^+_{t-1}			0.373**	0.472***			0.019	-0.077
			(0.152)	(0.152)			(0.087)	(0.098)
Δs^-_{t-1}			0.339**	0.234			-0.286*	0.082
			(0.155)	(0.155)			(0.163)	(0.184)
Δo_{t-1}	0.013	0.019			0.325***	0.323***		
	(0.087)	(0.087)			(0.071)	(0.080)		
Δo^+_{t-1}			0.080	0.181			0.508***	0.152
			(0.145)	(0.145)			(0.140)	(0.157)
Δo^-_{t-1}			-0.040	-0.130			0.270***	0.403***
			(0.146)	(0.146)			(0.082)	(0.092)
Q(4)	2,499	2,574	2,48	2,245	9.487*	3.342	10.003**	4.304

Note: **a:** Entries are point estimates with t-statistics in parentheses. ***, **, * indicate respectively significance at 1%, 5% and 10% levels.
b: z_{t-1} denotes the estimated error correction term (ECT) related to symmetric adjustment from the long-run. z^+_{t-1} and z^-_{t-1} are ECT showing adjustment to positive and negative deviations from the long-run.
The estimated coefficients of lagged differenced Quebec spot Δs_{t-1}; Δs^+_{t-1} and Δs^-_{t-1} indicate respectively the short-run symmetric adjustment, the short-run adjustments to positive and negative deviations.
The estimated coefficients of lagged differenced Ontario spot Δo_{t-1}; Δo^+_{t-1} and Δo^-_{t-1} indicate respectively the short-run symmetric adjustment, the short-run adjustments to positive and negative deviations.
c: Q(4) denotes the Ljung-Box statistic to test the null hypothesis that the first four residuals are not autocorrelated (jointly equal to zero.

6 Conclusion

This study contributes to the literature on asymmetric price adjustment by addressing the issue of temporal and spatial prices adjustment in Quebec grain market. We use daily, weekly and monthly time frequency data from 1994 to 2022 to examine temporal arbitrage of spot prices with future prices in both corn and soybean Quebec markets. Monthly data are used to examine spatial arbitrage of Quebec spot prices with Ontario spot prices. Stationary test results, DF-GLS unit root test with linear trend and Zivot-Andrew allowing for one break in trend and intercept, show that spot and future price series for corn and soybean are I(1). Results of Gregory and Hansen cointegration test show that spot and future for corn and soybean at any time frequencies move together with one regime shift. Monthly spots in Quebec and Ontario market are also cointegrated with one regime shift.

Linear and nonlinear cointegration models based on arbitrage theory, are used to test symmetric and asymmetric relationship between price series. Nonlinear or threshold cointegration models use the assumption that prices dynamic differs whether variation of the basis is positive or negative. Estimated results indicate threshold cointegration and price asymmetries between spot and future prices in both Quebec corn and soybean markets, whether time frequency is daily, weekly or monthly. Moreover, there is long run relationship and asymmetric adjustment between spot prices in Quebec and Ontario markets. Error correction models estimated with daily and weekly data suggest positive asymmetric price transmission in both corn and soybean markets, whereas asymmetric ECM with monthly data suggest negative APT. These findings show that despite Quebec and Ontario are neighbor provinces, adjustment between spot and future prices in grain market is different. Results also indicate that Quebec spot price responds faster to Ontario spot price increase for corn than to its decrease while the reverse are found for soybean. Positive corn price transmission between Quebec and Ontario markets maintains spot price for corn at high level and calls for market risk management strategies by users (hog and poultry farms). Negative soybean price transmission from Ontario market to Quebec market helps to maintain competitive environment for users.

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8 Annex: Results for Ontario market

Table 11: Summary statistics of Ontario spot and future prices for corn and soybean

(1) Variables	(2) N	(3) Mean	(4) Standard deviation	(5) Min	(6) Max
Monthly prices					
Corn spot in Ontario market	333	4.481	1.245	2.564	8.463
Soybean spot in Ontario market	333	10.623	2.859	5.679	20.32

Table 12: Stationnary tests results of Ontario spot and future prices for corn and soybean

