Kansas Grain Supply Response to Economic and Biophysical Factors, 1977-2007

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Measuring how grain supply is affected by weather, climate, and prices is imperative for policy makers and agribusinesses. These impacts have wide-reaching effects on the economy and the environment. Quantifying supply-production decisions creates more informed markets, which in turn lead to decreases in volatility. Indeed, a greater understanding of commodity supply is timely, important, and interesting, due to current events including biofuel demand increases, increased income in emerging economies, and world population increases. Agricultural supply response has two components: (1) acreage allocation, and (2) the impact of biophysical and economic variables on crop yields. Houck and Gallagher (1976) highlighted the importance of total supply analysis: "taking acreage response estimates as approximations to total supply elasticities is to seriously underestimate the price responsiveness of corn production." While the individual acreage and yield analyses are important for land use and policy analysis, it is less effective at understanding commodity response. McDonald and Sumner (2003) furthered discussed this point in an analysis of rice farmers. Through the careful quantification of acreage and yield responses, this research presents a method which more accurately and completely measures the supply response for agricultural commodities, in this case county-level wheat, corn, soybeans, and sorghum (milo) in Kansas, 1977-2007.

Heterogeneity of land is a fundamental issue in agricultural production research (Just 2000; Pope and Just 2003), and numerous methods for both acreage and yield responses have been undertaken (Choi and Helmberger 1993; Hardie and Parks 1997; Lichtenberg 1989; Miller and Plantinga 1999; Orazem and Miranowski 1994; Schlenker, Hanemann, and Anthony 2004). These methods account for land quality differences, but did not include other major supply determinants. Understanding the relationship between acreage and yields on total supply advances our knowledge of agricultural commodity markets.

This research develops a recursive model to estimate total supply where acreage is determined prior to yield response, following Choi and Helmberger (1993) and Houck and Gallagher (1976). By including the acreage response within the yield response, the results more accurately estimate total supply response to economic and biophysical variables, through incorporating the impact of expansion on the extensive margin for aggregate yield response. Further understanding of the extensive margin impacts is increasingly important as additional land is brought into production, as seen recently. Despite hypothesized and theoretical predictions of the negative impacts of increased acreage on yields, most previous research has not quantified these effects.

The second contribution of this research is the impact of potential climate changes on total grain supply. The impact of the potential changes in yields from long-term climate change is expected to have long-term impacts on planting decisions and commodity supply. As weather and climate change, producers' expectations of seasonal weather level and yields will be affected dramatically. Research has increasingly focused on the impact of biophysical changes on yield response (Huang and Khanna 2010; McCarl, Villavicencio and Wu 2008; Kaufmann and Snell 1997). However, acreage allocations are also affected by changes in relative yield expectations. Understanding the impact of weather and climate on relative yields and acreage allocations is important in advancing our knowledge of agricultural supply response.

Additionally, this research extends our knowledge of the effects of producer price and yield expectations on production decisions. Agricultural producers face a variety of risk and uncertainty in prices and yields when making acreage and yield production decisions. The volatility in markets, as well as the growing concern of climate change affects producer decisions. Given the large time period between planting and harvesting, understanding producer expectations provides enhanced understanding of agricultural commodity supply. Early agricultural supply research emphasized the importance of producer price expectations in non-stationary markets (Nerlove 1956). Later research used futures markets to quantify producer expectations (Chavas, Pope, and Kao 1983; Gardner 1976; Morzuch, Weaver, and Helmberger 1980; Orazem and Miranowski 1994). This method has been successful in estimating those expectations. However, increases in commodity volatility and changes within the market (Wright 2011) require new methods to estimate producer expectations.[1]

Producers base their price expectations, thus production decisions, on a variety of price signals, including current commodity market prices and the performance of these prices historically. Divergences between futures prices at planting and harvesting erode the ability of the use of futures prices to fully quantify expectations, thus impacting subsequent production decisions. Basis prices, the differences in cash and futures prices, are needed to quantify the changes in producer perceptions of futures contracts. This research analyzes the four most important Kansas grain crops: corn, soybean, sorghum, and wheat harvested for grain accounted for 97.3% of all acres harvested (USDA/Kansas Farm Facts 2008). This article presents a cross-sectional time series for 105 counties during 1977 to 2007.

Theoretical Perspective

McDonald and Sumner (2003) presented an efficient method for modeling multiple output crop acreage allocations for producers. The yield response model follows Choi and Helmberger (1993) and the acreage model is similarly constructed.

(1) $A = A[PX, PF, PS_i, E(Y_i), BPS_i, BPX, LA, E(C)]$

(2) $Y = Y(PX, PF, BPX, A, A\%, W)$

Acres planted *(A)* and crop yields *(Y)* are a function of output prices *(PX)* and input prices *(PF)*. Acres planted are also a function of substitute good prices *(PS)* and expected yields *[E(Y)]*, for crop i, i = 1,…,4. Expected climate *[E(C)]* is also anticipated to influence the number of acres planted. Lagged acres *(LA)* is included to measure limited ability to rapidly adjust crops planted, thus allowing the results to distinguish between long run and short run responses. Basis prices *(BPX & BPS)* are included, discussed below. Crop yields are a function of total acres planted *(A)*, percent of crop planted of all acres planted *(A%)*, and weather *(W)*. Previous research has analyzed prices through homogeneity assumptions, whether through relative crop prices in the acreage model or output-input prices in yield models. While this method follows from theoretical production considerations, homogeneity price restrictions may not strictly hold in practical applications. Furthermore, the separation of the prices allows for more direct interpretations of producer responses.

Acres and percent of acres are included in the yield model, as they provided separate indicators into yield response. A negative relationship between acreage and aggregate yields is expected. Profit maximization predicts that the highest quality land is brought into production initially, thus each additional increase of acres is of relatively inferior quality reducing average yields. The percent of crop acres planted measures county comparative advantage as well as omitted variables such as soil quality. Counties which produce more of a given crop are expected to hold comparative advantages within those crops. For example, counties with a higher percent of acres planted to corn are expected to have higher yields, as corn tends to be planted on higher quality land. This expected effect can be applied to additional crops as well, as producers within a county will plant the most profitable crop for that region's soil and producer characteristics.

