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Cointegration Analysis of Stocks-to-Use Ratios with Price and Acreage Response for Corn, Soybeans, and Wheat

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Supply and demand interactions determine prices that ration corn, soybeans, and wheat among various uses. This analysis investigates equilibrium conditions with supply and demand as determined by the stocks-to-use ratio. Results indicate that prices are inversely related with stocks-to-use ratios, and market equilibrium is maintained by corresponding acreage adjustments.

***Key words**:* Acreage response, commodity price, elasticity, market equilibrium, stocks-to-use, supply and demand

Corn, soybeans, and wheat are primary components of U.S. crop production. As feed crops, oil crops, and food grains, these three crops are associated with meat, poultry, and dairy production in the national food supply. Market conditions that affect commodity prices for corn, soybeans, and wheat have impacts throughout the agricultural sector. Prevailing commodity prices for these crops influence farm revenue for agricultural producers and food expenditures for consumers. Domestic circumstances for corn, soybeans, and wheat have international implications as the United States has a major role in production for the global food supply.

Corn accounted for 86% of U.S. feed crop cash receipts in 2010-2014 (U.S. Department of Agriculture (USDA), Economic Research Service (ERS), 2015). The 2015 estimate is for U.S. corn to total 36% of global production (USDA, World Agricultural Supply and Demand Estimates, 2016). With 12% of production exported, the United States accounts for 35% of world exports. Ethanol used as a fuel oxygenate for gasoline and by-products account for 39% of annual production which is equal to the percentage utilized as domestic feed. Ten percent of production is utilized domestically for food, seed, and other industrial uses.

In 2010-2014, soybeans were 94% of U.S. cash receipts for oil crops. The 2015 estimate is for U.S. soybeans to total 33% of global production. With 46% of production exported, the United States accounts for 35% of world soybean exports. Soybean crushing for meal as a feed ingredient and oil is 51% of total utilization. The remaining

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3% is utilized for seed. Twenty-eight percent of soybean oil is used as biodiesel, and the balance is utilized for food and other industrial uses.

Wheat accounted for 82% of U.S. food grains cash receipts in 2010-2014. The 2015 estimate is for U.S. wheat to total 8% of global production. With 40% of production exported, the United States accounts for 13% of world wheat exports. Forty-nine person of annual wheat production is for food, and 11% is utilized for feed and seed.

Market conditions for corn, soybeans, and wheat are important determinants of market conditions for other food- and energy-related industries. Commodity price is the signal that determines market conditions for decision-making by producers and consumers. The interaction of supply and demand is fundamental for understanding current market prices and investigating the nature of price volatility. U.S. agricultural production is characterized by technical innovations to enhance productivity which impacts supply and affects costs of production. Increasing global incomes lead to increased consumption for some food products and impacts demand for corn, soybeans, and wheat. In addition to changing commodity market conditions, prices are impacted by macroeconomic conditions that affect financial systems which involve production and international trade for crops.

Interactions of supply and demand, agricultural productivity, and macroeconomics determine equilibrium conditions for corn, soybeans, and wheat. Crop prices adjust in accordance with observable levels of these explanatory variables to establish long-term equilibriums. The objective of this research is to analyze equilibrium conditions for corn, soybean, and wheat prices with supply and demand as determined by the stocks-to-use ratio. Quantification of price with supply and demand equilibrium will establish a basis for industry stakeholders to evaluate market fundamentals in conjunction with other information in making decisions.

Corn, Soybean, and Wheat Price Determination Factors

Supply and demand interactions determine prices that ration commodities among various uses. Market conditions for corn, soybean, and wheat are summarized as the quantity remaining at the end of a market year relative to total annual use. Ending stocks for a specified market year become beginning stocks for the subsequent market year. Beginning stocks for the current period, as well as imports, are the supply available to satisfy demand until production in the period enters the marketing system. The components of supply are beginning stocks, imports, and production. Demand components are food, seed, industrial use, exports, feed, and ending stocks. In equilibrium conditions, ending stocks will equal the quantity required to satisfy demand until production is available for the current market year (Westcott and Hoffman, 1999). Increases in productivity lead to greater output per unit of input. Agricultural productivity in the crop sector occurs with two manifestations: 1) output per acre in the form of increased yields and 2) scale of operation that increases production capacity for each producer. Yield increases are due to seed technology, chemicals, irrigation, and information that increases the effectiveness of input applications. Increased production capacity results from larger equipment units that permit producers to manage increased acreage during a production year.

Agricultural commodities are traded in global markets and fluctuations in the value of the dollar relative to other currencies impacts U.S. prices. Increased value of the dollar leads to increased expenditures in terms of currencies for international purchasers of U.S. crops. This results in downward pressure for U.S. prices and could provide incentives for purchases from foreign competitors producing corn, soybeans, and wheat (Ray and Shaffer, 2015).

Ending stocks and expected use for corn, soybeans, and wheat are summarized in market analysis as the stocks-to-use ratio (SUR). Each crop has a market year that corresponds to its annual cycle of production and utilization. Market years are September-August for corn and soybeans and June-May for wheat. Total annual domestic consumption and exports account for annual use. Quantities remaining in the final month of the market year are ending stocks, and ending stocks at the end of a market year become beginning stocks for the subsequent market year. A ratio of ending stocks as a portion of annual use is expressed as the SUR. Market participants develop benchmarks of SUR, and monthly SUR estimates by the USDA establish a pace for buying and selling throughout the market year (Westcott and Hoffman, 1999).

Corn, soybeans, and wheat have two distinct eras of SUR during a period that includes 1970-2015 (USDA, Foreign Agricultural Service (FAS), 2016). Figure 1 shows corn SUR averaged 26.1 during 1970-1992 and had a sustained decrease to average 13.0 during 1993-2015. Similar decreases are presented for soybeans in Figure 2. Soybean SUR averaged 13.5 during 1970-1994 and decreased to average 7.9 during 1995-2015. In Figure 3, wheat SUR averaged 51.7 for the 1970-1987 period and 29.1 for the 1988-2015 period. In summary, all crops have the characteristic of an early period of SUR substantially greater than a later period with lower SUR.

