ECONOMETRIC ANALYSIS OF THE ARIZONA ALFALFA MARKET

by

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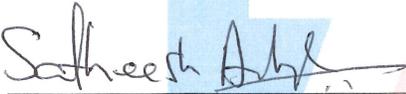In the Graduate College

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As members of the Master's Committee, we certify that we have read the thesis prepared by Chenyang Hu, titled "Econometric Analysis of the Arizona Alfalfa Market" and recommend that it be accepted as fulfilling the dissertation requirement for the Master's Degree.
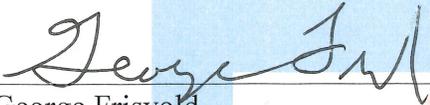
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ACKNOWLEDGEMENTS

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ABSTRACT

Alfalfa is an important crop in the United States, especially in the western United States. Over the past twenty years, alfalfa has occupied 20 percent of cropland in the western United States and is always ranking as the top 5 largest commodities in the West (Cann 2014). Arizona is a southwest state with a large amount of cropland occupied by alfalfa hay. Meanwhile, the livestock industry in Arizona requires high quality alfalfa as one of the main inputs for milk and beef cows. Pre-harvest alfalfa requires significant amounts of water for growth and its production could be affected by water shortages in the Southwest. In spite of this, there are relatively few studies having been done on Arizona's alfalfa market (Nielson et al.1975, Samani and Pessarakli 1986, Martin et al. 2006).

Surface water use for agriculture in Arizona is mainly from Colorado River and the Gila River system. There are predictions that Colorado River is going to have a water shortage in the next few years (Berardy & Chester 2017). Central Arizona holds "junior" priority water rights to Colorado River supplied by the CAP (Central Arizona Project). In this case, farms in Central Arizona may have to revert to pumping groundwater, plant other crops that require less water, or some combination of both. Central Arizona dairies may have to "import" alfalfa from other parts of Arizona or from other states.

Alfalfa in Arizona is a free market crop with no barriers on entry and exit. There is no production controls and no institutional prices in alfalfa market. Thus, the alfalfa price is determined by supply and demand. This paper aims to review previous studies of the alfalfa market

and use econometric models to assess how production shocks might affect state alfalfa prices.

OBJECTIVES

In this paper, a few econometric models will be built to estimate how different factors influence acreage response, yield, price flexibility, and year-end stocks of alfalfa in Arizona, Also, a few simulations will be done to predict the impact of a supply shock (for example, from a potential water shortage) on state prices paid for alfalfa.

This thesis' econometric model specification draws from Konyar and Knapp's (1988) study of the California alfalfa market, using state-level data from Arizona from 1980 to 2017. Because time series data were used and supply and demand relationships were estimated, tests were conducted for autocorrelation of errors. Further, the Arizona alfalfa market is econometrically estimated as a five-equation system that includes acreage response, yield, production, price flexibility, and end-of-year stock equations. To account for correlated errors across equations and potential simultaneity bias in equations, a three-stage least squares model was estimated and compared with separate ordinary least squares regressions.

LITERATURE REVIEW

Alfalfa hay is a major crop grown in the United States, especially in the western United States, but there are relatively few econometric studies of the alfalfa market. Because there are differences between the alfalfa market in the eastern and western United States, this thesis focuses on western studies.

Market Analysis of Alfalfa Hay: California Case

Konyar and Knapp (1988) developed structural equation econometric models and used time-series (ARIMA) techniques to estimate alfalfa acreage response and to forecast future acres planted. Depending on climate and l harvesting practices, alfalfa has an average stand life of three to seven years. The alfalfa acreage in year *t* is the sum of acreage of alfalfa of different ages. Farmers were assumed to expect the current year's yield will prevail again in the next year. With this assumption, Konyar and Knapp used lagged prices of alfalfa and competing crops as variables to explain acreage response. The competing crop price index was a weighted-average price of cotton, dry beans, barley, corn for grain, rice, sugar beets, sorghum, and wheat in California, with weights based on acreage. They also used a dummy variable to distinguish the policy changes in the federal cotton program

