Testing For Seasonal Cointegration and Error Correction: The U.S. Pecan Price-Inventory Relationship

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Selected Paper Prepared for Presentation at the Southern Agricultural Economics Annual Meeting, Little Rock, Arkansas, February 5-9, 2005

1. Introduction

Although pecan prices play a central role in the pecan industry little is known about their behavior. Because the pecan industry is not subject to any government support programs, prices are determined by the free interaction of pecan supply and demand. Pecan prices are, however, heavily influenced by supply forces because the demand for pecans is relatively stable (Shafer, 1997). Like most agricultural time series, pecan data exhibit seasonal behavior. Seasonality in the pecan industry is mainly supply influenced (Shafer, 1997; Jumah and Kunst, 1996). The supply-side seasonality results from the biological production cycle and the fluctuating volume in storage. Because pecans can be stored between harvests, the available supply consists of the current production and the carry-in inventory from the previous crop year. This study, however, uses monthly reported volume of pecans in cold storage.

Despite the awareness that most economic time series exhibit seasonality, most economists, following Box and Jenkins (1976), still treated seasonality as a nuisance. Engle and Granger, and Hallman (1989), however, argued that using the Box and Jenkins approach may have not only led to a loss of significant information on important seasonal behavior but also unintended mistakes regarding inferences with respect to economic relationships among the data. Therefore, this is a timely application of recent developments in time series modeling techniques that treat seasonality as part of economic reality to pecan price analysis. The goal of this study is to apply advanced time series techniques to analyze the nature of seasonality and to determine the relationship between pecan prices and pecan cold storage inventories.

This study applies the seasonal cointegration approach to pecan price analysis by first testing for seasonal unit roots in the time series variables using the Hylleberg, Engle, Granger and Yoo (henceforth, HEGY), (1990). The HEGY procedure is designed to test for the presence of seasonal unit roots (integration) in quarterly data. Secondly, we will use the nonstationary series to test for seasonal cointegration using the Engle, Granger, Hylleberg, and Lee (henceforth, EGHL), (1993). Finally, the error correction terms from the cointegrating equations will be used in the error correction models (ECM).

2. Seasonal unit roots in pecan price and cold storage inventories

First, the time series variables are tested for the presence of unit roots at the zero, semiannual, and annual frequencies using the HEGY procedure. To determine the order of integration and seasonal integration, the following regression model for quarterly data is estimated:

$$(1) \qquad \Delta_4 x_t = \pi_1 y_{1t-1} + \pi_2 y_{2t-1} + \pi_3 y_{3t-2} + \pi_4 y_{3t-1} + \varepsilon_t$$

where $\Delta_4 = (1 - B^4)$ and ε_t is an error term. The y_{it}'s (i=1, 2, 3) are the transformed series for unit roots at various frequencies. The y_{it}'s are designed such that y_{1t} is trending but non-seasonal, while y_{2t} and y_{3t} are non-trending and display seasonal cycles at π and $\pi/2$, respectively.

The transformations y_{it} of x_t removes the seasonal unit roots at certain frequencies while preserving them at other frequencies. For example, $y_{1t} = (1 + B + B^2 + B^3)x_t$ removes all seasonal unit roots, while preserving the long run or zero frequency unit roots. Next, $y_{2t} = -(1 - B + B^2 - B^3)x_t$ preserves unit roots at the biannual frequency which corresponds to a six month period. Finally, the $y_{3t} = -(1 - B^2)x_t$ transformation eliminates the unit roots at zero and biannual frequencies while preserving potential seasonal unit roots at the annual frequency. Additional lags of $\Delta_4 x_t$ are usually added to whiten the errors. Similarly, deterministic terms (a constant, seasonal dummies and a trend) may also be added to the equation. Under the HEGY technique, equation (1) is estimated using the ordinary least squares (OLS) method.

The tests for the presence of a unit root at each frequency is based on the t-statistics for π_i (i=1, 2, 3, 4) or joint F-test for π_i (i=3, 4), where equation (1) is the model under the null hypothesis. A failure to reject the null hypothesis implies the presence of unit roots. The procedure, therefore, requires tests for $\pi_1 = 0$, $\pi_2 = 0$, and a joint test $\pi_3 = \pi_4 = 0$. Critical values are obtained from Hylleberg et al. (1990).