Producers and consumers have competing interests for agricultural commodity prices. Producers seek increased prices relative to costs of production, and consumers seek decreased prices while satisfying food demand. Figure 4 through Figure 6 present 1950-2015 nominal prices for corn, soybeans, and wheat, respectively. Each crop has nominal prices that could be characterized as an increasing historical trend throughout the period. An alternative interpretation is that prices are clustered around three periodic means which have similar duration for each crop. The first periodic mean ends in 1972, and the second period is 1973-2005. The third period is 2006-2015 and includes an era to the present (Irwin and Good, 2013).

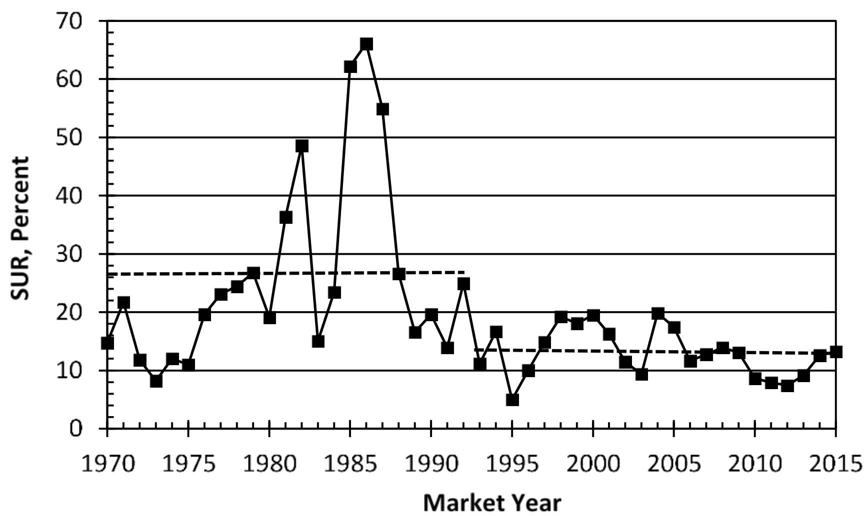

Figure 1. U.S. Corn Stocks-to-Use, 1970-2015. USDA, FAS.

In contrast to commodity prices with non-increasing trends and periodic means, nominal costs of production, including land rent, on a per acre basis demonstrate increasing trends during 1975-2015 (USDA, ERS, 2016). Calculated over *T* years (1975-2015) as $ln(Costs_t) = \beta_0 + \beta_1(Trend_t) + e_t$, OLS (Ordinary Least Squares) trend coefficients for each crop are corn (0.029), soybeans (0.028), and wheat (0.030). Costs of production include input quantities and input unit prices. Increased crop yields are a means in which producers attempt to maintain profitability as production costs increase. Yields, calculated as total U.S. production divided by harvested acreage, have sustained increases that are partial compensation for increased costs (USDA, National Agricultural Statistics Service (NASS), 2016). Calculated as $ln(Yield_t) = \beta_0 + \beta_1(Trend_t) + e_t$, OLS trend coefficients during 1975-2015 for each crop are corn (0.015), soybeans (0.013), and wheat (0.009). Thus, while crop prices do not have sustained increases in Figure 4 through Figure 6, costs of production per acre are increasing at a much greater rate than output per acre.

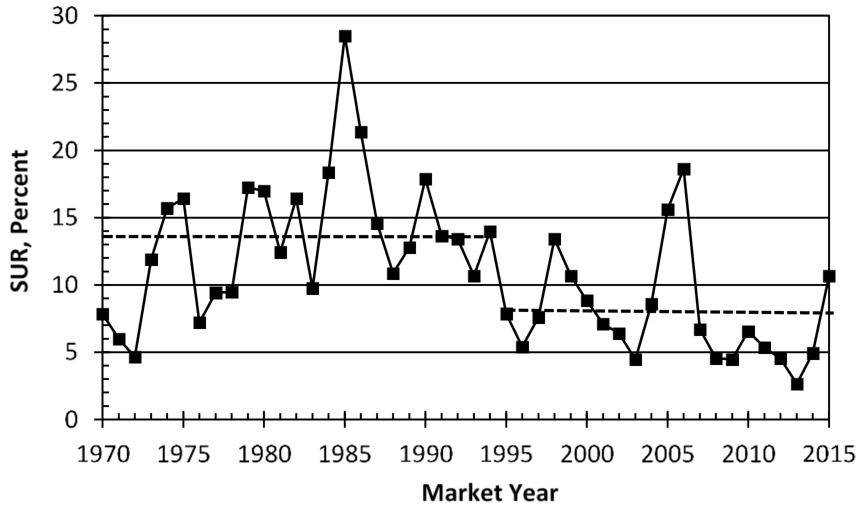

Figure 2. U.S. Soybean Stocks-to-Use, 1970-2015. USDA, FAS.

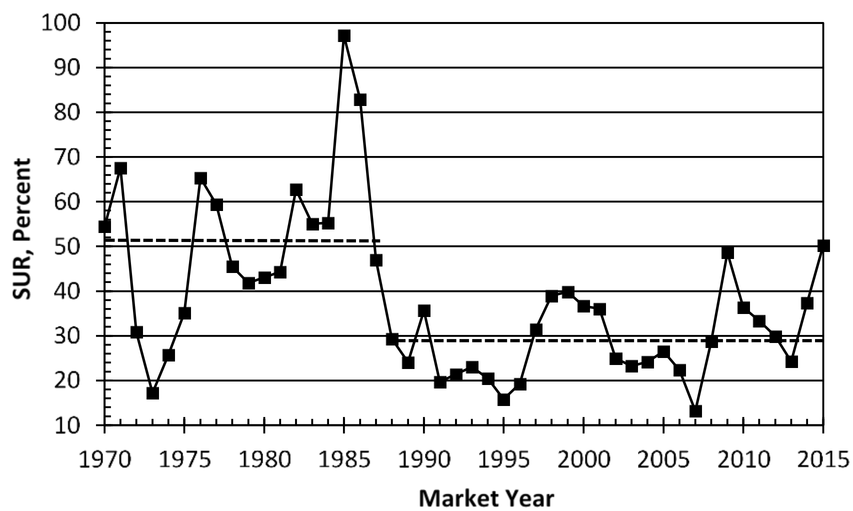

Figure 3. U.S. Wheat Stocks-to-Use, 1970-2015. USDA, FAS.