In their initial model, Konyar and Knapp used five different year's lagged own prices and competing crop prices and found most of the estimated parameters were statistically insignificant. In their final re-estimated model, they reduced this to two one-year lag for own price and the index of competing crop prices. Both these variables were statistically significant. The new model

explained 80% of the alfalfa acreage response in California. The test results indicated acreage response of alfalfa in California was mainly affected by changes in cattle inventory, competing crops, alfalfa own price, and, indirectly, by farm policy changes. The estimates indicated the alfalfa supply was inelastic with respect to both own prices and competing crop prices and acreage of alfalfa response to farm policy (cotton program) changes was also small.

In the second part of their article, Konyar and Knapp developed an alfalfa demand model and econometric forecast model to predict the future prices of alfalfa in California (1983-1986).

Dynamic Regional Analysis of the California Alfalfa Market with Government Policy Impacts

Konyar and Knapp (1990) created a dynamic spatial equilibrium model of the alfalfa market in California. They divided the California alfalfa hay market into 25 regions and created estimated acreage response functions. A few forecast tests were made to estimate for some individual components. Average errors were not a big gap between actual values and forecast acreage. In general, their model is sufficient for analyzing the alfalfa acreage response to several variables. The test results suggest the alfalfa market in California can reach economic equilibrium in the long run. Also, elasticities of alfalfa prices and alfalfa acreages response to exogenous variables are between negative one and positive one. Both in the short run and long run, the price of alfalfa was mostly affected by a feed cost index and livestock product prices. Acreage of alfalfa was mostly affected by alfalfa producers cost index in the short run and feed costs in the long run.

Factors Affecting Hay Supply and Demand in Tennessee

Bazen, et al. (2008) estimated a supply and demand model for the alfalfa hay market in Tennessee. Alfalfa is one of the state's most economically important crops. The variables they used in their supply model were similar to those used by Konyar and Knapp (1988), but they also included the price of fertilizer and separate variables for growing season and harvest season rainfall. Alfalfa hay yield was unresponsive to change in fertilizer prices with a yield elasticity of -0.07. Alfalfa hay yield increases by 0.12% and 0.14% in the short run when rainfall increases 1% in growing and harvest seasons. The elasticity of acreage response to the ratio of expected hay-to-wheat prices were 0.08 in the short run and 0.2 in the long run. They surmised the reason for this weak response was many dairy farmers grew their own alfalfa to supply their own farms with forage and to guarantee a sufficient supply of dry matter in the winter. They further argued that there were few viable substitute crops to grow in Middle and East Tennessee.

Structural Change of the Western United States Alfalfa Hay Market and its Effect on the Western United States Dairy Industry

The graph below shows fast increasing growth of the alfalfa exports since 1994. Cann (2014) hypothesized that this emerging export market created a structural break in the Western US alfalfa market and used year 1994 as the basis to test structural change.

Figure 1. U.S. Alfalfa Hay Exports in Thousand Dollars
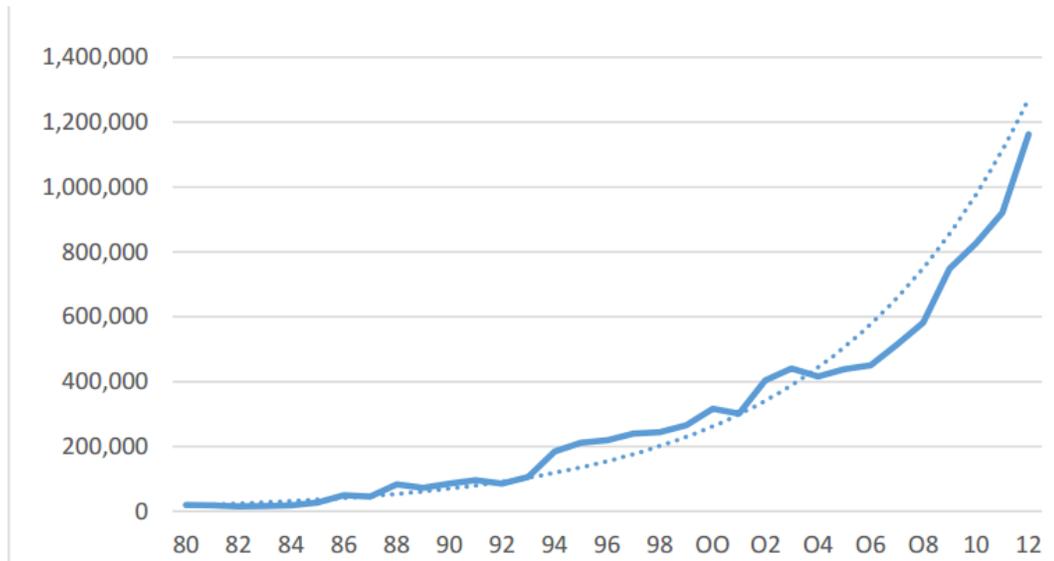
Note: Graph of alfalfa hay exports in thousand dollars from FAS

