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# Price Asymmetric Relationships in Commodity and Energy Markets

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*Abstract*

*Recent increases in the price of crude oil have led to a rise in the prominence of corn-based ethanol as an alternative source of energy. As a result linkages have been established between commodity and energy prices. The aim of this study is to determine if soybeans, corn, wheat, oil, and ethanol adjust their prices asymmetrically depending on whether their actual price is over- or under-predicted with respect to one another. This study's goal of determining if asymmetric price relationships exist is accomplished by using monthly time series price data incorporated into a distributed lag error correction model distinguishing between positive and negative price difference and positive and negative values of the error correction terms. The primary results of this study found that asymmetric price changes do occur in the commodity and energy markets. Interestingly, in all the asymmetric price adjustments that were found, with only one exception in the soybean-corn relationship, prices will adjust downward when the actual price of one variable is above its equilibrium price as determined by the price of another study variable and consequently would be expected to exhibit a downward adjustment in price in the following month.*

*Keywords: commodity prices, energy prices, price asymmetry*

*JEL classification: Q13.*

## 1. Introduction

In 2008 oil prices reached historically high levels. To combat these higher fuel prices the demand for alternate forms of energy dramatically increased. Governments, corporations, and individuals around the world were relying more heavily on these new, cleaner, and cheaper forms of energy in order to continue their daily activities. One of the alternate forms of energy that received a lot of attention during this period was corn-based ethanol. Over the past decade the production of ethanol has substantially increased. In 2000, the US had only 54 ethanol plants producing 1.6 billion gallons of ethanol fuel annually. By January 2011 the number of plants had grown to 204 and the production level of ethanol fuel had increased to 13.2 billion gallons annually. Production of ethanol at this level requires the utilization of approximately 13 million bushels of corn each week (Renewable Fuels Association) or about 676 million bushels annually. As Tyner (2009) points out, the price relationship between ethanol and corn prices is very important because the operating margin and profitability realized by ethanol plants is for the most part driven by these two prices.

Because an increasing amount of corn is being committed to the production of ethanol energy markets have become more closely related with agricultural markets, especially with regards to grain commodities. The general belief regarding the energy-grain commodity linkage is that as oil prices increase the demand for ethanol as a substitute will increase as well. This increase in demand for ethanol will increase the demand for corn, increasing the price of corn.

There has often been a correlation between prices received for soybeans, corn, and wheat as they are often viewed by producers as substitutes for one another competing for the same planting acreage. Oil prices have also played a role in the ultimate prices agricultural producers receive for their products as it is a significant cost component in agricultural production, used in fertilizers and pesticides as well as for fuel for machinery and the transportation of products from the farm to the site of usage. There is a connection between prices received by producers for agricultural products and crude oil prices. There is question as to how the price received for soybeans, corn, and wheat reacts to changes in oil prices. For example, do the prices of grains respond to decreases in oil prices at the same rate they respond to price increases? If the answer is yes, then price changes are said to be symmetric, if the answer is no then it appears that grain prices would exhibit an asymmetric price adjustment with respect to oil price increases and oil price decreases.

The objective of this paper is to examine the linkage between energy and commodity prices. The monthly prices changes of soybeans, corn, wheat, crude oil, and ethanol will be applied to a price asymmetry model in order to determine if asymmetric price changes occur with respect to the prices of each other and in which variables these asymmetric price changes are most profound. We seek to discover if prices are more likely to exhibit asymmetric responses if their actual value is above or below their predicted value with respect to the price of the other variables. For example, if the actual price is below its predicted price (the price was over-predicted) with respect to the price of another study variable then the price of the dependent variable would be expected to rise in the following time period. In the case of the actual price being higher than predicted (an under-prediction of price) with respect to the price of another variable then prices would be expected to adjust downward in the following time period. An asymmetric response in price changes would be said to occur if price adjustments are found to occur if they respond to only an under- or over-prediction in price or if prices respond at different rates to under-and over-predictions in price as predicted by the price of another variable.

The remainder of this paper will be outlined in the following way. First, we will review the literature regarding the relationship between energy and commodity prices as well as previous literature applying a price asymmetry model. A description of the data will then be followed with the development of the methodology used in this study. Results of the models will then be reported and discussed, concluding with a discussion regarding the implications of our findings and areas for further research opportunities.

## 2. Commodity and Energy Price Literature Review

The commodities and energy markets have both realized increasing prices (Figure 1) and increasing volatility (Figure 2) with the passage of time. It should come as no surprise that linkages have been uncovered between energy prices and agricultural commodity prices. Since the bio-fuel era, focused on alternative energies designed to lessen foreign oil dependencies and reduce greenhouse gas emissions, the integration between the energy and agricultural markets has grown even more profound. As the linkage between the two markets strengthened throughout the 2000s, the correlation between energy and commodity prices followed the same pattern.

Hertel and Beckman (2010) state that during the period of January 2001 through August 2007 when oil prices were below $75 per barrel the correlation between oil and corn prices was merely 32%. However, as oil prices drastically increased above this threshold the oil-corn price correlation strengthened to 92% between September 2007 and October 2008. Taheripour and Tyner (2008) state that a significant portion of price hikes in corn are a result of increasing oil prices and Tyner (2009) also noted that the ethanol market has significantly aided in the establishment of the link between the price of crude oil and the price of corn. Banerjee (2010) argues that once oil prices cross the threshold price at which gasohol becomes competitive, there is immediately a massive demand for ethanol and hence, a vast fuel-use demand for grains. Banerjee also states that the drastic increase in the demand for grains appears almost overnight. Not surprisingly, financial analysts have attributed the recent hikes in grain prices to increases in demand for ethanol (Chang et al 2010). Rosegrant (2008) concluded that 30% of increases in the prices of grains are due to increases in the demand for bio-fuel. Due to the concerns associated with rapidly increasing grain and food prices experienced in 2007, China was forced to suspend the use of corn for bio-fuel production (Keyzer et al. 2008). Rosegrant also indicated in his testimony to the US Senate Committee on Homeland Security and Governmental Affairs that not only does the increase in bio-fuel as an alternative energy play a role in food prices but also has a profound impact on the world food situation.