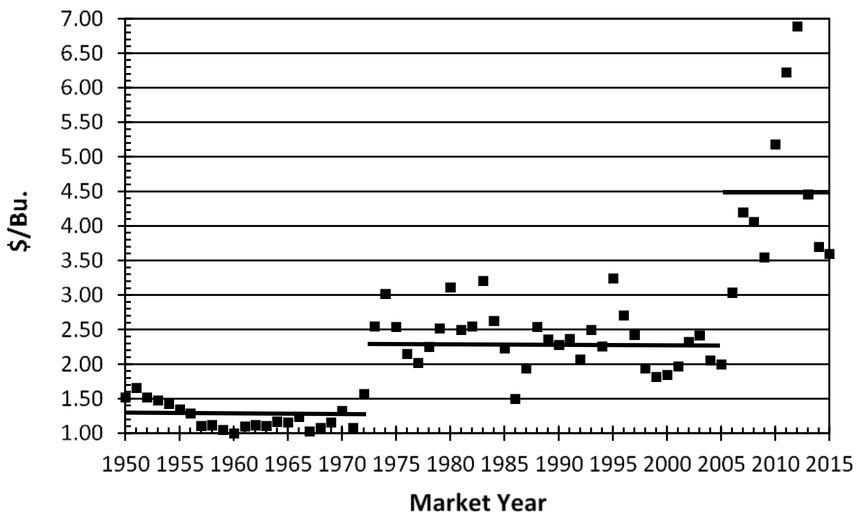

Figure 4. Market Year Corn Price, 1950-2015. USDA, NASS.

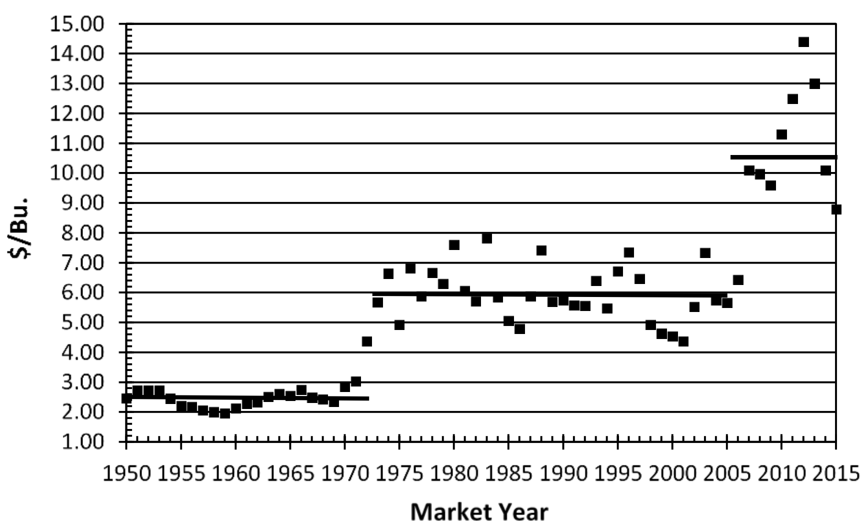

Figure 5. Market Year Soybean Price, 1950-2015. USDA, NASS.

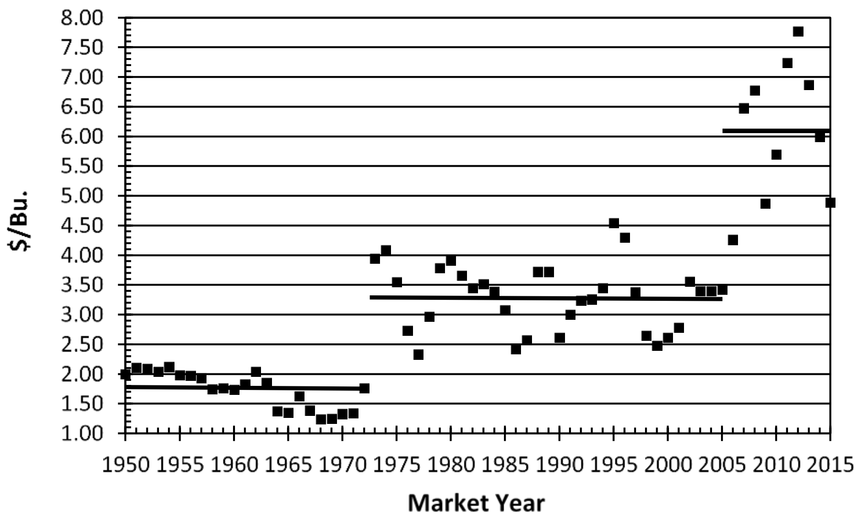

Figure 6. Market Year Wheat Price, 1950-2015. USDA, NASS.

Related Research

Single equation approaches investigating supply and demand for field crops focus on the relationship between commodity prices and SUR which is a numerical ratio quantified for the end of the market year. Inverse relationships between annual prices and ending U.S. SUR for corn and soybeans have been determined for the 1991-2015 period (Good and Irwin, 2015; Irwin and Good, 2015). The reports indicate that both U.S. and world coarse grain SURs have an inverse relationship in explaining U.S. corn prices. Other findings are that for soybeans, neither U.S. SUR nor world SUR are a determinant of U.S. prices for the period of analysis. The report for corn identifies 2006 as a transition year with subsequent years an era of increased corn prices having greater responsiveness to changes in SUR.

Westcott and Hoffman (1999) investigated market factors and government programs in price determination for corn and wheat during 1975-1996. Market factors were represented by U.S. annual SUR for both crops, and SUR of wheat for four main export competing countries. Each of the SUR measures were found to have statistically significant inverse relationships with crop prices.

Goodwin, Schnepf, and Dohlman (2005) proposed to expand on the Westcott and Hoffman (1999) analytical approach by improving the accuracy of forecasting models applying SUR for soybeans. Generally, research involving SUR applies total annual ending stocks as reported by USDA in publically available outlets for dissemination. Goodwin, Schnepf, and Dohlman discuss applying measures of soybean stocks for the fourth quarter and the first quarter as a percentage of annual use. The report states that data for the analysis were collected from a variety of USDA sources, but provides no references or bibliographical information. Uncertainty of data applied in the analysis limits review of the research for comparison to other SUR research findings. The authors offer to disclose exact data sources on request.

Wright (2014) demonstrated an inverse relationship between price and world SUR for rice with an upward trending SUR for 1960-2008. Extended analysis in the study aggregated corn, rice, and wheat to establish an inverse relationship for price with world SUR. The analysis indicates a new market regime with higher crop prices for the years after 2005.