Cann (2014) identified there was a structural change in the Western United States alfalfa market in 1994 using regression analysis and the Chow test and suggested that a second structural change may have occurred in 2006. The data ranged from 1980 to 2012 covered ten Western US states and four Midwestern states. The study also showed price of milk has the largest influence and inventory of dairy has a small impact on alfalfa price. However, I found the export data Cann used is hay exports in thousand dollars. The actual alfalfa export data from FAS is only available from 1994. There is no alfalfa export data prior to 1994.

ACREAGE RESPONSE

Model

The acreage response model employed here is based on that of Konyar and Knapp (1988).

Farmers are assumed to have naïve expectation on prices, that is, they expect the price of alfalfa in current year to prevail again in the next year. The following acreage response function is estimated:

$$A_t = \beta_0 A_{t-1}^{\beta_1} P_{t-1}^{\beta_2} CP_{t-1}^{\beta_3} e^{\beta_4 D} e^{\varepsilon} \tag{1}$$

Where β_i (i = 1 to 4) are the coefficients to be estimated, A_t is the acreage of alfalfa in Arizona in year t, A_{t-1} is acreage of alfalfa in Arizona in year t-1 (lagged one year), P_{t-1} is the price of alfalfa in Arizona in year t-1 (lagged one year), CP_{t-1} is the competing crop price index in year t-1 (lagged one year), D is the dummy variable for decoupling policy shift under the 1996 Farm Bill which removed a variety of acreage and planting restrictions on cotton, wheat, and other field crops that compete with alfalfa. t is time variable where t is from 1 to 38 representing year 1980 to 2017. The variable D = 1 if t = 17 or later, D = 0 if t = 16 or earlier. (overall, t = 1 to 38). The term ε is a stochastic error term. Alfalfa's competing crops in Arizona are different from those of California used by Konyar and Knapp for their competing crop index. Here, I choose the five main competing crops (cotton, barley, wheat, corn, corn silage) in Arizona and estimate the competing crop price index using the following equation:

$$CP_t = \sum_{i=1}^{5} \left(\frac{P_{it}}{P_{io}}\right) S_{it} \tag{2}$$

where P_{it} is the price of competing crop i in year t, P_{i0} is the price of crop i in base year, S_{it} is each competing crop's share of acreage in total acreage of their cropland.

Taking the logarithm of the acreage response function (equation 1) results in a log-linear regression equation:

$$\ln A_t = \beta_0 + \beta_1 \ln A_{t-1} + \beta_2 \ln P_{t-1} + \beta_3 \ln CP_{T-1} + \beta_4 D + \varepsilon \tag{3}$$

Based on economic theory, one would expect acreage to be increasing in the price of alfalfa and decreasing in the index of competing crops. Earlier legislated planting restrictions potentially penalized growers switching from program crops (e.g. cotton, wheat, corn, barley) to alfalfa. The removal of these penalizing restrictions would be expected to encourage alfalfa planting.