Both unadjusted and seasonally adjusted quarterly time series on Fancy Halves prices (log FHP) and millions of pounds of inshell pecan cold storage inventories (log ICSI), shelled pecan cold storage inventories (log SHCSI), and total pecan cold storage inventories (TCSI) are used. Each series is from 1991:2 to 2002:1, inclusive, and obtained from USDA–ERS (2001, 2002, 2003, and 2004) and NASS (2004). Note that the inshell cold storage volume was converted to the shelled pecan volume by assuming a 40% shell-out ratio.

The auxiliary regressions were only augmented with significant lags to whiten the residuals (Ghysels et al., 1993). Statistically significant lags of up to two years are added because shellers store pecans, on average, for up to two years. Deterministic terms including a constant (I), a linear trend (T), and seasonal dummies (SD) were also added.

All regressions included seasonal dummies because the omission of the seasonal dummies when necessary might have biased the results (Beaulieu and Miron, 1993).

Table 1 contains the HEGY test results for ICSI, TCSI, SHCSI, and FHP. Results indicate the presence of unit roots at the zero frequency for all variables. Table 1 also shows that TCSI and SHCSI variables have unit roots at all frequencies depending on what deterministic term was included in the auxiliary regression. However, no unit roots exist at the biannual frequency for ICSI and at annual frequency for FHP. In general, the HEGY tests suggest that all the time series variables are sensitive to the simultaneous addition of all deterministic terms.

Table 1. Results of Testing Pecan Inventory Series and Price Series for Seasonal Unit Roots

Variable	Auxiliary regression	't':π_1 (Zero frequency)	't':π_2 (Bi-annual)	'F': $\pi_3 \cap \pi_4$
	None	2.5937	3.1498**	1.9369
	I	0.4312	2.7389**	1.2738
ICSI	I, SD	-3.8639**	4.1419**	21.7962**
	None	1.7717	0.3930	0.1021
	I	-0.1781	0.3859	0.0792
TCSI	I, SD	-0.3755	3.3147	37.5490**
	None	0.8634	0.1475	0.2689
	I	-1.4223	0.1258	0.4186
SHCSI	I, SD	-1.94731	3.6638	17.698**
	None	-0.7433	3.4438**	8.4925**
	I	-3.0687	3.5044**	15.8450**
FHP	I, SD	-2.8694	3.4163	13.6388**

Note: ** indicates the rejection of the null hypothesis in question at 1% significance level. Null hypotheses: $\pi_1 = 0$, $\pi_2 = 0$, $\pi_3 = 0$, $\pi_4 = 0$, and $\pi_3 \cap \pi_4 = 0$.

Table 2. Results of Unit Roots Test

Variable	Lags	't':π_1 (Zero frequency)
ICSI:	4	-2.753
TCSI:	4	-2.504
SHCSI:	4	-1.361
FHP:	5	-2.829

Note: The critical value at the 5% significance level is 2.93.

Similarly, results in Table 2 show the presence of unit roots at the zero frequency when using seasonally adjusted data for all variables. Constant terms were added in the tests.

In sum, all series appear to have unit roots at the zero frequency in both adjusted and unadjusted data. The presence of seasonal unit roots at biannual frequency is an indication of varying stochastic seasonal patterns (Hylleberg, 1992). The results seem to confirm the concern that seasonally adjusting data without knowing the nature of the seasonality may bias the outcome. Moreover, the finding of seasonality in the unadjusted data is consistent with the nature of agricultural economic time series (Tomek, 2000).

3. Cointegration and seasonal cointegration

The evidence of the presence of unit roots in SHCSI, TCSI and FHP at the zero and semiannual frequencies, leads to an examination whether the series share a common unit root at each frequency. Following EGHL (1993), the cointegration and seasonal cointegration tests were estimated using the following regression equations:

(2a) $$\omega_{1t} = p_{1t} - \alpha_{12} y_{1t}$$

(2b) $$\omega_{2t} = p_{2t} - \alpha_{22} y_{2t}$$

(2c) $$\omega_{3t} = p_{3t} - \alpha_{32} y_{3t} - \alpha_{41} p_{3,t-1} - \alpha_{42} y_{3,t-1} .$$

Where p_{it} and y_{it} ($i = 1, 2, 3$) represent the transformed series at various frequencies. The linear combinations of these variables are, therefore, expected to be stationary, I (0), at all frequencies.

Cointegration of p_{1t} and y_{1t}, at the zero frequency implies long run equilibrium. Similarly, seasonal cointegration of y_{2t} and p_{2t} occurs at the biannual frequency if the null hypothesis of noncointegration is rejected. The EGHL-type test is a residual test and tests for cointegration at the zero and semiannual frequencies are conducted by testing the residuals from the cointegrating regressions. The test is meant to detect any remaining unit roots at the zero and biannual frequencies, respectively.