Climate and weather affect each supply response component differently. Weather expectations impact input use, capital expenditures, and suitability of crops for a given location. Actual weather, however, is expected to affect annual yields. Own price elasticities are calculated as follows.

(3) $TS = Y * A$

(4) $A = A(PX)$

(5) $Y = Y[A(PX), PX]$

Both acreage and yields are a function of own-price (equations 1 and 2). The recursive method allows the imbedded acreage own-price function in the yield model.

(6) $\frac{\partial TS}{\partial PX} = \frac{\partial TS}{\partial A}\frac{\partial A}{\partial PX} + \frac{\partial TS}{\partial Y}\frac{\partial Y}{\partial PX} + \frac{\partial TS}{\partial Y}\frac{\partial Y}{\partial A}\frac{\partial A}{\partial PX}$

This function can further be written as an own-price elasticity:

(7) $\varepsilon_{SR\ TS,PX} = \varepsilon_{A,PX} * \left(1 + \varepsilon_{Y,A}\right) + \varepsilon_{Y,PX}$

Each short-run elasticity with respect to price is expected to be positive, however $\varepsilon_{Y,A}$ is expected to be negative. A price increase is expected to raise the amount of acreage planted increasing total supply. However, the expanded acreage impacts aggregate yields, thus the yield-acreage elasticity is expected to mitigate a portion of the own-price acreage elasticity. Long run supply elasticities are estimated using distributed lags (Nerlove 1958). Previous research emphasized the importance of distributed lags measuring producers' aversion or inability to switching crops. The long run supply elasticity is given in equation (8).

(8) $\varepsilon_{LR\ TS,PX} = \frac{\varepsilon_{A,PX}}{1-\varepsilon_{A,LA}} * \left(1 + \varepsilon_{Y,A}\right) + \varepsilon_{Y,PX}$

The total supply elasticity with respect to input prices is similarly estimated. Production theory suggests that the total supply elasticity with respect to input prices is negative.

Data and Method

County acreage and yield measures for the four crops were obtained through the USDA National Agricultural Statistics Service (USDA/NASS). Weather data were obtained through the Kansas State Weather Data Library and the National Climatic Data Center (NCDC). Table 1 presents the variables included in the supply response models. Temperature is the monthly mean, and precipitation is the monthly sum, both at the county level.[2] Producer climate expectations are defined as ten-year lagged rolling average precipitation and temperature.[3] For the acreage model, producer expectations are analyzed for the entire period of crop production, defined as the two months before planting through harvest.[4] The use of historical measures were chosen over weather predictors, as these measures provide a baseline for producers weather expectations.

For the yield model, the period of crop production is separated into four distinct phases of production (table 2). Precipitation and temperature during these stages of crop growth are measured as the difference from the ten year historical average for each phase. This method is selected over ex post methods to incorporate actual producer expectations and quantify the effects of divergences from expectations on yields. These variables are in quadratic form as the effects of weather on yields have been shown to be non-linear (Schlenker and Roberts 2006).

Fertilizer prices are average prices paid by farmer for anhydrous ammonia per ton at planting (USDA).[5] Futures prices were obtained through the Chicago Board of Trade (Corn and Soybean) and the Kansas City Board of Trade (Wheat).[6] The prices were the prices before planting for forward contracts after harvest. The spring crops use future prices in the month of March. Corn and sorghum are for December delivery, while soybean is for November. Wheat is measured in September for July contract the following year. The cross prices for each crop are measured in the month of interest for the specific crop. Although the wheat contract in the spring crop analysis is only measured as March to July, it is assumed this gives an accurate producer perception of wheat as a substitute, given fall plantings are impacted by spring decisions.

This research uses basis prices to quantify producer price expectations. If futures prices have historically over- or under-valued the crop prices at harvest, producers adjust their perception of the efficiency and accuracy of these prices at predicting harvest prices. Given the large shifts in acreage and volatile prices as of recent, producers use all information available and make their decisions accordingly.

Recent events have shown with a price spike at harvest, subsequent production sees a large acreage shift toward the upward trending price (Hendricks 2011). However, in analyzing the two futures prices before planting, the difference is minimal in comparison to the larger shift in acreage. This result indicates producers likely value historical basis prices as well as futures prices. Basis prices are not new to commodity supply research, as they have been used to measure the impact of price risk (Chavas and Holt 1990). Here, basis prices are used to estimate producer price expectations. Basis prices are measured as a rolling three year average. They were calculated from the state cash price at harvest (Kansas State Ag Manager), and the difference from the futures price before planting. Three years was chosen to efficiently incorporate basis differences in individual years while not completely basing producer expectations off one year's experience. Future prices alone do not fully capture producer price expectations.

In the acreage model, expected yields are measured as the lagged five-year average yields within the county.[7] Expected yields dramatically impact the estimated profitability of crops, and therefore agricultural technology has grown at varying rates across crops. Corn yields have significantly increased over time in comparison to the other crops. Omission of these expectations ignores the relative per acre value of each crop over time and further the rational for removing homogenous price assumptions. To account for technology and other unexplainable factors over time, a quadratic time trend is included in the yield model.

Given the panel data, a fixed effects model was selected to estimate the marginal effect of these variables on county production.[8] Tables 3 to 6 present the summary statistics for wheat, corn, sorghum, and soybean supply response models. With the large differences in weather, county size, irrigation level, as well as other factors, the fixed effect model is assumed as the best model, as it quantifies the heterogeneity among counties. While irrigation significantly alters expected yields and producer decisions, quantifying the impacts across aggregate levels is difficult. With irrigation data recorded inconsistently, as well as the assumption of homogeneity of irrigation flawed due to varying technology and availability of water/ costs that differ immensely, the results do not identify irrigated acreage.

Results

Tables 7 and 8 present the regression results for the acreage and yield response models. The models fit both acreage and yield response models well, with R-squared values ranging from 0.901 to 0.986 for acreage, and 0.399 to 0.753 for yield. Prices are significant determinants of both acreage and yield responses. The statistical insignificance of the own-price coefficients in the sorghum and wheat acreage models (table 8) are of only mild concern, with expected high multicollinearity of prices, which results in less efficient, but unbiased estimators. The cross-price results differing from theoretical substitute goods are anticipated due to the complex nature of cropping decisions. The positive cross-price for wheat in the sorghum acreage model shows counties which plant sorghum also tend to plant wheat, since these two crops rely on similar growing conditions.