Data

Data to estimate this acreage response function come from the USDA Quick Stats website (https://quickstats.nass.usda.gov/). To estimate a linear regression, time series data of annual alfalfa prices and alfalfa acreage in Arizona are needed. In my analysis, I use annual data from year 1979 to 2017. This is a short period of time series data, but earlier years have missing data for many years which would affect the model. To calculate the competing crop price index, I chose the data of the five main competing crops (cotton, barley, wheat, corn, and corn silage) in Arizona, both the annual prices and acreage of the five main competing crops. Each competing crop's share of acreage in total acreage of their cropland was calculated by dividing its own acreage by total acreage of the five crops.

There were 10 missing values of annual alfalfa price in Arizona from year 1979 to 1988. But

there is data of monthly alfalfa price in Arizona from year 1979 to 1988. To estimate these values,

I used both the monthly data and annual data of alfalfa price in Arizona from year 1989 to 2017

and run a linear regression and estimate the coefficient of each month's price in annual price. Here

is the function to estimate the coefficients of each month:

$$P = \sum_{i=1}^{12} \beta_i P_i + \varepsilon \qquad (4)$$

where P is the annual price of alfalfa and P_i is the alfalfa price in month i.

The R-square of this prediction model is 0.999. Then "backcast" the annual alfalfa price in

Arizona from year 1979 to 1988 using the coefficients of each month and monthly alfalfa price

in Arizona from year 1979 to 1988.

Figure 2 Arizona Alfalfa Price (Dollar/Ton)
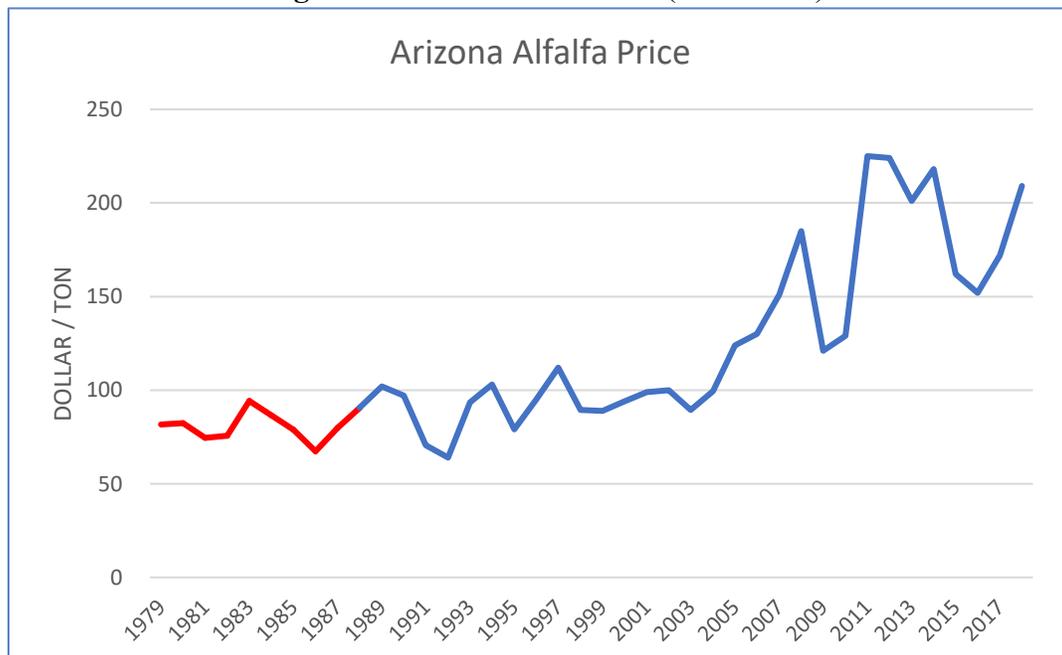
The figure above shows two stages of the Arizona alfalfa price. The red line ranged from 1979

to 1988 is the estimated Arizona alfalfa price line and the blue line ranged from 1989 to 2018 is

the actual Arizona alfalfa price line. All the nominal prices are deflated with the U.S. GDP price deflator and converted into real prices.