Equation (2c) is, however, treated differently. The cointegrating relation between p_{3t} and y_{3t} is estimated by regressing p_{3t} on y_{3t} and $y_{3t,t-1}$. Also, in this case, the residuals will be used to test for seasonal cointegration at the annual frequency. The ordinary least squares estimates of equation (2a-c) are expected to be "superconsistent" (EGHL, 1993). In addition, the error terms from the cointegrating equations are used directly in the error correction model. The critical values are obtained from Engle and Yoo (1987).

As required by the EGHL-type test, only variables that have unit roots at common frequencies are used and these include SHCSI, TCSI and FHP. In order to test for cointegration at the zero and semiannual frequencies, all variables were appropriately adjusted. For the zero frequency we removed unit roots at the biannual frequency by applying a seasonal filter, S(B) = (1+B) to each series. The resulting filtered series,

$SSHCSI_t = (1+B)\, SHCSI_t$, $STCSI_t = (1+B)\, TCSI_t$ and $SFHP_t = (1+B)\, FHP_t$, have unit roots only at the zero frequency. The semiannual frequency was adjusted by first differencing the series to remove possible unit roots at the zero frequency.

The results in Table 3 suggest that the null hypothesis of noncointegration at the long run frequency can not be rejected in both price-inventory relationships. The null hypothesis of the absence of seasonal cointegration is, however, rejected at the 5% significance level at the biannual frequency in both cases. The absence of cointegrating relationship at the zero frequency implies a lack of long run equilibrium between fancy halves prices and cold storage inventories. The presence of a seasonal cointegrating relationship at the biannual frequency suggests that seasonal fluctuations in shelled pecan prices may be a reflection of seasonal variations in pecan inventories. Although we should avoid drawing strong conclusions from the results, the following observations are in order. As expected, the results indicate an inverse relationship between shelled pecan prices and pecan cold storage inventories (i.e., shelled and total inventories). The signs of the coefficient estimates obtained for both shelled and total pecan cold storage inventory variables are consistent with prior expectations.

Table 4 reports the results for conventional cointegration using the Engle and Granger (1987) procedure. The underlying assumption of the conventional cointegration is that unit roots are only found at the zero frequency. The results show that shelled and total pecan cold storage inventories are conitegrated with shelled pecan prices at the zero frequency. Shelled pecan prices, however, are not cointegrated with total pecan cold storage inventories only when the deterministic or constant terms are omitted.

Table 3. Results for (Seasonal) Cointegration

Deterministic Term	Lags	Long run frequency	Lags	Bi-annual frequency
Shelled Pecan Price and Shelled Pecan Inventory				
None	1,2,3,4,5,6,7,8	-1.91921	0	-3.93437*
I	1,2,3,4,5,6,7	-2.48430	0	-3.96010*
I, SD	1,2	-2.68242	1	-4.39597*
I, T	1,2,3,4,5,6,7	-2.54261	1	-4.84719*
I, SD, T	1,2	-3.01185	1,2,3	5.29495*
Shelled Pecan Price and Total Pecan Inventory				
None	1,2,3,4,5,6,7,8	-2.12449	0	-3.98823*
I	1,2,3,4,5,6,7	-2.34461	0	-4.01643*
I, SD	1,2,3,4	-1.53934	0	-4.43838*
I, T	1,2,3,4,5,6,7	-2.45525	0	-4.01193*
I, SD, T	1,2,3,4	-1.74357	0	-4.43889*

* Indicates the rejection of the null hypothesis of noncointegration at 5% significance level.

Table 4. Estimation Results for the Shelled Pecan Price and Shelled Pecan and Total Pecan Inventories.

Deterministic Term	Lags	Long- run frequency
Shelled Pecan Price and Shelled Pecan Inventory		
I	1	8.1937*
I, T	1	8.2957*
Shelled Pecan Price and Inshell Pecan Inventory		
I	1, 3	-3.8561*
I, T	1, 3	-3.8690*
Shelled Pecan Price and Total Pecan Inventory		
I	1	-4.1210*
I, T	1	-4.1141*

* Indicates the rejection of the null hypothesis of noncointegration at 5% significance level.