Exports are a component of annual domestic use of U.S. corn, soybeans, and wheat. As the value of the U.S. dollar strengthens relative to other currencies, U.S. exports are more expensive in international markets. Ray and Shaffer (2015) state that relative dollar values should be considered on a currency-by-currency basis as the dollar may strengthen or weaken at varying rates among national currencies. For example, in 2015, the dollar had strengthened against the euro during the previous year but was approximately equal in value to the Chinese renminbi for that same time period. Another consideration is that most countries import only the difference between the amount needed and the amount produced on an annual basis. Increased production in a potential importing country leads to decreased imports, dampening currency impacts. Increased production among U.S. export competitors leads to decreased U.S. exports and vice versa.

U.S. agriculture has demonstrated achievements in aggregate productivity by increasing total output with only negligible aggregate input increases (Ball, Wang, and Nehring, 2016). Comparing aggregate farm prices paid and prices received demonstrates corresponding trends, but increases in prices paid greatly outpace increases in prices received (Zulauf and Retting, 2013). The analysis presents evidence that productivity increases compensate for differences in prices received and prices paid while reducing price disparities in long-term trends as more output is generated per unit of input.

Methodology and Data

Model

An equilibrium model for annually produced crops with potential inventories involves the relationship between market year prices and ending supply. Market conditions explaining price movements toward equilibrium are summarized by SUR. At equilibrium prices, p, for the market year, t, equilibrium quantities satisfy

(1) $S_t = D_t + K_t,$

where S_t is supply, D_t is demand, and K_t is ending stocks. Supply is positively related to price while demand is negatively related to price changes. Equilibrium conditions determine ending stocks in the previous market year, K_{t-1}, so that a sufficient quantity is available to satisfy short-term D_t until production is available in the current market year. Supply in the current year consisting of production, imports in the current year, and ending stocks from the previous year is $S_t(p_t,p_{t-1})$. Thus, for a given production technology and demand, equilibrium price for each market year determines the equilibrium $K_t(p_t)$ with prices inversely related to stocks expressed as

(2) $p_t = f^{-1}(K_t).$

To maintain constancy through time with increasing global population for domestic consumption and exports, K_t is expressed as a percentage of annual use K_t/D_t, or SUR_t.

Varian (1992) demonstrates that supply, S_t, and demand, D_t, are annual flow variables composing a structural system with price, p_t, such that $\frac{\partial S(p_t)}{\partial p_t} > 0$ and $\frac{\partial D(p_t)}{\partial p_t} < 0$. A reduced form regression equation for supply and demand determines unique parameter estimates for exogenous explanatory variables that can be applied to predict changes in the equilibrium price due to changes in these exogenous variables. With a single price variable, p_t, and two quantity flow variables, S_t and D_t, it is not possible to obtain unique parameter estimates for the effects of changes in supply and demand on price. Additionally, assumptions of ordinary least squares (OLS) regression analysis include that explanatory variables should not be correlated with the error term. This is not the case in equation (1) as supply is positively related to price changes and demand is negatively related to price changes.

Industry supply, $S(p_t)$, is the sum of individual firm supply functions, and industry supply in the current period has marginal cost components for current production, current imports, and ending stocks from the previous period. Marginal cost of ending stocks from the previous period that are carried over as supply in the current period is equal to storage cost per unit of production. Although markets seldom achieve conditions of perfect competition, it is appropriate to investigate models of perfect competition in order to generate insights for actual realized market conditions. Supply and demand determine a price for equating the marginal willingness to pay for a product and the marginal cost of production to achieve equilibrium output such that $\left|\frac{\partial D(p_t)}{\partial p_t}\right| = \left|\frac{\partial S(p_t)}{\partial p_t}\right|$, where both factors are absolute values. The equilibrium condition can be alternatively expressed as $\frac{\partial[S(p_t)-D(p_t)]}{\partial p_t} = 0$ or $\frac{\partial K(p_t)}{\partial p_t} = 0$, where $K(p_t)$ is a single variable for ending stocks. Thus, the reduced form equation for price and ending stocks represented by equation (2) at market equilibrium has a single quantity variable, and this stock variable is not correlated with the error term in OLS regression analysis.

Including relevant variables discussed in previous sections and market equilibrium conditions, equation (2) can be expanded as a cointegration model to investigate supply and demand equilibrium with annual market year price, P_t, as

$$(3) \qquad P_t = \beta_0 + \beta_1 SUR_t + \beta_2 T_t + \beta_3 D_{2006\text{-}2015} + \mu_t.$$

SUR_t is U.S. stocks-to-use, T_t is a trend variable for each year corresponding to P_t of the analysis, and $D_{2006\text{-}2015}$ is a dummy variable with value = 1 for each year during 2006-2015 and value = 0 for all other years. Years represented by the dummy variable correspond to a period identified as an era of increased agricultural commodity prices (Irwin and Good, 2013; Wright, 2014). The dummy variable coefficient captures effects of these years on prices as an intercept shifter for β_0. Parameters to be estimated are β_i (i= 0…3) for an intercept term and each explanatory variable with the stochastic error represented by μ_t in equation (3).

Data

Data for this analysis include eras with crop prices having two distinct periodic means (1973-2005 and 2006-2015) identified by Irwin and Good (2013) and discussed previously in conjunction with Figure 4 through Figure 6. Prices and stocks-to-use during 1973-2015 leads to 43 annual observations for the time series. Crop price is from the NASS (USDA, NASS, 2016). Stocks-to-use data are from the FAS (USDA, FAS, 2016).

Equation (3) is specified to have a logarithmic functional form with data for prices and SUR transformed into natural logarithms.

Results

Equilibrium Price Determination

Applying the augmented Dickey-Fuller (ADF) test to SUR_t in equation (3) indicates it is a stationary variable for all three crops. ADF results for P_t determines it to be a nonstationary variable for each crop. Investigating potential cointegration relationships concludes that the residuals for $P_t = \beta_0 + \beta_1 SUR_t + \beta_2 T_t$ are not trend stationary. Applying Dickey-Fuller (DF) unit root tests to the residuals for the complete model represented by equation (3) indicates stationarity and cointegrating relationships among variables for all crops (Gujaratti and Porter, 2009). Engle-Granger tau-statistics and MacKinnon p-Values are reported in Appendix 1.