(1)	(2)	(3)	(4)	(5)	(6)	(7))
Variables	DF-GLS Linear trend		DF-GLS No linear trend		Zivot-Andrew	
	Level	First difference	Level	First difference	Level	First difference
Monthly prices						
Corn spot in Ontario market	-3.058**	-8.280***	-0.659	-4.985***	-3.978	-8.696***
Soybean spot in Ontario market	-3.278**	-10.069***	-0.369	-8.615***	-4.174	-9.156***

Note: The optimal lag length was determined based on the minimum modified Akaike Information Criterion. ***, **, * indicate respectively significance at the 1%, 5% and 10%. DF-GLS test, with linear trend or not, performed in this study compared statistic values to Elliott-Rothenberg-Stock critical values: −3.48, −2.89, and −2.57 respectively for 1%, 5%, and 10% significance levels. Zivot–Andrews test allows for one single break at an unknown point in both the intercept and the linear trend; with -5.57, -5.08, and -4.82 as critical values at 1%, 5%, and 10% levels.

Table 13: Results of Gregory and Hansen test for spot prices in Quebec and Ontario markets

(1) Cointegration relationships [a]	(2) t-statistics	(3) Estimated break points
Monthly corn spot: Quebec - Ontario	-99.31***	December 2000
Monthly soybean spot: Quebec - Ontario	-191.58***	August 2004

Note: a: Gregory and Hansen test performed in this study, estimated cointegration model with break in constant and trend.
Model estimated is $S_{t,Quebec} = \gamma_0 + \gamma_1.D_t + \gamma_2.t + \gamma_3.S_{t,Ontario} + Z_t$,with monthly spot prices.

Table 14: Results of threshold cointegration between monthly spot in Quebec and Ontario markets[a]

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Monthly corn spot in Quebec and Ontario markets				**Monthly corn spot in Quebec and Ontario markets**			
	TAR	cTAR	MTAR	cMTAR	TAR	cTAR	MTAR	cMTAR
ρ_1^b	-0,193***	-0,558***	-0,1**	-0,247***	-0,097	-0,703***	-0,243***	-0,475***
	(0,06)	(0,123)	(0,044)	(0,052)	(0,066)	(0,083)	(0,059)	(0,064)
ρ_2	-0,042	-0,428***	-0,12***	-0,391***	-0,242***	-0,801***	-0,107**	-0,804***
	(0,053)	(0,077)	(0,042)	(0,07)	(0,073)	(0,244)	(0,051)	(0,144)
Threshold	0	-0.0198	0	0.0125	0	0.0263	0	0.0272
Hypothesis test								
$\rho_1 = \rho_2 = 0^c$	7.86***	25.92***	6.59***	26.94***	9.61***	41.58***	10.44***	42.75***
$\rho_1 = \rho_2^d$	2.52	0.80	0.12	2.74*	1.62	0.15	3.16*	4.33**
$Q(4)^e$	21.42***	7.064	22.858***	6.034	34.29***	1.205	31.52***	0.752
AIC	-1262,372	-2338,543	-1259,94	-2337,031	-1313,106	-2382,777	-1314,657	-2370,033
BIC	-1248,551	-2315,73	-1246,119	-2314,218	-1299,302	-2359,964	-1300,853	-2347,22

Note: **a:** Long-run relationship estimated at first step is $S_{t,Quebec} = \beta_0 + \beta_1 S_{t,Ontario} + Z_t$ and at second step residual stationnarity is verified with $\Delta Z_t = I_t \rho_1 Z_{t-1} + (1 - I_t)\rho_2 Z_{t-1} + \sum_{i=1}^{k}(\sigma_i \Delta Z_{t-i} + v_t)$ with the heaviside indicator depending on the threshold model. TAR, cTAR, MTAR, cMTAR indicate respectively results from Threshold autoregressive model, consistent TAR model, Momentum TAR model, consistent MTAR model. **b:** ρ and σ are parameters from residual stationnarity. Entries are point estimates with t-statistics in parentheses. ***, **, * indicate respectively significance at 1%, 5% and 10% levels. **c:** Entries in this row are modified Fisher statistics or Φ-statistics to test the null hypothesis $\rho_1 = \rho_2 = 0$. Statistics are compared with critical values given by Enders and Siklos (2001). **d:** Entries in this row are the standard Fisher statistics to test the null hypothesis $\rho_1 = \rho_2$. **e:** Q(4) denotes Ljung-Box statistic to test the null hypothesis that the first four residuals are not autocorrelated (jointly equal to zero.