The limited significance of soybean price in the corn acreage model (table 7) further demonstrates the complex nature of planting. Higher corn prices lead to more corn acres as well as soybean acres due to planting rotations. With soybeans used as complements in production for fixing nitrogen in the soil, they are also competitors for acreage with changes in input and output prices. This complex relationship is also evident in the yield model with the insignificant fertilizer price coefficient for soybean and the negative coefficient in the corn model (table 7). Soybeans require limited fertilizer application and can be used as long term substitutes for fertilizers as they fix nitrogen in the soil for subsequent production seasons. Higher fertilizer prices incentivize producers to plant less input-intensive crops on all qualities of land. With soybeans traditionally planted on marginal quality land, higher fertilizer prices increases the aggregate quality of land in which soybeans are planted, increasing yields.

The role of land quality and input use is further evident in the yield model through the statistically significant own-price coefficients (table 8). These results follow Houck and Gallagher (1976) and contradict Menz and Pardey (1983) that prices influence yield response. The negative fertilizer price coefficients follow a priori expectations of input prices, including the insignificant nitrogen fixing soybeans. Basis prices are shown to significantly impact producer decisions. Own basis prices are positive and statistically significant across most acreage and yield models with the exception of wheat yields and soybean acres, which were statistically insignificant. The results suggest that producer perception of future harvest prices extend beyond the forward contracts, validating further research toward analyzing these perceptions. Analyzing basis prices in both acreage and yield models, a $0.50 basis price would increase production of corn by 5,424 bushels per county, and a $1 price would increase production by 21,694 bushels. Although these production shifts appear minimal, on national scales the impact would be large and significant.

The significance of the lagged acreage variable is expected, as it measures producers' inability or unwillingness to respond to price changes due to a variety of factors including capital purchases and farmer preferences. On a less aggregate scale, this variable could be used to quantify crop rotations and has been shown to be negative in select crops (Hendricks 2011). However, at aggregate levels, such measurements of site specific characteristics and cropping patterns are unobservable. At the county level, the lagged dependent variables measures general trends within agriculture. The results showed corn acreage to adjust slower to the long run equilibrium than wheat acres. The large coefficient for corn is likely due to the increases in direct payments and other government programs which have limited the efficiency of traditional price incentives.

The inclusion of acres in the yield models was found to be statistically significant for corn and wheat yields. The positive percent acreage (A%) for both corn and wheat shows the comparative advantage of these crops within counties. The negative coefficient for the acreage (A) variable proves the impact of increases in production on the extensive margin to negatively impact yields. This result proves the recent expansion of corn production to have negatively impacted aggregate yields. This result is expected, as corn tends to be planted on higher quality land and the addition of marginal acres is expected to reduce average yields. This effect is vital for policy makers and agribusinesses to recognize the effect of acreage forecasts on yields and subsequently supply.

Soybeans have the highest short run total supply elasticity followed by wheat, corn, and sorghum (table 9). Corn and soybean have the highest own-price acreage elasticity as these crops are highly substitutable in production. The corn and soybean results are similar to Lin and Dismukes (2007). However, the wheat elasticity more closely follows Huang and Khanna (2010), which shows the limited acreage response of the winter crop. Corn has the lowest own-price yield elasticity. With the own-price yield elasticity capturing both increases in input use and soil quality, any increases in corn yields can only be met with increases in input use as it is already planted on the highest quality land. Sorghum, soybean, and wheat are planted on inferior land in comparison to corn, and increases in these prices likely increase the quality of land for those three crops as land is interchanged with corn. Thus the own-price yield elasticity is greater for crops other than corn.

The expansion into marginal acreage decreases the corn total supply elasticity the greatest. Although the impact is relatively small, corn expansion into marginal quality acreage reduces the supply elasticity by 4%. Soybean, wheat, and sorghum supply elasticities are decreased by less than 1% with acreage expansion. This result is important as policies which set production quotas must increase corn acreage at higher rates to meet demand given the negative relationship of acreage and yields.

The elasticity results demonstrate the importance of analyzing both acreage and yield responses as the omission of one portion of supply would underestimate total response. Individual acreage and yield elasticities are significantly lower than the combined total supply result. This outcome is increasingly evident in the long run elasticities. With the lagged acreage variable measuring the impact of production decisions impacting subsequent seasons, the lagged acreage elasticity affects the acreage related elasticities. Wheat and sorghum have relatively smaller acreage response elasticities, thus are affected relatively less in the long run elasticities than corn and soybeans.

Although some of the long run supply elasticities fall outside of traditional production theory with the assumed inelasticity of supply prices, they do provide insight into producer behavior and general trends. The elasticity results, however, are similar to previous long run supply elasticities (Nerlove and Addison 1958). With the increase in government programs over the period of analysis the expected effect on corn acreage is large. The programs further incentivized producers to maintain or increase corn production. This result is additionally compounded by the unbalanced increases in crop genetics and technology for corn as well as soybean.

The supply responses elasticities with respect to fertilizer prices are negative for wheat and sorghum, and positive for corn and soybean. The positive corn elasticity is due to the positive acreage elasticity, likely due to the high correlation of the price of corn, oil, and fertilizer resulting in a positive marginal effect. Corn, an input-intensive crop, is expected to have a significant negative coefficient, opposite of what these results show. The highest yield elasticity with respect to fertilizer price is corn due to the high level of inputs required for corn, especially in the case of corn when not produced in a rotation. The positive soybean elasticity is against a prior expectations, however, is likely due to soybeans being planted as an alternative to more input-intensive crops and as a long run substitute to fertilizers.

The impact of climate and weather were shown to impact acreage and yields. The impact of climate on acreage decisions was significant only for soybeans and wheat. Higher levels of precipitation decrease wheat acres planted and the largest amount of sorghum acres were planted at approximately 29 inches of total rainfall. Wheat was the only crop where the temperature variables were statistically significant. The marginal effect of temperature on wheat acres is shown to be positive, with higher temperatures the number of wheat acres increase.