OLS results to establish cointegration of variables in equation (3) indicate the presence of serial correlation for each crop. A model with first-order serial correlation, AR(1), has residuals, μ_t, in period t that are correlated with residuals in period t-l with ρ as the measure of correlation between residuals expressed as $\mu_t = \rho\mu_{t-1} + v_t$. The general formulation for first-order serial correlation with an independent variable, Y_t, and one explanatory variable, X_t,

$$(4) \qquad Y_t = \beta_0(1-\rho) + \beta_1 X_t + \rho Y_{t-1} + \rho\beta_1 X_{t-1} + v_t$$

is a transformed model with a stochastic error term, v_t, that is uncorrelated over time (Hill, Griffiths, and Lim, 2011). Expanding equation (4) for all variables in equation (3) and minimizing the sum of squares of errors derives coefficient estimates for explanatory variables that are estimated simultaneously with ρ.

Table 1 presents coefficient estimates, t-statistics, and p values indicating statistical significance levels for variables in the price equilibrium model. AR(1) is the coefficient for estimated correlation, ρ, among residuals. SUR has the expected inverse relationship with price and high levels of statistical significance for each crop. A negative coefficient for the soybean trend variable is consistent with slightly declining nominal prices after controlling for other factors of price equilibrium. Trend coefficients for corn and wheat are consistent with non-increasing nominal prices. The dummy variable coefficients are supportive of a shift representing a new era of crop prices during the 2006-2015 period with results indicating a stronger impact for corn and soybeans than for wheat.

Application of U.S. SUR includes impacts of international trade through imports and exports. Global SUR encompasses trade flows among all nations which potentially affect U.S. commodity prices by both direct and indirect impacts. A second regression is applied to equation (3) with U.S. SUR substituted by world SUR. Results indicate that all crops have statistically significant coefficient estimates for world SUR that are greater in absolute values than coefficients for U.S. SUR in Table 1. For hypothesis testing, the coefficients for world SUR are compared to U.S SUR coefficients with world SUR standard errors applied to calculate *t* values. The hypothesis, H_0: World SUR = U.S. SUR, is rejected at a 90% confidence level for corn with a world SUR coefficient estimate of -0.612. The hypothesis is not rejected at a 90% confidence level for soybeans and wheat.

Table 1. Price, Long-Term Equilibrium Model Coefficient Estimates.

Variable	Corn	Soybean	Wheat
Intercept	1.803	2.663	2.337
t-Statistic	*8.317*	*13.389*	*5.826*
p-Value	*<0.001*	*<0.001*	*<0.001*
SUR, Stocks-to-Use	-0.266	-0.296	-0.342
t-Statistic	*-4.939*	*-4.873*	*-4.443*
p-Value	*<0.001*	*<0.001*	*<0.001*
Trend	-0.008	-0.008	0.006
t-Statistic	*-1.562*	*-1.839*	*0.622*
p-Value	*0.127*	*0.074*	*0.538*
Year = 2006-2015	0.552	0.458	0.240
t-Statistic	*4.473*	*4.002*	*1.656*
p-Value	*<0.001*	*<0.001*	*0.106*
AR(1)	0.531	0.436	0.802
t-Statistic	*3.939*	*2.761*	*7.233*
p-Value	*<0.001*	*0.009*	*<0.001*
R^2	0.846	0.819	0.837
Durbin-Watson	1.908	1.949	1.696

Although cointegration results indicate there is long-run equilibrium between variables, there may be disequilibrium in the short run represented by the error terms in equation (3). Gujarati and Porter (2009) show that corrections for disequilibrium are represented with the error correction mechanism (ECM). First differences of the dependent variable are regressed with first differences of the explanatory variables and the lagged residuals from the cointegrating regression. The ECM regression equation for equation (3) with U.S SUR is

$$(5) \qquad \Delta P_t = \beta_0 + \beta_1 \Delta SUR_t + \beta_2 T_t + \beta_3 D_{2006\text{-}2015} + \mu_{t-1} + a_t$$

where μ_{t-1} is the lagged residuals from the cointegrating equation (3) and the stochastic error is represented by ε_t.

Table 2. Price, Short-Term Equilibrium Model Coefficient Estimates.

Variable	Corn	Soybean	Wheat
Intercept	0.046	0.023	0.023
t-Statistic	*1.002*	*0.481*	*0.512*
p-Value	*0.323*	*0.633*	*0.612*
ΔSUR, Stocks-to-Use	-0.272	-0.247	-0.291
t-Statistic	*-6.371*	*-4.706*	*-4.561*
p-Value	*<0.001*	*<0.001*	*<0.001*
Trend	-0.003	-0.001	-0.001
t-Statistic	*-1.166*	*-0.572*	*-0.633*
p-Value	*0.251*	*0.571*	*0.531*
Year = 2006-2015	0.115	0.065	0.094
t-Statistic	*1.656*	*0.887*	*1.418*
p-Value	*0.106*	*0.381*	*0.165*
Price, ECM	-0.565	-0.559	-0.475
t-Statistic	*-4.309*	*-3.566*	*-3.442*
p-Value	*<0.001*	*0.001*	*0.001*
R^2	0.637	0.559	0.599
Durbin-Watson	1.746	1.763	1.603

Table 2 presents OLS results for short-term price equilibrium in equation (5). Statistical significance of ECM suggests that prices adjust to SUR with a lag for all crops. For corn, long-term price elasticity (-0.266) with SUR in Table 1 is approximately equal to short-term elasticity (-0.272) in Table 2. Long-term soybean and wheat elasticities are slightly greater than short-term elasticities. ECM coefficients represent the percentage of discrepancy between long-term price and short-term price that is corrected within one year. Corn (-0.565), soybean (-0.559), and wheat (-0.475) ECM coefficients indicate that approximately 50% of adjustments in prices that are necessary for returning to equilibrium with SUR occur within one year.

Equilibrium of Price and Crop Acreage

Producers utilize many information sources when making planting decisions. Futures contracts and forward cash contracts for crops to be harvested and delivered at a future date have crop prices that are determined by anticipated market conditions. Outlooks for market conditions are based on expected supply and demand which is measured by SUR (CME Group, 2016). Market forces, as measured by supply and demand, influence prices. SUR measures summarize the effects of both supply and demand factors during the year and are indicators of price movements for commodities (Westcott and Hoffman, 1999). Thus, there is an implied equilibrium between crop price and acreage as a supply response.