Results in Tables 3 and 4 indicate the existence of inconsistencies between the seasonally adjusted data and unadjusted data. These inconsistencies have serious implications. The conclusions about the long run relations between fancy halves prices and cold storage inventories are obviously sensitive to whether the data have been seasonally adjusted or not. The seasonal adjustment seems to have a distorting effect on the outcome of the Engle-Granger (1987) type tests in favor of long-run cointegration**.**

4. Error Correction Models and Price-Inventory Relationships

The seasonal error correction model (SECM) is the second stage of the EGHL-type cointegration procedure. This is similar to the Engle and Granger (1987) two-step cointegration procedure. The SECM can only be estimated as part of the two-stage procedure if cointegration is found for each frequency. The lagged residuals from the cointegrating residuals are used in the SECM. Given that cointegration is established at the long run and seasonal frequencies, the SECM is written as

$$\Delta_4 p_t = \lambda_1 \omega_{1t-1} + \lambda_2 \omega_{2t-1} + \lambda_3 \omega_{3t-2} + \lambda_4 \omega_{3t-1} + \varepsilon_{1t}, \tag{3}$$

Here ω_{it} ($i = 1, 2, 3$) are residuals from the cointegrating equations, λ_k ($k = 1, 2, 3, 4$) are coefficients and ε_{1t} is a stationary disturbance. Both lagged dependent and explanatory variables can also be added to measure short run dynamics.

The SECM can be used to determine the speed of adjustment (Enders, 1995; 1996). The speed of adjustment determines the rate at which the dependent variable corrects short run deviations. The advantage of using the SECM is that it provides an interpretation that is amenable to economic theory. Similarly, the clear separation between long- and short-run parameters in the SECM makes it an excellent framework for assessing the validity of the long-run and seasonal implications of a theory and the involved dynamic processes.

Since ‘fancy halves’ prices are seasonally cointegrated with cold storage inventories at the semiannual frequency, the Engle- Granger (1987) two-step procedure can be used to determine the speed of adjustment (EGHL, 1993). The absence of cointegration at the zero frequency means that the ECM to be estimated is of the form

$$\Delta_2 p_t = \lambda_2 \omega_{2t-1} + \sum_{j=1}^{q} \alpha_{1j} \Delta_2 p_{t-j} + \sum_{i=1}^{k} \delta_{1i} \Delta_2 y_{t-i} + \varepsilon_{1t}, \tag{5}$$

and $\Delta_2 = \left(1 - B^2\right)$, where B is a lag term.

Once the seasonal cointegration relationships are established, the SECM can be estimated. Seasonal error correction terms, obtained from the first stage are lagged one quarter period and substituted as explanatory variables in the SECM. Similarly to the EGHL (1993) procedure, the regressions were augmented with deterministic terms. The deterministic terms were added in the cointegrating equations but not to the auxiliary regressions. The coefficients of the seasonal error correction terms are interpreted as the speed of adjustment. The results from estimating the SECM with appropriately adjusted data are as follows:

(6a)
$$\Delta_2 PFHP_t = - 0.022 + 0.153\,\Delta_2 PFHP_{t-1} + 0.097\,\Delta_2 SHPCSI_{t-1} + 1.3650\,\hat{z}_{t-1}$$
$$(-0.980) \qquad (1.055) \qquad (1.782) \qquad (5.090)$$

$R^2 = 0.68$, DW= 1.53; t-values are in parentheses.

In the SECM (6a), the t-statistic for the seasonal error correction term, $\hat{z}_{t-1}$, turned out to be significant, while the lagged values for $\Delta_2 PFHP_t$ and $\Delta_2 SHPCSI_t$ are not significantly different from zero. The SECM equation for the shelled pecan inventories is

(6b)
$$\Delta_2 SHPCSI_t = 0.001 - 1.229\,\Delta_2 PFHP_{t-1} - 0.114\,\Delta_2 SHPCSI_{t-1} + 1.349\,\hat{z}_{t-1}$$
$$(0.013) \qquad (-2.730) \qquad (-0.676) \qquad (0.828)$$

$R^2 = 0.18$, DW= 1.85; t-values in parentheses.

In equation (6b), none of the variables are significantly different from zero with the exception of lagged prices. The results imply that in the process of discovering shelled pecan prices, short run dynamics of shelled pecan prices and total pecan cold storage inventories do not occur.

Equations (7a and 7b) represent the SECM results for the shelled pecan price discovery process with respect to total pecan cold storage inventories. Equation (7a) depicts the relationship between ‘fancy halves’ prices and the total pecan inventories:

(7a)
$$\Delta_2 PFHP_t = -0.018 + 0.340\,\Delta_2 PFHP_{t-1} + 0.018\,\Delta_2 TPCSI_{t-1} + 0.981\,\hat{\varepsilon}_{t-1}$$
$$(-0.600) \qquad (1.743) \qquad (0.227) \qquad (2.563)$$

$R^2 = 0.47$, DW= 1.50; t-values are in parentheses.