Estimation and Results

First, using all the data needed in the logarithmic function of acreage response, a linear regression was applied in Excel with an Ordinary Least Squares routine. There are 38 observations and 4 independent variables. The regression estimates are given in Table 1 below with an Adjusted R Square value of 0.96.

Table 1. Econometric Estimates of Alfalfa Acreage Response in Arizona (full model)

Variable Name	Parameter Estimate	P-value	Standard Error
Intercept	2.32	0.0044	0.76
log of lagged real price of alfalfa	0.18	0.0023	0.05
log of lagged real price index for competing crops	-0.14	0.0130	0.05
log of lagged alfalfa acreage	0.73	0.0000	0.07
Dummy variable for commodity program decoupling	0.10	0.0058	0.03
R Square	0.96		
Durbin's h	-0.13	0.45	

All the estimated parameter coefficients have the expected signs and all are significant at the 1% level except the log of lagged real competing crop price index, significant at 5% level.

The estimated parameter coefficients in this logarithmic function of acreage response represent elasticities directly. The elasticity of alfalfa supply with respect to its own price is 0.18, which is inelastic. A 1% increase of alfalfa price this year will approximately increase next year's alfalfa acreage by 0.18%. The elasticity of alfalfa supply with respect to its competing crop price

index is -0.14, which is also inelastic. A 1% increase of competing crop price index this year will approximately decrease next year's alfalfa acreage by 0.14%. These small elasticity values are not surprising given that alfalfa is more like a perennial crop with three to seven years of life Also, dairy farms in Arizona often grow their own alfalfa to feed their cows. One would expect this feed demand to be relatively inelastic.

The dummy variable explains the positive trend of alfalfa acreage after federal planting restrictions were removed in 1996. One can see that alfalfa acreage was relatively constant in the state until the year of the policy change. Alfalfa acreage grew by 30,000 acres in 1997 (See Figure 1 below), one year after the farm policy changed. Acreage grew steadily for several years after that. The acreage response study in other papers did not address the effects of the FAIR Act of 1996.

Figure 3. Acreage of Alfalfa in Arizona
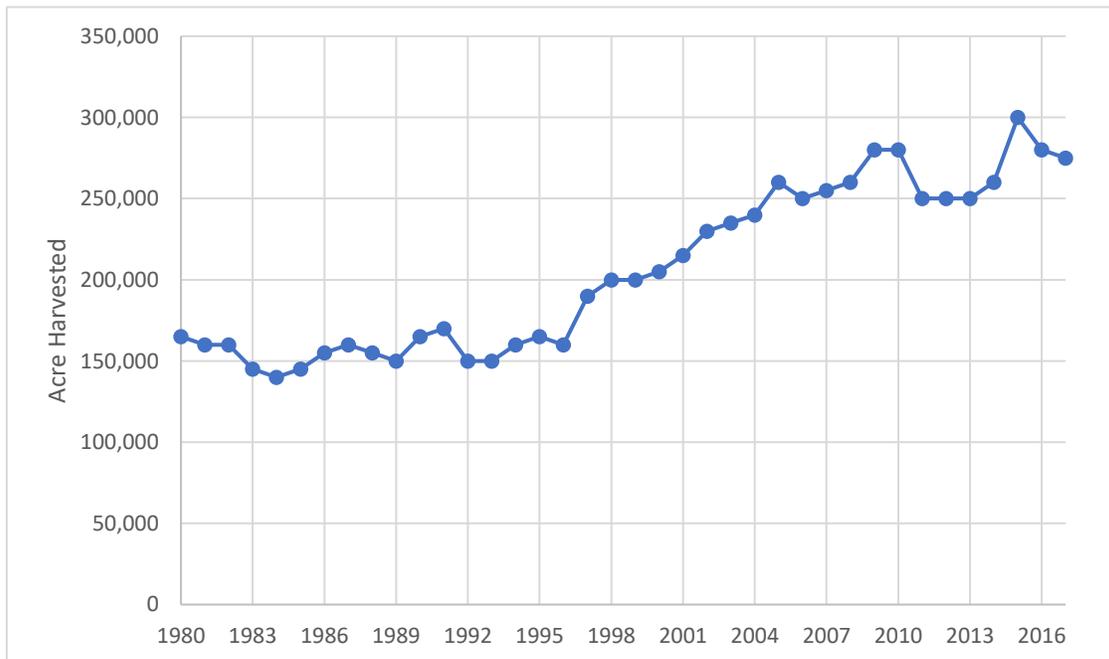
The own price and cross price elasticities of alfalfa acreage response were close in terms of