The variability in futures grain prices as a source for hedging risk has also been studied intently to determine what factors are at the source of grain price movements. Karali and Thurman (2010) concluded that volatility in daily futures prices of grain is greatly impacted by seasonality, especially in the time immediately preceding harvest, and as the contract maturity date nears. A concern due to increased amounts of corn being allocated for ethanol production is that the increased integration of agricultural and energy markets could add to already volatile agricultural prices.

Changes in oil prices also affect the prices received by agricultural producers for their crop. Oil price changes impact the cost of inputs used by producers of commodities. von Braun et al. (2008) were able to link high energy prices to increases in agricultural production costs, namely such inputs as fertilizers and pesticides. Saghaian (2010) investigated the impact of the energy sector on commodity prices in order to determine if there was a causal relationship present. His conclusion was that a strong correlation among oil and commodity prices is present but the evidence of a causal link from oil prices to those commodities prices is inconclusive.

This study adds to the previously existing literature by focusing on how changes in grain and energy prices respond to one another, especially regarding the long-term equilibrium price relationship between two study variables. In addition to focusing on price adjustments toward a long-run equilibrium, this study will provide updated information regarding these two markets by incorporating monthly price data through December 2010. These updated prices will enhance the literature regarding prices in the grain and energy markets because the two years of 2009 and 2010 represent a period of economic recession in the U.S. economy. Literature regarding the linkages between grain and oil prices was focused on a period when crude oil prices were rising drastically to record high levels leading to more attention focused on alternative energy sources such as ethanol. In 2009 and 2010 oil prices, for the most part, were lower and less volatile. Therefore, ethanol as an alternative energy source became less of an immediate priority. The inclusion of these data points in this study help to examine how the linkage between grain and energy prices may have evolved under these different economic conditions.

## 3. ASYMMETRIC PRICE TRANSMISSION LITERATURE REVIEW

The issue of asymmetric price transmission has been found to be more of the rule than the exception (Peltzman, 2000). This is also the outcry of many consumers that prices, especially at the retail level, appear to rise significantly faster and with a larger magnitude than which they decline. Evidence of this claim was found in the gasoline market where it was concluded that retail gasoline prices respond more quickly to increases in crude oil prices than to decreases (Borenstein, Cameron and Gilbert, 1997). Several agricultural markets such as oranges, lemons, dairy products, pork, and beef have also been found to exhibit evidence of asymmetric price transmissions between the producer and retail levels (Karrenbrock, 1991). Gomez, Lee, and Koerner (2009) examined the international coffee market and the impact of changes in international coffee prices on retail prices in Germany, France, and the United States.

In each of the studies described above the asymmetric price transmission model was utilized to determine if the asymmetries in price adjustments existed within the vertical marketing channel. While determining the existence of asymmetric price transmission in the vertical marketing channel has been the most commonly applied use for the price asymmetry model, additional research has been conducted to test for asymmetric price changes in futures markets for various commodities. Gravelines and Boyd (1999) studied price changes in futures markets for a variety of agricultural commodities, metals, and financial instruments. Their goal was to determine if price changes adjust upward at the same rate they adjust downward. The findings concluded that all of the variables used in the analysis showed asymmetric price changes. Mashamite and Maholwa (2005) utilized the same price asymmetry model as the aforementioned study and applied it to the South African futures market. Using daily and weekly futures price data for white and yellow maize, wheat, and sunflower seeds it was concluded that price asymmetry was only present in the daily price changes for wheat, where its price appeared to respond more quickly to price decreases as opposed to price increases.

Price asymmetry has even been found to exist in commodity price cycles. Cashin, McDermott and Scott (2002) concluded that the duration and magnitude of price slumps, defined as a general trend of declining prices, tends to exceed both the duration and the magnitude of price booms, or a trend of generally increasing prices. Within the grain and ethanol markets Chang et al (2010) examined long- and short-run asymmetric price adjustments between the spread of spot and futures prices for corn, soybeans, and sugar compared to the spread between the spot prices for these commodities with the futures price for ethanol. Their conclusion was that asymmetric adjustments occur mainly during periods where the spread between the spot and futures prices are narrowing.

This study will contribute to the literature regarding price asymmetry models by examining asymmetric price adjustments in the grain and energy markets. Because the linkage between these two markets has become more profound within recent years, literature examining potential price asymmetries is under-developed. This study of price asymmetries in grain and energy markets will help fill this void in previous literature.

## 4. DATA

In order to test causality and asymmetric price transmission, monthly price data from January 1995 until December 2010 were obtained and utilized. Prices for soybeans, corn, wheat, oil, and ethanol were included in this study. Soybean, corn, and wheat prices are reported as price per bushel while oil and ethanol prices are reported as price per gallon. The prices for soybeans, corn, and wheat are acquired from the National Agricultural Statistics Service as the prices received from each crop by month. Because of the different varieties of wheat that are produced and traded in the United States the "all wheat" price is used in this analysis. The price for oil is that for Light Sweet Crude Oil, Crushing, Oklahoma, Contract 1 as traded on the NYMEX and acquired from the U.S. Energy Information Administration. The price for oil was reported in dollars per barrel and thus required transformation into dollars per gallon. Each data point was divided by 42, to represent the number of gallons per barrel. Finally, the price per gallon for ethanol was acquired from the Nebraska Ethanol Board. These prices represent "rack prices", or wholesale prices, charged at the point of loading, or F.O.B, Omaha, where the seller is paying for the transportation to Omaha, NE. Descriptive statistics of the variables included in this analysis can be found in Table 1. The data were analyzed using Stata 10.1.

The correlation matrix in Table 2 shows that there is a very high correlation of prices between soybeans, corn, and wheat. The soybean-corn relationship is the strongest with a 90% correlation between the price series, followed closely by the corn-wheat relationship with an 89% price correlation, and finally between soybeans and wheat where the correlation is 82%. In the energy sector the correlation between oil prices and ethanol is also high at 84%.