Average annual increases in use composed of domestic consumption and exports for corn (2.6%), soybeans (2.9%), and wheat (0.7%) are reflected by crop acreages for the market year of each crop during 1970-2015 which are presented in Figure 7. Corn and soybean acreage have increased, and corresponding trends indicate complementary use as animal feed, as well as similar increases in industrial use for both crops. Yield increases relative to usage have allowed decreased acreage to maintain adequate supply for wheat use.

Evidence of long-term equilibrium in Table 1 suggests acreage decisions are made by producers which lead to annual production that maintains a balance between supply and demand. High stocks-to-use leads to market signals for less production and planted acreage should decrease. Likewise, low stocks-to-use leads to market signals for more production and acreage should increase. Equilibrium of price with SUR implies a relationship between acreage and price, $A_t = f(p_t)$, as production adjustments are a component of adjustments in equilibrium ending stocks. A model for the relationship between planted acreage and stock-to-use is

$$(6) \qquad A_t = \beta_0 + \beta_1 SUR_t + \beta_2 T_t + \beta_3 D_{2006\text{-}2015} + e_t.$$

A_t is national planted acreage, SUR_t is as defined for equation (3) and includes U.S. SUR for 1973-2015, T_t is a trend variable for each year corresponding to A_t of the analysis, and $D_{2006\text{-}2015}$ is a dummy variable with value = 1 for each year during 2006-2015 and value = 0 for all other years. Years represented by the dummy variable correspond to a period identified as an era of increased agricultural commodity prices (Irwin and Good, 2013; Wright, 2014). The dummy variable coefficient captures effects of these years on acreage as an intercept shifter for β_0. Parameters to be estimated are β_i (i= 0…3) for an intercept term and each explanatory variable with the stochastic error represented by e_t in equation (6). SUR data are ending measures for a marketing year and are available to indicate market conditions when planting decisions are made by producers. Data for planted acreage are reported in the marketing year of harvest which is subsequent to the marketing year of SUR and planting decisions. Thus, SUR data are beginning stocks corresponding to planted acreage. Equation (6) is specified to have a logarithmic functional form with data for acreage and SUR transformed into natural logarithms.

SUR_t is a stationary variable in equation (3), and ADF results for A_t determine acreage to be a stationary variable for corn and wheat, but soybean acreage is a nonstationary variable. Applying ADF unit root tests to the residuals for the complete model represented by equation (6) indicates cointegrating relationships at a 76% confidence level for soybeans with a constant term in the cointegrating equation. Engle-Granger tau-statistics and MacKinnon p-Values reported in Appendix 1 indicate cointegrating relationships at a 96% confidence level for the soybean cointegration equation without a constant term.

Applying AR(1) least squares estimation to equation (6) results in coefficient estimates, t-statistics, and *p* values indicating statistical significance levels for variables in the acreage equilibrium model which are reported in Table 3. SUR has an inverse relationship with acreage, and *p* values indicate high levels of statistical significance for each crop. The interpretation is that as ending stocks differ from equilibrium levels, acreage adjusts as a response to return SUR to equilibrium.

The trend variable indicates increased soybean acreage and decreased acreage for wheat in achieving equilibrium. Corn acreage does not have a statistically significant trend coefficient. The dummy variable is positive for corn and negative for soybeans. The era of higher equilibrium prices established in equation (3) led to increased corn acreage in equation (6) that was a substitute for decreased soybean acreage, although soybean acreage has a long-term increasing trend. For wheat, an era of higher prices has not induced increased acreage.

Federal legislation enacted in 2005 known as the Renewable Fuel Standards (RFS) established mandates for increased ethanol production. The RFS contained provisions for biofuels that included soybean oil, but the concentration was for fuel ingredients produced from corn (Carter, Rausser, and Smith, 2013). Results from equation (3) and Table 1 indicate that competition for corn acreage among crops led to increased prices for all crops, but the RFS increased acreage for only corn in equation (6) and Table 3.

Although cointegration results indicate there is long-run equilibrium between acreage and explanatory variables, there may be disequilibrium in the short-run, represented by the error terms in equation (6). The ECM regression equation for equation (6) is

$$(7) \qquad \Delta A_t = \beta_0 + \beta_1 \Delta SUR_t + \beta_2 T_t + \beta_3 D_{2006\text{-}2015} + e_{t-1} + z_t$$

where e_{t-1} is the lagged residuals from the cointegrating equation (6) and the stochastic error is represented by z_t.

Table 3. Acreage, Long-Term Equilibrium Model Coefficient Estimates.

Variable	Corn	Soybean	Wheat
Intercept	4.673	4.244	4.939
t-Statistic	*50.899*	*32.636*	*43.548*
p-Value	*<0.001*	*<0.001*	*<0.001*
SUR, Stocks-to-Use	-0.093	-0.076	-0.119
t-Statistic	*-3.673*	*-3.960*	*-4.803*
p-Value	*<0.001*	*<0.001*	*<0.001*
Trend	-0.002	0.009	-0.014
t-Statistic	*-1.564*	*2.159*	*-6.867*
p-Value	*0.126*	*0.037*	*<0.001*
Year = 2006-2015	0.155	-0.132	0.051
t-Statistic	*3.933*	*-2.638*	*1.156*
p-Value	*<0.001*	*0.012*	*0.255*
AR(1)	0.272	0.836	0.568
t-Statistic	*1.485*	*9.093*	*5.546*
p-Value	*0.146*	*<0.001*	*<0.001*
R^2	0.695	0.873	0.904
Durbin-Watson	1.942	1.746	1.831

Table 4 presents OLS results for short-term price equilibrium in equation (7). Statistical significance of ECM suggests that acreage adjusts to SUR with a lag for all crops. Long-term acreage and SUR elasticities are slightly greater than short-term elasticities for all crops. The ECM coefficient for corn indicates that approximately 75% of the discrepancy between long-term acreage and short-term acreage is corrected within one year. For wheat, approximately 42% of the discrepancy between long-term acreage and short-term acreage is corrected within one year, and the soybean correction is approximately 28% within one year.

Table 4. Acreage, Short-Term Equilibrium Model Coefficient Estimates.