The impact of weather on crop yields varied by crop and the level of statistical significance of precipitation on yields was greater than temperature. Only two of the thirty-four precipitation variables were insignificant at 90% confidence intervals, while only half of the temperature variables were significant. The amount of precipitation on corn, sorghum, and soybean yields in the period between planting and harvesting significantly impacted yields. Yield maximizing levels during this period were 6.06, 5.63, and 6.65 inches of rain above expected levels for corn, sorghum, and soybeans respectively. Furthermore, these spring crops have higher yields with modest increases in precipitation across all periods of production.[9] Wheat yields are negatively impacted by increases in precipitation in the later periods of growth and harvest, as the grains require drying out before harvesting.

Given the recent discussion of the impact of changes in climate on agricultural production, simulated climate changes were estimated using the regression results for the four crops. With weather measured in the acreage model as long term lagged annual values while the yield model analyzed weather through seasonal differences from expectations for multiple periods, calculations are required to create identical responses across models. In the acreage model, the simulations are estimated through increases to the observed mean values of the climate variables. With the yield model measuring weather variables separately through multiple periods, changes are given as equal proportional changes given the expected annual change. A one degree (one inch) increase in annual temperature (precipitation) increases the mean value of each growing period by one degree (0.25 inch) for the spring crops respectively. Wheat precipitation is changed at rates of one fifth of an inch in each growing season, resulting in an increase in annual precipitation by one inch.

Figures 1 and 2 show the estimated impact of changes in temperature and precipitation respectively, on total grain supplied in thousands of bushels per county. The differences between the traditional acreage/yield responses and the combined method on total supply, demonstrates the significance of analyzing both production responses. The estimated decreases in supply for corn due to the negative impact of temperature on yields are mitigated by the positive acreage affect. The combination effect of precipitation changes on wheat yield and acreage show total supply as more highly sensitive to precipitation when compared to previous research methods. Similarly to the supply elasticities, the yield effect tends to dominate both sorghum and wheat supply responses. Meanwhile, the corn and soybean figures show more equitable yield and acreage effects on total supply.

The negative marginal effect of precipitation on wheat supply is a result of the strong negative impact of increasing precipitation levels in the final months of growing and harvesting. Conversely, the greatest impact on total supply is the expected decreases from increasing temperatures in wheat production. A five degree increase in temperature is expected to reduce wheat supply by 27%, showing that wheat supply is higher in colder climates. The significance of evotranspiration on corn yields and supply is also evident. The high early nutrient and precipitation requirements as well as relatively high transpiration levels show the sensitivity of corn supply to climate changes. Additionally, the increase in temperature on corn supply further reveal the importance of analyzing both acreage and yield response, as the separate responses contradict one another.

Conclusion

A greater understanding of land use and supply decisions is imperative for the agricultural industry to move forward. The results suggest an intricate relationship between the two supply response components, acreage and yield. Grain producers and processors benefit from increased knowledge in future supply estimates for hedging and production decisions. The models presented here estimated acreage and yields for the four major field crops in the state of Kansas showing producers' land use decisions were sensitive to both weather and prices. With recent changes in markets and weather, further understanding is imperative. The combined elasticity method presented in this research more accurately estimates supply response as it captures traditional acreage and yield response as well as the impacts of increasing production on the extensive margin. Ignoring production on the extensive margin using traditional methods will overestimate supply estimations. With recent record acreage levels, understanding the extensive margin is ever more important. Own-price acreage elasticities alone were shown to underestimate supply response by 37-97%, while the own-price yield elasticities singularly would underestimate total response by 3-62%. These results signal the importance of the combined analysis

Another goal of this research was to present a new method to estimate producer price expectations with lagged basis prices. The results showed strong statistical significance of these prices on subsequent production. With an efficient futures market, long run basis prices would be expected to average toward zero or a premium, however, the prices vary significantly affecting short run supply. The marginal impacts of basis prices, as opposed to just futures prices, more accurately account for producer perception of futures markets. Additional research could compare various methods involving basis prices as well as different weighting strategies to accurately measure producer price expectations.

With expected climate changes affecting agricultural supply a greater understanding of the role of climate is important. Although the success of estimating supply shifts due to climate changes was limited, the results signaled the importance of combined analysis. The impacts of analyzing both the change in yields and acreage more accurately estimated total supply response. Furthermore, by incorporating the effects of changes in yields on acreage allocations furthered the understanding of the total effects of climate change. The endogeneity issue of acreage and yield supply is estimated to be limited. The minimal differences in supply despite varying the recursive techniques showed the results are fairly robust and not sensitive to the specific methods, indicating limited endogeneity. Further research could estimate the impacts of these production changes due to climate change on consumer and producer welfare.

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Notes

[1] The role of risk certainly plays a role in agricultural supply, however, the success of quantifying the impacts of risk have been met with limited success. Early models in this research attempted to analyze risk following previous research methods (Chavas and Holt 1990; Huang and Khanna 2010; Lin and Dismukes 2007); however, the results lacked robustness and proved to be inconclusive. Furthermore, analyzing risk with aggregate level data is likely to present incorrect estimates (Just and Weninger 1999).

[2] Missing temperature values were estimated through OLS regression with county and year dummy variables. Missing observations accounted for 2.6% of all observations.

[3] Ten years was selected to capture climate perceptions likely based on longer historical trends then seasonal shifts. Thus with a ten year average a significant one year anomaly is less likely to impact producer expectations. Further research could analyze the impact of weather anomalies on expectations.

[4] These climate expectations are in quadratic form as there is an expected non-linearity of climates suitable for the select crops.

[5] Anhydrous ammonia was used instead of the USDA fertilizer price index under the belief the annual index inaccurately measures prices at planting, as it is expected to be influenced by future prices and partial endogenous of acre and yield response. Furthermore, NH3 is often a large

factor of input costs and a pairwise correlation test show its' price is highly correlated with other fertilizer prices, thus an effective price proxy.

[6] With no sorghum futures market, prices were estimated using corn cash price at planting divided by the sorghum cash price, then multiplied by the corn futures price. Given the high substitutability of corn and sorghum in feed rations, producers use corn prices to estimate sorghum values.

[7] Chavas and Holt (1990) quantified yield expectations by regressing actual yields on a trend variable. The five year lagged average method was chosen for simplicity as well as it is explains producer expectations within the specific county. All lagged average expectations in this research are weighted equal across years. Additional research could analyze the difference using various weighting methods. Various weighting methods for climate, basis prices, and yields were chosen to account for producers expectations of changes to these measures given short and long term impacts. One dry season is expected to change future weather expectations less than a large basis price on producers' future market expectations.