## 5. METHODS

The aim of this study is to develop a model in order to test for asymmetric price transmissions in the grain and energy markets. The variables of interest in this study are: soybean, corn, wheat, oil, and ethanol prices. Throughout the models we use the notation of $p_i$ to denote the price of the commodity of interest and the notation of $p_j$ to denote the price of any of the four remaining variables that could be used to describe $p_i$. The term $t$ is the time variable and $m$ is used to describe the lags that are included in the models. These terms are described as months due to the collection of monthly data in this study. Due to the use of time series data in this study, we use Dickey-Fuller tests to test for nonstationary variables. Granger causality tests are conducted to determine if causal linkages between the grain and energy markets exist. Finally, we develop the model to determine asymmetric price transmissions between variables using positive and negative price changes in conjunction with positive and negative values of the error correction term. The error correction terms were derived from the estimations of long-run equilibrium between the variables of interest. From the asymmetric price transmission model we determine if the prices of grains and energy adjust differently due to positive and negative deviations from long-run equilibrium. We tested the data assuming the null hypothesis of a unit root. In each equation, with the exception of ethanol, a unit root was present in the data. We determined that after first differencing the data we could reject the null hypothesis of a unit root meaning that the variance and covariance are defined and that the data are considered stationary. Ethanol prices were also differenced in order to maintain consistency in the data. It was also determined that the inclusion of a time trend was not significant.

Since the Dickey-Fuller test concluded that all variables are I(1) where the first difference results in stationarity it is possible to perform a pairwise Granger Causality test between the variables (Granger 1969). This test is used to forecast future values of one variable based on past values on another. The null hypothesis in Granger Causality is that past price changes of commodity $j$ do not Granger cause future price changes of commodity $i$. The inverse equation is then subsequently tested with the null hypothesis that past price changes of commodity $i$ do not Granger cause future price changes of commodity $j$. In each test two lags of the dependent variable's own price changes are included with two lags of price changes of another descriptive variable. The dependent variable's lagged price changes are included to account for its own history while causality is tested by determining if the coefficients on the lagged price changes on the descriptive variable are significantly different than zero. If the pairwise test shows that the lagged price changes on both descriptive variables are significantly different than zero then it can be implied that a bidirectional relationship exists between the two variables.

The F-test is utilized in this study to determine lag coefficients of price changes of the descriptive variable can jointly be a leading indicator of future changes in the price of the dependent variable. If the F-test is rejected it can be interpreted as the past two months of price changes for commodity $j$ can together be a leading indicator of future price changes in commodity $i$. Even if individual test statistics are not significantly different from zero performing a joint F-test may state otherwise (Verbeek 2008).

In order to estimate the rate at which prices of soybeans, corn, wheat, oil, and ethanol adjust relative to one another a simple linear long-run relationship is estimated between the variables. The relationship takes the form of:

(1) $$p_{i,t} = a + bp_{j,t} + \varepsilon_t$$

where $p_{i,t}$ and $p_{j,t}$ are the prices for commodities $i$ and $j$ in time $t$, and $\varepsilon_t$ is a normal i.i.d. error term. A time trend was not included in the long-run relationship because of our previous finding in the Dickey-Fuller test that is was not significant. The error correction term is interpreted as the actual value of the dependent variable less the predicted value of the dependent variable where $p_{i,t}$ is the actual value and $\hat{p}_{i,t}$ is the predicted value. We can then formulate that

(2) $$ECT_{i,j,t} = p_{i,t} - \hat{p}_{i,t} = p_{i,t} - \hat{a} - \hat{b}p_{j,t}.$$

A combination of a distributed lagged adjustment model and an error correction model is estimated in the following form:

(3)

$$\Delta p_{i,t} = \alpha + \sum_{m=1}^{M} \left(\beta_m^+ D^+ \Delta p_{j,t-m}\right) + \sum_{m=1}^{M} \left(\beta_m^- D^- \Delta p_{j,t-m}\right) + \theta ECT_{i,j,t-1} + \varepsilon_t$$

where $\Delta p_{i,t} = p_{i,t} - p_{i,t-1}$ for commodity $i$ in month $t$ and $p_{j,t}$ is the price for commodity $j$ in month $t$, $D^+$ and $D^-$ are dummy variables with $D^+$ = 1 if $\Delta p_{j,t-m} > 0$ and $D^+$ = 0 otherwise; $D^-$ = 1 if $\Delta p_{j,t-m} < 0$ and $D^-$= 0 otherwise. The $ECT_{i,j,t-1}$ is the one-period lagged residual from equation 1 and described in equation 2. However, this model assumes that price adjustments are symmetric between upward and downward price movements due to the term $\theta ECT_{i,j,t-1}$. Therefore, the results of this regression are not reported in the tables.

In order to examine the asymmetric price adjustment between variables, the residuals ($ECT_{i,j,t}$) from the cointegrating equations must be separated into $ECT_{i,j,t}^+$ and $ECT_{i,j,t}^-$ (Scholnick, 1996). Therefore we segregate the error correction terms accordingly where,

(4)
$$ECT^{+}_{i,j,t} = \begin{cases} ECT_{i,j,t} \ if \ ECT_{i,j,t} > 0 \\ 0 \ if \ ECT_{i,j,t} \leq 0 \end{cases}$$

and

(5)
$$ECT^{-}_{i,j,t} = \begin{cases} ECT_{i,j,t} \ if \ ECT_{i,j,t} < 0 \\ 0 \ if \ ECT_{i,j,t} \geq 0 \end{cases}$$

The use of a distributed lag model allows for the testing of asymmetric price changes between variables. If a distributed lag structure is considered, the presence of asymmetry is only tested on the error correction term (Frey and Manera, 2007). The error correction term accounts for the long-run relationship between the variable of interest $(i)$ and the descriptive variable $(j)$. Therefore, by testing the following model we can observe if price asymmetry exists based upon testing if the coefficients on the positive and negative values of the error correction terms are significantly different than zero. Lagged price differences are also separated into positive and negative values thus leading to the following specification.

(6)
$$\Delta p_{i,t} = \alpha + \sum_{m=1}^{M} \left(\beta^{+} D^{+} \Delta p_{j,t-m}\right) + \sum_{m=1}^{M} \left(\beta^{-} D^{-} \Delta p_{j,t-m}\right) + \theta^{+} ECT^{+}{}_{i,j,t-1} + \theta^{-} ECT^{-}{}_{i,j,t-1} + \varepsilon_t$$

The equilibrium relationship between the dependent and independent variable is defined simply as the mean of the residual series from the appropriate cointegrating equation and if their values are above (below) their mean they will eventually adjust downward (upward) toward equilibrium. Therefore, a positive value of the error correction term $ECT^{+}_{i,j,t}$ would be interpreted as the price of $i$ being above its equilibrium price with respect to the price of $j$ and if the coefficient $\theta^{+}$ is negative we would expect the price of $i$ to adjust downward in the following time period. A negative value of the error correction term would have the opposite meaning; the price of $i$ is below its equilibrium price with respect to the price of $j$ and would be expected to adjust upward toward long-run equilibrium in the subsequent time period (Scholnick 1996, Martens 2009). Therefore the $\theta^+$ and $\theta^-$ coefficients are interpreted as price adjustments of one commodity with respect to another.