In the SECM (7a), the t-statistic for the seasonal error correction term, $\hat{\varepsilon}_{t-1}$, appeared to be significant while that of the lagged values for $\Delta_2 TPCSI_t$ and $\Delta_2 PFHP_t$ are both insignificant. The lack of statistical significance implies that there is no relationship between prices and the short run dynamics of prices and total pecan inventories.

The results in equation (7b) show that the t-statistic for $\hat{\varepsilon}_{t-1}$ and the lagged values for $\Delta_2 PFHP_t$ and $\Delta_2 TPCSI_t$ all appear not to be significantly from zero.

$$\text{(7b)} \qquad \underset{}{\Delta_2 TPCSI_t} = \underset{(-0.0026)}{-0.0002} \underset{(-1.4763)}{-0.9401\,\Delta_2 PFHP_{t-1}} \underset{(-0.0741)}{-\,0.0147\,\Delta_2 TPCSI_{t-1}} + \underset{(0.9648)}{1.2480\,\hat{\varepsilon}_{t-1}}$$

$R^2 = 0.08$, DW= 1.77; t-values in parentheses.

The speeds of adjustment in equations (6) and (7) indicate the ‘fancy halves’ prices adjust after a shock to cold storage inventories. Note, however, that the speeds of adjustment in equations (6) and (7) are positive, implying the adjustment will cause the system to gradually deviate from the equilibrium. In the case of SECM, the sign of the speed of adjustment does not matter (Lee, 1992; Shen and Huang, 1999).

The speeds of adjustment also suggest that while FHP adjusts to shocks in TCSI at a fast rate, FHP overshoots in its adjustments to a deviation in SHCSI.

5. Conclusions

The seasonal cointegration methodology has not been used widely by agricultural economists in empirical research even though it has been established that agricultural economic data commonly suffer from seasonality problems. This paper has successfully applied the seasonal cointegration methodology to pecan price analysis. We have gained insights into relationships of prices with pecan cold storage inventories. Specifically, we have uncovered the influence cold storage inventories have on shelled pecan prices using time series modeling techniques.

The tests for unit roots confirm the presence of unit roots at the zero frequency when both unfiltered and filtered data are used. The result suggests pecan data are nonstationary at the zero frequency. But the presence of seasonal unit roots when unadjusted data are used suggests pecan data are characterized by varying and stochastic seasonal patterns. To obtain stationarity the data have to be seasonally differenced. The Box-Jenkins approach, however, results in first differencing the data to achieve stationarity, which could lead to biased results and possibly wrong economic interpretations. Findings of this study are consistent with the observation that most agricultural economic time series have seasonal components (Tomek, 1994).

The study finds that ‘fancy halves’ prices are seasonally cointegrated with pecan cold storage inventories at the semiannual frequency. Thus, the pecan price-inventory relationship is seasonal in nature. The absence of cointegration at the zero frequency, however, implies there is no long run equilibrium in the pecan market, when only cold storage inventories are considered. Furthermore, the finding of the seasonal components in the pecan inventory data suggests shellers may be holding pecan inventories, for the most part, to meet contractual obligations. In addition, the speeds of adjustment indicate that prices adjust to cold storage deviations and not the vice versa. This behavior will enable the economist to make better price forecasts.

This study may be limited by factors such as the paucity of data and the averaging of monthly data. However, the USDA started only collecting monthly data on pecan cold storage inventories in 1991. Because shellers are assumed to make decisions on quarterly rather than monthly basis, quarterly data were needed for this study. The created quarterly data are monthly averages and the aggregation may have caused autocorrelation and heteroskedasticty problems (Tomek, 1994). Another limitation of the study is the use of the HEGY test which is said to have a low power in moderate size samples (Canova and Hansen, 1995).

The large size of speed adjustment coefficients is questionable in this initial study. This calls for further studies using highly efficient methods such as the Lee's maximum likelihood approach to seasonal cointegration. The maximum likelihood approach allows for the testing of several null hypotheses separately for each case, without having any prior knowledge about cointegration relations at other frequencies. Also, the use of monthly data will allow the researcher to apply the Beaulieu and Miron (1993) or Frances (1991) seasonal cointegration techniques. Finally, the seasonal error correction term can be used in forecasting pecan prices. According to Lee and Siklos (1997) having a significant error correction term suggests seasonality can be explicitly used in the forecasting process.

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