[8] Hausman tests further supported the use of fixed effects over random effect models.

[9] Only the planting months for corn have higher yields with modest decreases in precipitation. All eleven other stages have higher yields when greater than zero.

Table 1. Kansas Crop Supply Response Model Variable Description and Source

Code	Description	Source
PF	Price of anhydrous ammonia before planting	USDA
PX	Futures price of crop before planting for contract after harvest	CBOT, KCBOT
BPX	Three year lagged basis price	AgManager
A	Total acres planted, 1,000's	NASS
	Acreage Model	
PS_i	Future price of substitute crop, i=1,2	CBOT, KCBOT
LA	Previous year total acres planted, 1,000's	NASS
Y_i	Five year lagged county average yield, i=1,2,3,4	NASS
BPS_i	Three year lagged basis price substitute crop, i=1,2	AgManager
CP	Ten year lagged average annual total precipitation, inches, quadratic form	KSWDL
CT	Ten year lagged average annual mean temperature, °F, quadratic form	NCDC
	Yield Model	
Y	County yield	NASS
T	Time trend, quadratic	
A%	Percent of crop of interest of total acres planted of the four crops	NASS
WP_i	Difference from ten year average precipitation for specific season, quadratic, i=1,2,3,4	KSWDL
WT_i	Difference from ten year average temperature for specific season, quadratic, i=1,2,3,4	NCDC

All prices are deflated at 2007 values (BLS).

Table 2. Kansas Crop Supply Response Model Crop Growing Period Definitions

Crop	1	2	3	4	5
Corn	Feb-Mar	Apr-May	Jun-Aug	Sep-Nov	--
Sorghum	Mar-Apr	May-Jun	Jul-Aug	Sep-Nov	--
Soybeans	Mar-Apr	May-Jun	Jul-Aug	Sep-Nov	--
Wheat	Jul-Aug	Sep-Oct	Nov-Feb	Mar-May	Jun-Jul

Source: Kansas State University Agricultural Experiment Station and Cooperative Extension Service. *Corn (2007), Soybean (1997), Sorghum (1998), and Wheat (1997) Production Handbooks*

Table 3. Kansas Crop Supply Response Model Summary Statistics Wheat

Variable	Obs.	Mean	St. Dv.	Min	Max
		Both Models			
PF	2732	382.24	115.73	238.75	673.47
PX	2732	5.29	0.70	3.98	6.65
BPX	2732	-0.71	0.67	-1.98	0.61
A	2732	106.00	79.72	1.10	525.00
		Acreage Model			
PS1	2732	3.71	0.60	2.49	5.37
PS2	2732	9.25	1.49	5.48	12.91
LA	2732	106.85	80.11	3.40	525.00
YC	2732	104.19	31.86	44.60	193.20
YS	2732	30.17	7.96	13.14	56.40
YM	2732	63.15	11.81	34.00	101.40
YW	2732	35.49	5.65	21.60	62.20
BPS1	2732	-0.34	0.39	-1.13	0.67
BPS2	2732	-0.65	0.67	-1.65	1.21
CP	2732	34.23	8.57	15.98	54.90
CT	2732	56.75	1.71	51.89	60.61
CP^2	2732	1245.39	589.82	255.42	3014.23
CT^2	2732	3223.20	193.35	2692.65	3673.20
		Yield Model			
Y	2732	35.88	9.67	9.00	80.00
T	2732	16.53	8.58	1.00	31.00
T^2	2732	346.89	284.97	1.00	961.00
A%	2732	50.39	22.59	0.74	97.92
WP1	2732	0.12	3.81	-8.59	20.58
WP2	2732	-0.23	3.17	-8.79	19.75
WP3	2732	-0.12	2.38	-7.71	12.35
WP4	2732	-0.09	3.31	-9.08	16.70
WP5	2732	0.20	4.00	-10.80	19.30
WT1	2732	0.13	2.50	-6.71	8.48
WT2	2732	-0.01	2.15	-6.74	6.32
WT3	2732	0.17	3.01	-9.96	6.39
WT4	2732	0.17	2.50	-8.53	5.91
WT5	2732	0.04	2.21	-6.36	7.84
WP1^2	2732	14.55	27.06	0.00	423.45
WP2^2	2732	10.12	25.29	0.00	390.18
WP3^2	2732	5.70	10.41	0.00	152.57
WP4^2	2732	10.93	18.50	0.00	278.82
WP5^2	2732	16.01	30.68	0.00	372.49
WT1^2	2732	6.28	9.21	0.00	72.00
WT2^2	2732	4.61	5.84	0.00	45.36
WT3^2	2732	9.10	11.68	0.00	99.15
WT4^2	2732	6.27	7.48	0.00	72.76
WT5^2	2732	4.90	7.48	0.00	61.47

PS1 = corn, PS2 = soybeans

Table 4. Kansas Crop Supply Response Model Summary Statistics Corn

Variables	Obs.	Mean	Sd. Dv.	Min	Max
			Both Models		
PF	2784	405.17	128.81	248.94	761.46
PX	2784	4.00	0.43	3.09	5.12
BPX	2784	-0.34	0.38	-1.13	0.67
A	2784	22.84	24.71	0.20	164.50
			Acreage Model		
PS1	2784	5.25	0.53	4.49	6.25
PS2	2784	9.44	1.22	7.11	13.57
LA	2784	22.15	24.10	0.20	142.80
YC	2784	104.57	31.91	44.60	193.20
YS	2784	30.28	8.02	13.14	56.40
YM	2784	63.25	11.75	34.00	101.40
YW	2784	35.38	5.54	21.60	59.20
BPS1	2784	-0.70	0.66	-1.98	0.61
BPS2	2784	-0.68	0.68	-1.74	1.21
CP	2784	28.64	7.27	13.62	45.40
CT	2784	59.56	1.78	54.44	63.52
CP^2	2784	873.13	416.39	185.59	2060.71
CT^2	2784	3550.50	211.24	2963.93	4034.16
			Yield Model		
Y	2784	108.18	36.73	18.00	207.00
T	2784	16.95	8.80	1.00	32.00
T^2	2784	364.80	300.67	1.00	1024.00
A%	2784	12.37	10.73	0.10	59.36
WP1	2784	0.02	1.95	-6.22	9.17
WP2	2784	0.01	3.04	-7.70	15.27
WP3	2784	0.23	4.81	-12.67	23.59
WP4	2784	-0.37	3.59	-12.75	20.30
WT1	2784	-0.16	3.68	-12.01	8.48
WT2	2784	0.02	2.66	-10.29	6.00
WT3	2784	0.13	2.06	-6.85	7.15
WT4	2784	0.19	2.07	-6.79	6.04
$WP1^2$	2784	3.80	6.20	0.00	84.16
$WP2^2$	2784	9.26	15.77	0.00	233.11
$WP3^2$	2784	23.18	37.58	0.00	556.25
$WP4^2$	2784	13.04	30.90	0.00	412.13
$WT1^2$	2784	13.52	16.24	0.00	144.13
$WT2^2$	2784	7.04	9.64	0.00	105.84
$WT3^2$	2784	4.26	7.12	0.00	51.17
$WT4^2$	2784	4.31	5.81	0.00	46.15