Variable	Corn	Soybean	Wheat
Intercept	0.011	0.014	0.021
t-Statistic	*0.502*	*0.801*	*1.166*
p-Value	*0.619*	*0.428*	*0.251*
ΔSUR, Stocks-to-Use	-0.068	-0.068	-0.094
t-Statistic	*-2.933*	*-3.475*	*-3.927*
p-Value	*0.006*	*0.001*	*0.004*
Trend	-0.001	0.000	-0.002
t-Statistic	*-0.518*	*-0.196*	*-1.644*
p-Value	*0.608*	*0.846*	*0.109*
Year = 2006-2015	0.026	-0.004	0.030
t-Statistic	*0.770*	*-0.146*	*1.116*
p-Value	*0.446*	*0.885*	*0.272*
Acreage, ECM	-0.752	-0.281	-0.415
t-Statistic	*-3.894*	*-2.580*	*-3.532*
p-Value	*<0.001*	*0.014*	*0.001*
R^2	0.541	0.393	0.511
Durbin-Watson	2.081	2.080	1.766

Structural Stability of Equilibrium

A lengthy time series for annual data increases degrees of freedom for statistical applications. Coefficient estimates for 1973-2015 are single elasticity measures for a period in which structural shifts may have unique elasticities for a specific subset of years. Potential structural shifts for price and acreage elasticities are the two distinct SUR periods for each crop discussed previously and presented in Figure 1 through Figure 3. Each of the four equations previously applied for long-term equilibrium and short-term equilibrium are revised to quantify potential structural shifts in elasticities. Following Gujarati and Porter (2009), two variables are added to each equation that account for a unique intercept and elasticity during the later periods for each crop with lower average annual SUR measures. Later periods are 1993-2015 for corn, 1995-2015 for soybeans, and 1988-2015 for wheat. The variable added to quantify an intercept shift is a dummy variable with a value of 1 for each of the years in the later period of higher SUR and a value of 0 for other years. The variable added to quantify a shift in elasticity is the annual SUR value multiplied by the dummy variable. Statistical significance of an added variable signifies a structural shift. Applying the methodology to equation (3), equation (4), equation (6), and equation (7) indicates that only short-term price elasticity for corn has a structural shift in the later period with lower average SUR. Table 2 has corn price elasticity of -0.272 for the 1973-2015 period. Structural shift analysis indicates a short-term price elasticity of -0.270 with a statistically significant structural shift coefficient of -0.090 for the later period. Short-term price elasticity for corn of -0.360 during the 1993-2015 period is a summation of both coefficients. The dummy variable for a structural shift in the intercept is not statistically significant. No other structural shifts in long-term or short-term elasticities are identified by statistical significance of structural shift variables. Thus, other than corn short-term price elasticity, intercepts and elasticities reported in Table 1, Table 2, Table 3, and Table 4 are applicable for the complete time series.

Discussion

Characteristics of Price and Acreage Equilibrium

Results for long-term equilibrium and short-term adjustments to sustain equilibrium coincide with observable characteristics of crop prices and acreage. A complete discussion of equilibrium market conditions for corn, soybeans, and wheat includes characteristics that are fundamental to U.S. production. In 2015, total U.S. planted acreage of major field crops was 249.7 million acres. Corn (88.0 million), soybeans (82.7 million), and wheat (54.6 million) composed 225.3 million acres, or 90%, of total major row crop acreage.

Corn and soybeans are concentrated in 13 Midwestern[1] states with suitable soils and climate for production. These states planted 85% of U.S. corn acreage and 82% of U.S. soybean acreage in 2015. This region represents only 48% of U.S. wheat acreage as it is a grass crop potentially utilized in double-cropped production or in mixed-annual production for cattle grazing and subsequent grain marketing. Wheat is often planted as a winter cover crop or for grazing with intension of harvest for grain only when market conditions are favorable.

[1] The 13 Midwestern states are Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

Corn and soybean production have geographic concentrations that limit production alternatives to these crops in achieving optimal productivity efficiencies. Market efficiency for crop production is characterized by production decisions that switch out of one crop to a crop with greater profit while following crop rotation practices determined by agronomic science. Some areas may have agronomic characteristics making monoculture production optimal, but most areas are best suited for a rotation of corn and soybean acreage that excludes alternative crops. Corn and soybean rotations have varying crop proportions that are based on relative yield potentials and crop prices. Aggregate acreage data result from individual farms in unique rotation sequences that partially counter adjustments of other farms that are in alternative rotation sequences. Changes in aggregate acreage are marginal changes in crop allocations and are indicative of marginal changes at the farm level which include considerations of crop rotation, relative yields, and market conditions.

Price elasticities in Table 1 are market reactions to SUR. Acreage elasticities in Table 3 are aggregate responses by producers and are representative of marginal acreage adjustments due to SUR. Acreage elasticities that are significantly less than price elasticities are consistent with a degree of stickiness in acreage adjustments to price changes. Efficiency of investment in capital equipment leads to production capacity that balances the requirements of equipment common for each crop, as well as equipment that is unique for each crop. In achieving optimal scale efficiency, producers are committed to a fixed combination of crop acreage with only marginal changes in annual acreage decisions.

Acreage ECM coefficients in Table 4 represent conditions that are entailed in annual planting decisions for corn and soybeans. Comparison of short-term elasticities shows that corn acreage decisions have greater flexibility than soybeans, and soybean acreage decisions have more stickiness than corn acreage. The linear correlation between corn price and soybean price of 0.94 indicates a tendency for similar price movements. Lower production costs for soybeans compared to corn are an inducement for slower soybean acreage adjustments when soybean prices and corn prices are not at long-term equilibriums. Thus, the ECM coefficient indicates that while corn acreage adjusts by 75% within one year in returning to equilibrium, soybean acreage only adjusts by 28% within one year.

Price and SUR long-term elasticities quantified in this analysis are similar for corn and soybeans. Market analysis of corn and soybeans often involves consideration of a ratio that is soybean price divided by corn price (Schnitkey, 2014). Figure 8 is the market year soybean/corn price ratio for 2005-2015. The average price ratio for 2005-2015 is 2.44, with five years above the average, five years below the average, and one year equal to the average. The temporal balance of the soybean/corn price ratio is a manifestation of market forces maintaining price and acreage equilibriums with stocks-to-use ratios for both crops. In areas where both crops are produced, the optimal planting window for corn is early in the production season and the optimal planting window is later for soybeans, and planting both crops extends annual hours usage for a fixed equipment complement. Long-term acreage and SUR elasticities that are similar for corn and soybeans maintaining equilibrium, coupled with identical short-term elasticities, are consistent with observed price relationships maintaining equilibrium.