Two F-tests are performed to establish whether or not there are significant price adjustments, and if there are, whether they are asymmetric with respect to over-prediction and under-prediction in prices. The purpose of the first F-test is to determine if the coefficients of $\theta^+$ and $\theta^-$ are jointly significantly different than zero. A rejection of the null hypothesis that $\theta^+ = \theta^- = 0$ indicates that the price of variable $i$ adjusts for changes in the price of variable $j$, i.e. there is a significant price adjustment. The second F-test is conducted to determine if the coefficients of $\theta^+$ and $\theta^-$ are significantly different from one another. A rejection of the null hypothesis that $\theta^+ - \theta^- = 0$ means that adjustments that occur are not symmetric between positive and negative price changes.

## 6. RESULTS

Results from the F-tests of the pairwise Granger causality tests in Table 3 show that changes in the prices of grains (corn, soybeans, and wheat) can be a leading indicator of changes in the price of oil. When the reverse situation was subsequently tested it was determined that changes in the price of oil were not a leading indicator of changes in the price of corn, soybeans, or wheat. Further Granger results observing the relationship between that of corn, soybeans, and wheat with respect to ethanol show that changes in the price of corn and changes in the price of soybeans are leading indicators of changes in the price of ethanol. The null hypothesis that a change in the price of wheat does not Granger cause changes in the price of ethanol was failed to be rejected. Also, like oil, changes in the prices of ethanol are not leading indicators of changes in the prices of grains.

Within the grain market, Granger Causality tests using two lagged periods show changes in the price of wheat can be a leading indicator of changes in the prices of corn and soybeans. Conversely, the reverse of each test is failed to be rejected with changes in the price of corn and soybeans not being leading indicators of changes in the price of wheat. Within the energy market the Granger causality tests show that changes in the price of oil are a strong indicator of future changes in the price of ethanol. This relationship is unidirectional with changes in the price of ethanol unable to help predict future changes in the price of oil.

We expect to observe asymmetric price relationships, especially in those variables that are strongly correlated with one another (Table 2) and in relationships where Granger causality results were significant (Table 3). The results of the price asymmetry model presented in equation 6 regarding changes in the price of soybeans are reported in Table 4. Results indicate that the price of soybeans responds asymmetrically to deviations from long-run equilibrium as measured with respect to the prices of corn and oil. We also observe evidence of an asymmetric adjustment toward long-run equilibrium in changes in the price of soybeans with respect to changes in the prices of corn and oil due to the rejection of the hypothesis $\theta^{+} - \theta^{-} = 0$. This result shows that the coefficients on the positive and negative values of the error correction term are significantly different from one another, thereby signaling that changes in the price of soybeans responds asymmetrically to changes in the prices of corn and oil. This result does not indicate in which direction the asymmetric adjustment occurs, only that there is evidence it does. In order to observe the direction and magnitude of the asymmetric price adjustment the significance of the coefficients on the positive and negative vales of the error correction term are examined individually. The asymmetric response to these variables occurs under opposite conditions. When the price of soybeans is below its predicted value with respect to the price of corn then the price of soybeans would then be expected to increase in the subsequent time period by 38% of the value of the error correction term, which is the difference between the actual and predicted price of soybeans as measured by corn prices. Regarding the soybean-oil relationship, the asymmetric response occurs when soybean prices are above equilibrium with respect to the price of oil. When this occurs the price of soybeans is then expected to exhibit a downward adjustment by 9% of that equation's error correction term the following month. By comparison we see that the price of soybeans responds more than four times faster to its price being below predicted values with respect to corn than it would to being above its predicted value as predicted by oil prices.

It is observed in Table 5 that price changes that occur in corn with respect to soybeans are asymmetric. In the corn-wheat relationship we fail to reject that the coefficients on the positive and negative values of the error correction term are significantly different from one another, however, we do observe that adjustments that do occur are significant. By examining the coefficients on the positive value of the error correction term in the corn-wheat relationship we observed that the individual adjustment by itself is indeed significant. Therefore, it is concluded that changes in the price of corn respond asymmetrically to positive deviations from long-run equilibrium as measured with respect to the prices of soybeans and wheat. This means that the price of corn adjusts downward when its actual value is higher than predicted with regards to the price of these variables. This result is interpreted by saying when the price of corn is above its predicted value as predicted by soybean prices then it will likely experience a downward adjustment in the following month by 9% of the value of the error correction term. Regarding the corn-wheat relationship a downward adjustment of 16% of the value of the error correction term in the following month is expected when the price of corn is higher than its expected value with respect to the price of wheat. Therefore, it can be observed that corn prices will adjust downward nearly twice as fast when its actual value is higher than predicted with respect to wheat prices than with respect to soybean prices.

The results from the price asymmetry model for changes in the price of ethanol are presented in Table 6. It is concluded from the joint test of the coefficients on the positive and negative values of the error correction term that the null hypothesis that the values are jointly equal to zero is rejected in all four ethanol relationships. When testing to determine if the values of the coefficients of the positive and negative values of the error correction term are equal to one another a rejection of the null is only found in the ethanol-corn relationship. In each of the four models testing the significance of the coefficients on the positive and negative values of the error correction term individually leads to a rejection of the hypothesis that the coefficient on the positive value of the error correction term is equal to zero. These results lead to the conclusion that ethanol prices show evidence of an asymmetric response when the actual price of ethanol is higher than its predicted price with regards to each of the four additional variables used in this analysis. A higher than predicted price of ethanol with regards to soybean prices will likely result in a downward adjustment of ethanol prices toward the ethanol-soybean long-run equilibrium price by 9% of the value of the error correction term. The ethanol-corn and ethanol-wheat relationships are very similar. When the actual price of ethanol deviates from long-run equilibrium with respect to each corn and wheat then in the following month we would expect that ethanol prices would adjust downward by 12% of the value of the error correction terms in these equations. The fastest adjustment of ethanol prices towards long-run equilibrium occurs when ethanol prices are higher than expected as predicted by oil prices. When the ethanol price deviates above long-run equilibrium with respect to the price of oil then in the following month the price of ethanol is likely to adjust downward toward that long-run equilibrium by 22% of the error correction term. This downward adjustment is nearly two and a half times faster than the downward adjustment that ethanol exhibits due to higher than predicted prices with respect to soybeans and nearly two times faster than higher than predicted ethanol prices as predicted by corn and wheat.