PS1 = wheat, PS2 = soybeans

Table 5. Kansas Crop Supply Response Model Summary Statistics Sorghum

Variables	Obs.	Mean	Sd. Dv.	Min	Max
		Both Models			
PF	2796	404.70	128.72	248.94	761.46
PX	2796	3.50	0.43	2.60	4.62
BPX	2796	-0.33	0.41	-1.30	0.64
A	2796	37.36	26.15	0.30	199.00
		Acreage Model			
PS1	2796	5.25	0.53	4.49	6.25
PS2	2796	9.43	1.22	7.11	13.57
LA	2796	37.86	26.38	0.90	199.00
YC	2796	104.46	31.94	44.60	193.20
YS	2796	30.25	8.02	13.14	56.40
YM	2796	63.15	11.77	34.00	101.40
YW	2796	35.35	5.52	21.60	58.40
BPS1	2796	-0.70	0.66	-1.98	0.61
BPS2	2796	-0.68	0.68	-1.74	1.21
CP	2796	27.61	6.89	13.35	42.39
CT	2796	62.34	1.79	57.09	66.27
CP^2	2796	809.86	379.75	178.20	1797.17
CT^2	2796	3888.92	221.47	3259.40	4392.32
		Yield Model			
Y	2796	64.84	18.21	12.00	134.00
T	2796	16.90	8.80	1.00	32.00
T^2	2796	362.91	300.30	1.00	1024.00
A%	2796	19.67	9.84	0.20	63.04
WP1	2796	-0.01	2.32	-7.46	10.94
WP2	2796	0.12	3.94	-9.43	17.98
WP3	2796	0.09	3.78	-8.59	20.58
WP4	2796	-0.38	3.59	-12.75	20.30
WT1	2796	-0.02	2.94	-8.27	6.49
WT2	2796	0.02	2.30	-8.83	6.30
WT3	2796	0.24	2.45	-7.14	8.48
WT4	2796	0.19	2.06	-6.79	6.04
$WP1^2$	2796	5.40	8.65	0.00	119.66
$WP2^2$	2796	15.54	26.47	0.00	323.32
$WP3^2$	2796	14.27	26.81	0.00	423.45
$WP4^2$	2796	13.05	30.84	0.00	412.13
$WT1^2$	2796	8.66	9.32	0.00	68.34
$WT2^2$	2796	5.30	7.25	0.00	77.97
$WT3^2$	2796	6.03	9.16	0.00	72.00
$WT4^2$	2796	4.30	5.82	0.00	46.15

PS1 = wheat, PS2 = soybeans

Table 6. Kansas Crop Supply Response Model Summary Statistics Soybean

Variables	Obs.	Mean	Sd. Dv.	Min	Max
		Both Models			
PF	2764	403.97	127.94	248.94	761.46
PX	2764	9.43	1.19	7.11	13.57
BPX	2764	-0.68	0.68	-1.74	1.21
A	2764	23.69	24.41	0.05	126.50
		Acreage Model			
PS1	2764	5.25	0.53	4.49	6.25
PS2	2764	4.00	0.43	3.09	5.12
LA	2764	23.13	24.25	0.05	126.50
YC	2764	104.21	31.89	44.60	193.20
YS	2764	30.20	8.01	13.14	56.40
YM	2764	63.33	11.69	34.60	101.40
YW	2764	35.38	5.56	21.60	59.20
BPS1	2764	-0.70	0.66	-1.98	0.61
BPS2	2764	-0.33	0.38	-1.13	0.67
CP	2764	27.73	6.87	13.35	42.39
CT	2764	62.34	1.79	57.09	66.27
CP^2	2764	816.44	379.07	178.20	1797.17
CT^2	2764	3888.85	221.51	3259.40	4392.32
		Yield Model			
Y	2764	31.09	10.86	6.90	61.00
T	2764	16.92	8.77	1.00	32.00
T^2	2764	363.18	300.09	1.00	1024.00
A%	2764	17.69	18.76	0.02	72.22
WP1	2764	0.00	2.33	-7.46	10.94
WP2	2764	0.11	3.95	-9.43	17.98
WP3	2764	0.11	3.79	-8.59	20.58
WP4	2764	-0.38	3.61	-12.75	20.30
WT1	2764	-0.02	2.94	-8.27	6.49
WT2	2764	0.02	2.30	-8.83	6.30
WT3	2764	0.25	2.45	-7.14	8.48
WT4	2764	0.19	2.07	-6.79	6.04
$WP1^2$	2764	5.43	8.68	0.00	119.66
$WP2^2$	2764	15.60	26.44	0.00	323.32
$WP3^2$	2764	14.38	26.94	0.00	423.45
$WP4^2$	2764	13.14	31.01	0.00	412.13
$WT1^2$	2764	8.63	9.28	0.00	68.34
$WT2^2$	2764	5.30	7.27	0.00	77.97
$WT3^2$	2764	6.05	9.18	0.00	72.00
$WT4^2$	2764	4.30	5.82	0.00	46.15