Winter wheat averaged 73% of total wheat acreage during 1975-2015. Winter wheat can be doubled cropped with another crop planted in the spring and can be a secondary crop or a primary crop, depending upon circumstances (Borchers et al., 2014). In contrast, corn and soybeans have one potential season in the United States and are exclusively planted in spring months. Greater flexibility for planted wheat acreage is consistent with a wheat long-term acreage and SUR elasticity that is 28% greater than the corresponding elasticity for corn and 57% greater than the soybean elasticity. Winter wheat is often planted as a cover crop or for grazing, and acreage harvested for grain is determined in the spring based on market conditions. Thus, wheat planted acreage and SUR long-term and short-term elasticities may understate actual flexibility for acreage decisions. Achieving scale efficiencies requires planting acreage at full capacity each year for field crops. In the geographic latitudes where most U.S. corn and soybeans are produced, efficiency entails planting a feasible acreage combination of corn and soybeans with winter wheat added when market conditions are most favorable.

Implications of Price Equilibrium

Results in this analysis have implications for farm managers making planting decisions and marketing crops. SUR represents market fundamentals and establishes a basis for price expectations when allocating crop acreage. Technical factors in market analysis create short-term opportunities for crop decisions, but long-term expectations will involve market fundamentals as determined by SUR. The cyclical patterns in Figure 1 through Figure 3 indicate market forces interact to balance supply and demand around discernable equilibrium levels. The supply portion of equilibrium adjustments is farm management decisions made to increase or decrease acreage as production responds to prevailing market conditions.

Public policy implications are indicated by results of this analysis. Decreasing commodity prices relative to production are supportive of commodity programs that establish price floors as crop supply and demand follow cycles that periodically result in short-term equilibrium prices that are less than unit costs of production. Decreased commodity prices lead to supply and demand adjustments that result in subsequently higher commodity prices which correspond to years in which no commodity program payments are received.

Crop prices develop historical statistical distributions that determine expected payments for Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) programs of the 2014 Farm Bill (Schnitkey and Good, 2014). Evaluating annual payments in the context of long-term price equilibrium determines the efficacy of programs in meeting public policy objectives of stabilizing crop revenue during periods of price declines. PLC payment rates are triggered when annual prices are less than a reference price that is fixed for the duration of the farm bill legislation. This program mechanism is consistent with the characteristics of equilibrium prices that are observed to establish a periodic mean for each crop.

The county version of the Agricultural Risk Coverage (ARC-CO) program sets payment rates in each county that are based on historical national prices and county yields. Payments are triggered when current revenue for a county, determined by national price and county yield, are below a moving benchmark revenue. The moving benchmark revenue is determined by five-year Olympic averages for county yields and national prices. A feature of this program is that realized farm yields may differ greatly from county yields, and the need for revenue support could differ among farms in the same county. Another feature of this program is that revenue support will differ between counties as historical yields and current yields have differing relative values (Westoff, Foster, and Gerlt, 2016).

The price component of ARC-CO changes as crop prices potentially have periods of high or low annual prices (Barnaby, 2016). This feature is not consistent with observed characteristics of long-term equilibrium crop prices which have tendencies to periodic means as demonstrated in Figure 4 through Figure 6. Results of the price equilibrium models indicate that the variable price component of ARC-CO correlates with volatile market conditions that are determined by SUR.

Summary and Conclusions

Market forces, capital efficiency, and agronomic science contribute to establish supply and demand equilibrium for corn, soybeans, and wheat. Supply and demand are quantified by a ratio of ending stocks as a portion of annual use which is expressed as the SUR. Commodity price is the signal that determines decision making by consumers and producers to achieve market equilibrium. Analysis in this research indicates that prices are inversely related with SUR, and equilibrium is maintained by acreage adjustments that are also inversely related with SUR.

Increased productivity in crop production is composed of technological advances from inputs on a per-acre basis and scale efficiencies from capital investment inputs. Productivity increases compensate producers for cost increases as more output is generated per unit of input. Research and technological innovation lead to U.S. agriculture achieving increasing output that is marketed at decreasing real prices per unit of production. Productivity efficiency allows producers to apply technological innovations without passing the full costs to consumers.

This report documents that nominal crop prices are non-increasing while production costs are increasing during 1975-2015. Temporary deviations from equilibrium quantified in this analysis potentially occur at price levels that are less than production costs per bushel for efficient producers, and crop prices should be evaluated with attributes of public policy programs intended to stabilize farm revenue. Results of this research, evaluated in conjunction with inherent characteristics of efficient field crop production, indicate that various programs enacted during 1975-2015 have not obviated a market relationship between planted acreage decisions and SUR.

Crop prices are demonstrated in this report to achieve equilibriums in which prices are volatile around deterministic means. Agricultural policies have triggers for price supports when realized prices are less than a determined threshold level. The ARC-CO alternative program available, with policy established in the 2014 Farm Bill, possesses a moving price threshold determined by recent historical national prices. This moving price threshold is not consistent with the natural behavior of crop prices tending toward periodic means. A feature of this revenue protection program is that extended years of high prices increase the price threshold while extended years of low prices diminish the price threshold. The result is that this program, in some years, could lead to payments in excess of levels necessary to stabilize revenue until prices return to profitable levels. Likewise, in other years, this program could lead to payments less than levels necessary to satisfactorily stabilize revenue until prices return to profitable levels.

This analysis presents a basis for investigating factors that impact crop prices as equilibrium is established with supply and demand. Crops not included in the current analysis have supply and demand quantified by SUR and could be investigated with the same approaches applied in this study. This analysis does not attempt to quantify existing or proposed agricultural commodity programs. Investigation of equilibrium price determination provides a basis for generalized concepts associated with public policy for agriculture.

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Appendix. Cointegration Results for Equilibrium Residuals.

	Long-Run Price Equilibrium		
Crop	Corn	Soybean	Wheat
Engle-Granger Tau-Statistic	-4.013	-4.471	-4.687
MacKinnon p-Value	0.100	0.041	0.026
Durbin-Watson	1.812	1.925	1.903

	Long-Run Acreage Equilibrium		
Crop	Corn	Soybean	Wheat
Engle-Granger Tau-Statistic	-5.090	-3.476[a]	-4.593
MacKinnon p-Value	0.010	0.244[a]	0.032
Durbin-Watson	1.929	2.010	1.764

[a] *Engle-Granger Tau-Statistic without intercept term: -4.030,*

MacKinnon p-Value: 0.040