According to the results wheat prices (Table 7) and oil prices (Table 8) do not exhibit any asymmetric price adjustments with regard to the prices of the other variables used in this study. The insignificant coefficients on the positive and negative values of the coefficients mean there is not enough evidence that the prices of the dependent variable respond to an over- or under-shooting of the actual values as compared to the predicted values with respect to the prices of the independent variable used in the analysis. In both of these cases none of the coefficients on the positive and negative values of the error correction term are significantly different from one another. Also in the joint test of the coefficients of the positive and negative values of the error correction term the null hypothesis that they are jointly different than zero failed to be rejected, concluding that there is not significant evidences that price adjustments are significant.

Comparing all of the variables that exhibit an asymmetric price adjustment we noticed that the price of soybeans being lower than expected with respect to corn is the most responsive relationship with a 38% upward adjustment of the error correction term. This is also the only occurrence, according to the data, where a lower than predicted price will most likely respond with an upward price in the following month. The second most responsive price relationship occurs in the energy market with ethanol prices respective to oil prices with the 22% downward adjustment expected in the following month. The corn-wheat relationship adjusts downward at only one-half the rate of the error correction term of the soybean-corn upward adjustment. Ethanol responds to higher than expected prices as predicted by corn and wheat at less than one third the rate of the soybean-corn adjustment rate. We also note that the soybean-oil, corn-soybean, and ethanol-soybean relationships are expected to exhibit the slowest adjustment at 9% of the error correction term, less than one-fourth the speed of the aforementioned soybean-corn adjustment.

One of the most interesting results from the price asymmetry model comes from the soybean-corn relationship. First of all, it is the only relationship observed where a lower than expected price of one variable with respect to another variable leads to an upward price adjustment in the following month. Secondly, this relationship was the most responsive of all the asymmetric price relationships tested. The prices of these variables were also the most strongly correlated of all the variables included in this study. Finally, referencing back to the results from Granger causality we see that changes in corn prices can be a leading indicator of changes in soybean prices. However, when we observe the reverse relationship of corn prices with respect to soybeans prices there is only slight evidence (10% significance level) of asymmetric price transmission and Granger causality leading from soybeans to corn was failed to be rejected.

Another interesting result occurs with the relationships of oil prices with respect to grain prices. It was earlier noted that oil and grain prices have become more highly correlated in 2009 and 2010. Granger causality test results show that grain prices can be a leading indicator of oil prices. However, no asymmetric price relationship was found to exist in oil prices with respect to any of the grain price variables.

We notice that ethanol prices adjust downward in the following month when its price is higher than predicted as predicted by each of the additional variables in this study. A change in the prices of each of the variables, with the exception of wheat, was also determined by Granger causality to be a leading indicator of changes in the price of ethanol. The ethanol-oil asymmetric price relationship exhibits the second greatest adjustment of all relationships tested as well as the seconds highest F-statistic in the Granger causality results.

The corn-wheat relationship is also relatively strong and is the second most highly correlated price relationship. The results also show a downward price adjustment of corn when its actual price is higher than predicted with respect to wheat. Changes in the price of wheat were also found to be leading indicators of changes in the price of corn.

Wheat is a very interesting case itself, as it was not found to exhibit an asymmetric price relationship with any of the variables used in this study. Also, price changes in any of the additional variables were not found to be a leading indicator of changes in the price of wheat.

Wheat prices and changes in wheat prices could be considered to be independent of the prices and changes in the prices of soybeans, corn, oil, and ethanol.

## 7. DISCUSSION

In this analysis we examined the price relationship between soybeans, corn, wheat, oil, and ethanol. In the first part of the analysis we conducted Granger causality tests to determine if causal relationships are present in the variables. The second part of the analysis focused on asymmetric price adjustment between variables in order to determine if prices respond differently to under- and over-predictions in price with respect to one another.

To summarize the results of this study we first found Granger causality tests show that previous price changes in the energy markets are not leading indicators of future price changes in grains. We did conclude that past price changes in grains could be a leading indicator of future changes in energy prices with only the one exception of the ethanol-wheat price relationship. Secondly, we found that asymmetric price changes do occur in the commodity and energy markets. More importantly, the findings of this study show that most all of these asymmetric adjustments, with the exception of the soybean-corn relationship, occur when the actual price of one variable is above its equilibrium price as determined by the price of another study variable and consequently would be expected to exhibit a downward adjustment in price. Finally, we conclude that the price of ethanol is the most responsive variable used in this analysis. Previous changes in the prices of corn, soybeans, and oil are found to be leading indicators of future price changes in ethanol prices according to Granger causality tests. Ethanol prices are also found to exhibit a downward asymmetric adjustment when its actual price is higher than predicted as predicted by the price of corn, soybeans, wheat, and oil.

These results provide important implication for individuals involved in the grain or energy markets. Grain producers can use this information in helping to determine the prices they receive for their crop based on the price relationships between grains and the price relationships between grains and energy commodities. This can be useful in hedging practices designed to eliminate price risks due to uncertainty. For example, if a grain producer notices that the price received for corn in higher than expected with respect to the price received for soybeans and wheat, according to the results of this study, that producer may want to contract corn through a forward or futures contract because corn prices would be expected to adjust downward in the following month. On the flip side, producers of products where corn is used as an input, such as ethanol or food products, may want to hold off purchasing corn until the following month because corn prices would be expected to adjust downward. Ethanol plants can also use this information to help them better predict their operating margins and profitability based on the ethanol-corn or ethanol-oil price relationships.

While this study examines the asymmetric price relationships between grains and energy prices there are many other macroeconomic factors that play an important role in the determination of these prices. Different policies regarding the blending of ethanol with gasoline would likely have an effect on the price relationship of these variables. One area for further research would be to determine the effect different blending capacities would affect the asymmetric price relationship between ethanol and corn and ethanol and oil. Another area for future research would be examining the existence of asymmetric price relationships between ethanol and other crops that can be used in its production, such as sugarcane and switch grass. The use of these crops in the production of ethanol would most likely help ease the food versus fuel debate and also have an effect on the price relationships between soybeans, corn, and wheat.