PS1 = wheat, PS2 = corn

Table 7. Kansas Crop Supply Response Model Acreage Regression Results

	Sorghum			Corn			Soybean			Wheat		
Variable	**Coef.**	**t**	**P>t**	**Coef.**	**t**	**P>t**	**Coef.**	**t**	**P>t**	**Coef.**	**t**	**P>t**
PX	0.126	0.29	0.77	1.529	4.73	0.00	0.981	8.15	0.00	0.709	1.50	0.13
PS1	0.920	2.59	0.01	0.060	0.27	0.79	0.092	0.38	0.70	4.027	5.42	0.00
PS2	-0.844	-5.20	0.00	-0.026	-0.20	0.84	-1.266	-3.63	0.00	0.407	1.43	0.15
PF	-0.001	-0.38	0.70	0.004	3.06	0.00	0.006	5.89	0.00	-0.032	-11.73	0.00
LA	0.732	30.55	0.00	0.926	46.53	0.00	0.777	36.88	0.00	0.616	26.06	0.00
YC	-0.106	-6.36	0.00	0.051	5.17	0.00	-0.017	-2.11	0.04	-0.083	-4.11	0.00
YS	0.224	4.32	0.00	0.063	1.79	0.07	0.116	4.54	0.00	-0.211	-3.18	0.00
YM	0.086	3.05	0.00	-0.012	-0.57	0.57	0.101	7.30	0.00	0.007	0.21	0.84
YW	-0.228	-4.77	0.00	-0.054	-1.57	0.12	-0.045	-1.51	0.13	0.138	2.13	0.03
BPX	7.220	8.14	0.00	2.076	3.43	0.00	0.303	1.20	0.23	6.330	17.69	0.00
BPS1	-5.100	-9.92	0.00	0.599	2.15	0.03	0.335	1.34	0.18	-11.283	-10.91	0.00
BPS2	-0.386	-1.14	0.25	-0.460	-1.75	0.08	-2.102	-3.80	0.00	1.150	2.16	0.03
CP	0.942	1.49	0.14	-0.170	-0.40	0.69	-0.967	-3.55	0.00	-1.937	-4.33	0.00
CT	-1.946	-0.41	0.68	-1.802	-0.56	0.58	-1.879	-0.67	0.51	-30.480	-1.93	0.05
CP^2	-0.016	-1.72	0.09	0.004	0.69	0.49	0.017	3.55	0.00	0.022	3.97	0.00
CT^2	0.015	0.39	0.69	0.015	0.56	0.57	0.015	0.66	0.51	0.277	1.99	0.05
Constant	68.415	0.47	0.64	45.271	0.47	0.64	63.061	0.72	0.47	916.744	2.04	0.04
R-Squared	0.9014			0.9644			0.9655			0.9856		
Adj. R-Sqr.	0.897			0.9628			0.9639			0.985		
F	195.57			463.63			375.57			248.45		
Obs.	2796			2784			2764			2732		

(PS1, PS2) = Wheat (corn, soybeans); Corn (wheat, soybeans); Sorghum (wheat, soybeans); Soybeans (wheat, corn)

Table 8. Kansas Crop Supply Response Model Yield Regression Results

	Soybean			Corn			Sorghum			Wheat		
Variable	**Coef.**	**t**	**P>t**	**Coef.**	**t**	**P>t**	**Coef.**	**t**	**P>t**	**Coef.**	**t**	**P>t**
T	0.926	14.20	0.00	2.393	12.08	0.00	1.828	13.38	0.00	0.509	5.10	0.00
T^2	-0.016	-7.47	0.00	-0.034	-5.09	0.00	-0.037	-7.91	0.00	-0.006	-1.56	0.12
PF	0.002	1.13	0.26	-0.017	-3.58	0.00	-0.009	-2.55	0.01	-0.005	-1.90	0.06
PX	0.780	6.30	0.00	4.858	5.02	0.00	6.640	9.28	0.00	3.566	12.33	0.00
BPX	0.629	2.94	0.00	10.449	9.57	0.00	1.423	1.89	0.06	-0.310	-1.01	0.31
A	-0.021	-1.15	0.25	-0.271	-4.77	0.00	-0.035	-0.99	0.32	-0.040	-3.09	0.00
A%	-0.044	-1.64	0.10	0.739	5.37	0.00	0.065	0.84	0.40	0.187	5.30	0.00
WP1	0.056	0.87	0.39	0.442	2.00	0.05	0.629	4.57	0.00	-0.193	-3.32	0.00
WP2	0.185	5.43	0.00	-0.330	-2.36	0.02	0.446	5.67	0.00	0.396	5.83	0.00
WP3	1.006	25.02	0.00	1.766	20.87	0.00	2.241	27.16	0.00	0.196	2.28	0.02
WP4	0.408	11.17	0.00	0.767	6.71	0.00	0.549	6.90	0.00	-0.433	-7.46	0.00
WP5										-0.589	-10.63	0.00
WT1	0.182	1.96	0.05	-0.469	-1.97	0.05	-0.111	-0.61	0.54	0.039	0.47	0.64
WT2	-0.036	-0.29	0.78	-0.370	-1.23	0.22	0.529	2.13	0.03	0.189	2.20	0.03
WT3	-0.130	-1.14	0.26	0.919	2.72	0.01	-0.228	-0.96	0.34	-0.362	-5.94	0.00
WT4	-0.002	-0.02	0.99	-0.602	-1.64	0.10	0.590	2.31	0.02	-0.541	-7.71	0.00
WT5										-0.240	-2.37	0.02
$WP1^2$	-0.047	-2.56	0.01	0.022	0.30	0.77	-0.085	-2.27	0.02	0.010	1.68	0.09
$WP2^2$	-0.012	-2.60	0.01	-0.058	-2.38	0.02	-0.067	-5.86	0.00	-0.037	-5.24	0.00
$WP3^2$	-0.076	-12.80	0.00	-0.146	-13.53	0.00	-0.199	-13.02	0.00	-0.039	-2.23	0.03
$WP4^2$	-0.033	-8.37	0.00	-0.060	-4.83	0.00	-0.040	-5.42	0.00	-0.084	-7.08	0.00
$WP5^2$										0.016	2.27	0.02
$WT1^2$	-0.006	-0.33	0.74	0.062	1.66	0.10	0.032	0.78	0.43	-0.126	-7.42	0.00
$WT2^2$	0.028	1.04	0.30	0.091	1.50	0.13	0.041	0.70	0.48	0.141	4.63	0.00
$WT3^2$	0.001	0.06	0.95	0.041	0.53	0.60	0.090	2.10	0.04	0.015	0.91	0.36
$WT4^2$	-0.002	-0.08	0.94	-0.220	-2.46	0.01	0.063	0.96	0.34	-0.159	-6.87	0.00
$WT5^2$										-0.197	-8.23	0.00
Constant	16.627	11.60	0.00	71.534	14.93	0.00	31.438	8.73	0.00	10.648	3.91	0.00
R-Squared	0.6724			0.7531			0.4866			0.3999		
Adj. R-Sqr.	0.6567			0.7414			0.4623			0.3699		
F	106.98			81.6			74.05			49.37		
Obs.	2764			2784			2796			2732		