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**Figure 1. Price of Grains and Energy Commodities from Jan 1995 – Dec 2010.**

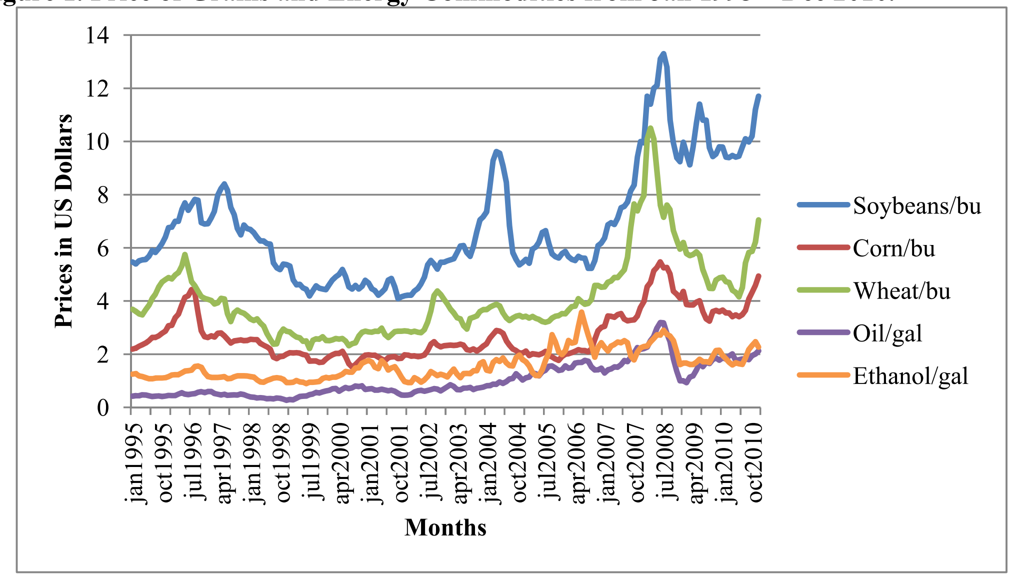


**Figure 2. Price Changes in Grains and Energy Commodities from Jan 1995 – Dec 2010.**

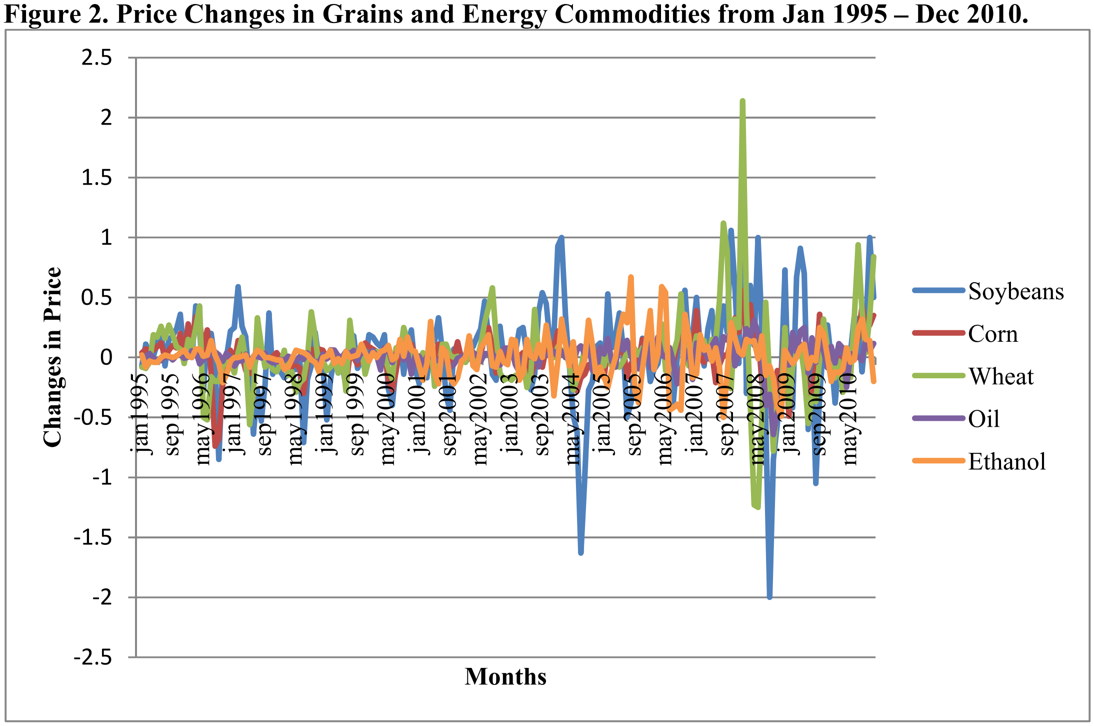

**Table 1. Descriptive Statistics of Variables**

| Variables | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Soybeans[1] | 6.84 | 2.16 | 4.09 | 13.30 |
| Corn[1] | 2.71 | 0.90 | 1.52 | 5.47 |
| Wheat[1] | 4.10 | 1.52 | 2.22 | 10.50 |
| Oil[3] | 1.02 | 0.64 | 0.27 | 3.19 |
| Ethanol[3] | 1.59 | 0.55 | 0.90 | 3.58 |

n=192
[1] Dollars/Bushel
[2] Dollars/Pound
[3] Dollars/Gallon

**Table 2. Correlation Matrix of Variables for Jan 1995 – Dec 2010.**

| Variables | Soybeans | Corn | Wheat | Oil | Ethanol |
|---|---|---|---|---|---|
| Soybeans | 1.00 | | | | |
| Corn | 0.90 | 1.00 | | | |
| Wheat | 0.82 | 0.89 | 1.00 | | |
| Oil | 0.70 | 0.64 | 0.73 | 1.00 | |
| Ethanol | 0.49 | 0.49 | 0.58 | 0.84 | 1.00 |