(PS1, PS2) = Wheat (corn, soybeans); Corn (wheat, soybeans); Sorghum (wheat, soybeans); Soybeans (wheat, corn)

Table 9. Kansas Crop Supply Response Model Total Supply Elasticities.

	$\varepsilon_{A,PX}$	$\varepsilon_{Y,A}$	$\varepsilon_{Y,PX}$	$\varepsilon_{SR\,TS,PX}$	$\varepsilon_{A,LA}$	$\varepsilon_{LR\,TS,PX}$
Wheat	0.035	-0.119	0.525	0.556	0.621	0.608
Corn	0.268	-0.057	0.180	0.432	0.898	2.647
Soybean	0.390	-0.016	0.237	0.621	0.759	1.827
Sorghum	0.012	-0.020	0.359	0.370	0.742	0.403
	$\varepsilon_{A,PF}$	$\varepsilon_{Y,A}$	$\varepsilon_{Y,PF}$	$\varepsilon_{SR\,TS,PF}$	$\varepsilon_{A,LA}$	$\varepsilon_{LR\,TS,PF}$
Wheat	-0.114	-0.119	-0.057	-0.157	0.621	-0.321
Corn	0.073	-0.057	-0.063	0.005	0.898	0.606
Soybean	0.109	-0.016	0.023	0.131	0.759	0.469
Sorghum	-0.009	-0.020	-0.054	-0.062	0.742	-0.086

Note: $\varepsilon_{i,j}$- i refers to model, j refers to variable of interest (equations 3 to 5):
i : A = acreage, Y = yield, SR TS = short run total supply, LR TS = long run total supply

j : A = acreage, PX = output own price, PF = input (fertilizer) price,
LA = lagged dependent variable (lagged acreage)

Figure 1. Total Supply Response to Changes in Precipitation

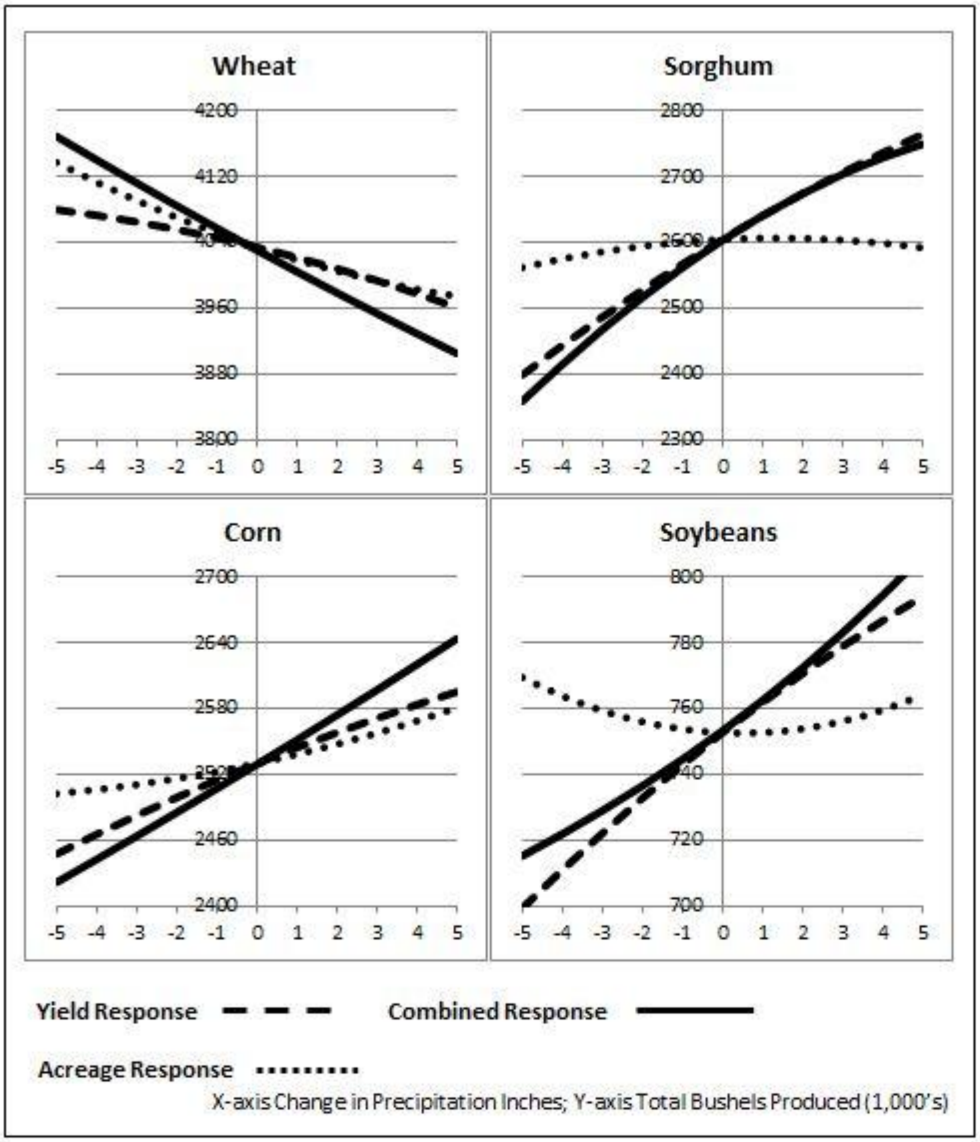

Figure 2. Total Supply Response to Changes in Temperature