**Table 3. F-Statistics of Granger Causality Tests**
(Variable on horizontal axis is dependent variable)

| | Soybeans | | Corn | | Wheat | Oil | | Ethanol | |
|---|---|---|---|---|---|---|---|---|---|
| Soybeans | - | | 0.09 | | 0.29 | 3.28 | ** | 2.37 | * |
| Corn | 3.34 | ** | - | | 0.97 | 3.85 | * | 6.02 | *** |
| Wheat | 12.21 | *** | 6.45 | *** | - | 3.93 | ** | 1.53 | |
| Oil | 0.47 | | 1.62 | | 0.22 | - | | 10.69 | *** |
| Ethanol | 1.15 | | 1.59 | | 0.47 | 0.81 | | - | |

*** 1% significance level  ** 5% significance level  * 10% significance level

**Table 4. Error Correction Model with Lagged Price Adjustment for Soybeans: Dependent Variable is Change in the Price of Soybeans ($\Delta p_{i,t}$)**

| | *Model for Soybeans with respect to:* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *j = Corn* | | *j = Wheat* | | *j = Oil* | | *j = Ethanol* | |
| $D^+ \Delta p_{j,t-1}$ | 0.1927 | | -0.0941 | | 0.5136 | | 0.1463 | |
| | (.3225) | | (.1480) | | (.5496) | | (.3295) | |
| $D^+ \Delta p_{j,t-2}$ | 0.9000 | *** | 0.2736 | * | 0.6447 | | 0.1347 | |
| | (.3357) | | (.1546) | | (.5532) | | (.3388) | |
| $D^- \Delta p_{j,t-1}$ | 0.9856 | *** | -0.1594 | | 0.9473 | * | 0.0256 | |
| | (.2847) | | (.2054) | | (.4861) | | (.3786) | |
| $D^- \Delta p_{j,t-2}$ | -0.0376 | | 0.3590 | * | -0.4529 | | -0.541 | |
| | (.2826) | | (.2109) | | (.4891) | | (.3707) | |
| $ECT^+_{i,j,t-1}$ | -0.1668 | | -0.0690 | | -0.0891 | ** | -0.045 | |
| | (.1322) | | (.0422) | | (.0425) | | (.0338) | |
| $ECT^-_{i,j,t-1}$ | 0.3778 | *** | -0.0791 | | 0.0483 | | 0.0484 | |
| | (.1423) | | (.0712) | | (.0457) | | (.0429) | |
| Constant | 0.0920 | * | 0.0279 | | 0.0939 | | 0.0596 | |
| | (.0488) | | (.0538) | | (.0654) | | (.0573) | |
| N | 189 | | 189 | | 189 | | 189 | |
| $R^2$ | 0.1849 | | 0.1209 | | 0.0657 | | 0.0221 | |
| Test $ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}= 0$ | 3.56 | ** | 3.7800 | ** | 2.22 | | 0.97 | |
| Test $ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}$ | 5.73 | ** | 0.0100 | | 3.02 | * | 1.84 | |

***1% significance **5% significance *10% significance

Standard Errors in Parenthesis

$D^+ \Delta p_{i,t-m}$ is the change in the price of commodity j for lagged m periods if positive, zero if negative

$D^- \Delta p_{i,t-m}$ is the change in the price of commodity j for lagged m periods if negative, zero if positive

$ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}= 0$ F(2,182)

$ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}$ F(1,182)

**Table 5. Error Correction Model with Lagged Price Adjustment: Dependent Variable is Change in the Price of Corn ($\Delta p_{i,t}$)**

| | *Model for Corn with respect to:* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *j = Soybeans* | | *j = Wheat* | | *j = Oil* | | *j = Ethanol* | |
| $D^+ \Delta p_{j,t-1}$ | 0.0550 | | 0.0920 | | 0.0884 | | 0.1855 | |
| | (.0516) | | (.0619) | | (.2326) | | (.1399) | |
| $D^+ \Delta p_{j,t-2}$ | 0.0883 | | 0.1455 | ** | -0.1377 | | 0.0166 | |
| | (.0538) | | (.0655) | | (.2329) | | (.1414) | |
| $D^- \Delta p_{j,t-1}$ | 0.1466 | *** | -0.0187 | | -0.0755 | | -0.2006 | |
| | (.0534) | | (.0827) | | (.2057) | | (.1586) | |
| $D^- \Delta p_{j,t-2}$ | -0.0125 | | 0.0713 | | 0.3179 | | -0.0094 | |
| | (.0528) | | (.0891) | | (.2083) | | (.1535) | |
| $ECT^+_{i,j,t-1}$ | -0.0892 | * | -0.1599 | *** | -0.0465 | | -0.0288 | |
| | (.0527) | | (.0603) | | (.0329) | | (.0303) | |
| $ECT^-_{i,j,t-1}$ | 0.0999 | | -0.0366 | | 0.0099 | | 0.0344 | |
| | (.0643) | | (.0685) | | (.0378) | | (.0404) | |
| Constant | 0.0363 | * | 0.0134 | | 0.0382 | * | 0.0093 | |
| | (.0212) | | (.0177) | | (.0227) | | (.0220) | |
| N | 189 | | 189 | | 189 | | 189 | |
| $R^2$ | 0.1073 | | 0.0739 | | 0.0355 | | 0.0181 | |
| Test $ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1} = 0$ | 1.86 | | 5.33 | *** | 1.08 | | 0.55 | |
| Test $ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1}$ | 3.66 | * | 1.27 | | 0.89 | | 1.06 | |

***1% significance **5% significance *10% significance
Standard Errors in Parenthesis
$D^+ \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if positive, zero if negative
$D^- \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if negative, zero if positive
$ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1} = 0$ F(2,182)
$ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1}$ F(1,182)

**Table 6. Error Correction Model with Lagged Price Adjustment: Dependent Variable is Change in the Price of Ethanol ($\Delta p_{i,t}$)**

| | *Model for Ethanol with respect to:* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *j = Soybeans* | | *j = Corn* | | *j = Wheat* | | *j = Oil* | |
| $D^+ \Delta p_{j,t-1}$ | 0.1256 | ** | 0.3635 | *** | 0.0685 | | 0.4411 | ** |
| | (.0519) | | (.1346) | | (.0605) | | (.2139) | |
| $D^+ \Delta p_{j,t-2}$ | -0.0080 | | -0.0179 | | 0.0491 | | 0.0649 | |
| | (.0533) | | (.1351) | | (.0608) | | (.2176) | |
| $D^- \Delta p_{j,t-1}$ | 0.0023 | | 0.1120 | | 0.0699 | | 0.6215 | *** |
| | (.0532) | | (.1196) | | (.0879) | | (.1854) | |
| $D^- \Delta p_{j,t-2}$ | 0.0730 | | 0.2696 | ** | -0.0032 | | -0.1041 | |
| | (.0535) | | (.1206) | | (.0881) | | (.1850) | |
| $ECT^+_{i,j,t-1}$ | -0.0910 | ** | -0.1192 | *** | -0.1173 | *** | -0.2161 | *** |
| | (.0415) | | (.0401) | | (.0452) | | (.0604) | |
| $ECT^-_{i,j,t-1}$ | 0.0103 | | 0.0601 | | 0.0366 | | -0.0356 | |
| | (.0815) | | (.0706) | | (.0801) | | (.0922) | |
| Constant | 0.0159 | | 0.0369 | | 0.0269 | | 0.0212 | |
| | (.0302) | | (.0271) | | (.0254) | | (.0196) | |
| N | 189 | | 189 | | 189 | | 189 | |
| $R^2$ | 0.0916 | | 0.1494 | | 0.0631 | | 0.2126 | |
| Test $ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1} = 0$ | 3.27 | ** | 4.76 | *** | 3.94 | ** | 8.42 | *** |
| Test $ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1}$ | 0.84 | | 3.35 | * | 1.93 | | 1.95 | |

***1% significance **5% significance *10% significance
Standard Errors in Parenthesis
$D^+ \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if positive, zero if negative
$D^- \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if negative, zero if positive
$ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1} = 0$ F(2,182)
$ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1}$ F(1,182)

**Table 7. Error Correction Model with Lagged Price Adjustment: Dependent Variable is Change in the Price of Wheat ($\Delta p_{i,t}$)**

| | *Model for Wheat with respect to:* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *j = Soybeans* | | *j = Corn* | | *j = Oil* | | *j = Ethanol* | |
| $D^+ \Delta p_{j,t-1}$ | 0.0662 | | 0.2585 | | -0.9557 | ** | 0.1575 | |
| | (.1027) | | (.2763) | | (.4309) | | (.2609) | |
| $D^+ \Delta p_{j,t-2}$ | -0.0542 | | -0.1063 | | -0.5595 | | -0.0178 | |
| | (.1097) | | (.2732) | | (.4253) | | (.2655) | |
| $D^- \Delta p_{j,t-1}$ | 0.1377 | | 0.2550 | | 0.5154 | | -0.3243 | |
| | (.1035) | | (.2395) | | (.3733) | | (.2902) | |
| $D^- \Delta p_{j,t-2}$ | 0.0494 | | 0.0011 | | 0.3332 | | 0.2399 | |
| | (.1024) | | (.2384) | | (.3760) | | (.2839) | |
| $ECT^+_{i,j,t-1}$ | -0.0083 | | 0.0258 | | -0.0041 | | -0.0446 | |
| | (.0478) | | (.0502) | | (.0376) | | (.0307) | |
| $ECT^-_{i,j,t-1}$ | 0.0388 | | 0.0646 | | -0.0545 | | 0.1077 | |
| | (.0601) | | (.0820) | | (.0549) | | (.0526) | |
| Constant | 0.0546 | | 0.0306 | | 0.0834 | * | 0.0337 | |
| | (.0398) | | (.0391) | | (.0429) | | (.0393) | |
| N | 189 | | 189 | | 189 | | 189 | |
| $R^2$ | 0.0286 | | 0.0281 | | 0.0739 | | 0.0207 | |
| Test $ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1} = 0$ | 0.22 | | 0.67 | | 0.73 | | 1.13 | |
| Test $ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1}$ | 0.26 | | 0.12 | | 0.39 | | 0.74 | |

***1% significance **5% significance *10% significance
Standard Errors in Parenthesis
$D^+ \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if positive, zero if negative
$D^- \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if negative, zero if positive
$ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1} = 0$ F(2,182)
$ECT^+_{i,j,t-1} = ECT^-_{i,j,t-1}$ F(1,182)

**Table 8. Error Correction Model with Lagged Price Adjustment: Dependent Variable is Change in the Price of Oil ($\Delta p_{i,t}$)**

| | *Model for Oil with respect to:* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *j = Soybeans* | | *j = Corn* | | *j = Oil* | | *j = Ethanol* | |
| $D^+ \Delta p_{j,t-1}$ | 0.0562 | * | 0.1869 | ** | 0.0734 | * | -0.0445 | |
| | (.0327) | | (.0901) | | (.0382) | | (.0889) | |
| $D^+ \Delta p_{j,t-2}$ | 0.0102 | | 0.0579 | | 0.0194 | | 0.1002 | |
| | (.0341) | | (.0912) | | (.0383) | | (.0894) | |
| $D^- \Delta p_{j,t-1}$ | 0.0767 | ** | 0.1039 | | -0.0627 | | 0.1916 | * |
| | (.0335) | | (.0802) | | (.0555) | | (.0995) | |
| $D^- \Delta p_{j,t-2}$ | 0.0560 | * | 0.0537 | | 0.1428 | ** | -0.0133 | |
| | (0337) | | (.0803) | | (.0573) | | (.0974) | |
| $ECT^+_{i,j,t-1}$ | -0.0510 | | -0.0367 | | -0.0568 | | 0.0041 | |
| | (.0340) | | (.0306) | | (.0353) | | (.0385) | |
| $ECT^-_{i,j,t-1}$ | 0.0275 | | 0.0233 | | 0.0191 | | 0.0473 | |
| | (.0363) | | (.0324) | | (.0371) | | (.0610) | |
| Constant | 0.0300 | * | 0.0132 | | 0.0201 | | 0.0208 | |
| | (.0157) | | (.0149) | | (.0140) | | (.0135) | |
| N | 189 | | 189 | | 189 | | 189 | |
| $R^2$ | 0.121 | | 0.0764 | | 0.0956 | | 0.0354 | |
| Test $ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}= 0$ | 1.13 | | 0.73 | | 1.35 | | 0.43 | |
| Test $ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}$ | 1.62 | | 1.23 | | 1.46 | | 0.26 | |

***1% significance **5% significance *10% significance
Standard Errors in Parenthesis
$D^+ \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if positive, zero if negative
$D^- \Delta p_{j,t-m}$ is the change in the price of commodity j for lagged m periods if negative, zero if positive
$ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}= 0$ $F(2,182)$
$ECT^+_{i,j,t-1}= ECT^-_{i,j,t-1}$ $F(1,182)$