absolute values. A new variable can be generated using the alfalfa price divided by competing crop price index, in short, a price ratio of own and competing prices. The new acreage response function is estimated:

$$A_t = \beta_0 A_{t-1}^{\beta_1} \frac{P_{t-1}^{\beta_2}}{CP_{t-1}^{\beta_2}} e^{\beta_4 D} e^{\varepsilon} \tag{5}$$

Taking the logarithm of this new acreage response function (equation 5) results in a log-linear regression model:

$$\ln A_t = \beta_0 + \beta_1 \ln A_{t-1} + \beta_2 (\ln P_{t-1} - \ln CP_{T-1}) + \beta_3 D + \varepsilon \tag{6}$$

This new logarithmic function is a restricted model of the original model. The restriction here is $\beta_2 = -\beta_3$. A linear regression was applied in Excel with an Ordinary Least Squares routine. This reduces the number of explanatory variables to three, which increases degrees of freedom. The model fit of the new regression is the same as the original with an Adjusted R Square e of 0.96. All variables are significant at the 1% level.

Table 2. Econometric Estimates of Alfalfa Acreage Response in Arizona (restricted model)

Variable Name	Coefficients	P-value	Standard Error
Intercept	2.26	0.0050	0.75
DiffPCP	0.15	0.0026	0.05
log of lagged acreage	0.74	0.0000	0.07
Dummy	0.09	0.0078	0.03

A log likelihood ratio test was used to test whether the null hypothesis $\beta_2 = -\beta_3$ is true. The formula for LR test is:

$$2(LnL_{unrestricted} - LnL_{restricted}) \sim \chi_Q^2$$

There is only one restriction here so Q=1. Using LLFUNC procedure in SAS, $LnL_{unrestricted} =$

62.13 and $LnL_{restricted} = 61.66$. The test result is 0.93 (two times the differences) which is much smaller than the test value of 3.84 from chi square table. Thus, this null hypothesis $\beta_2 = -\beta_3$ cannot be rejected at the 5% level.

When analyzing time series data, test of autocorrelation is always unavoidable and important. The LnA_{t-1} is an independent variable and LnA_t is dependent variable here. A test of autocorrelation between LnA_{t-1} and LnA_t is conducted in SAS. The null hypothesis here is LnA_{t-1} has no autocorrelation with LnA_t. Using PROC AUTOREG procedure in SAS, the Durbin's h statistic value from the test is -0.13 and p-value is 0.45, which indicates we do not reject the null hypothesis at 5% level and it means LnA_{t-1} has no autocorrelation with LnA_t.

YIELD EQUATION

Model

The yield of alfalfa in Arizona is affected by a few different factors. Similarly, the following yield function is estimated:

$$Y_t = \beta_0 Y_{t-1}^{\beta_1} P_{t-1}^{\beta_2} Qstock_{t-1}^{\beta_3} e^{\beta_4 DrySP12_t} e^{\beta_5 WetSP12_t} e^{\beta_6 t} e^{\varepsilon} \tag{7}$$

where β_i (i = 1 to 6) are the coefficients to be estimated, Y_t is the yield of alfalfa in Arizona in year t, Y_{t-1} is yield of alfalfa in Arizona in year t-1 (lagged one year), P_{t-1} is the price of alfalfa in Arizona in year t-1 (lagged one year), $Qstock_{t-1}$ is the alfalfa stock on farm in Arizona in the December of year t-1, $DrySP12_t$ is the SP12 drought measure in year t, $WetSP12_t$ is the SP12 excessive moisture measure in year t, t is time variable where t is from 1 to 38 representing year 1980 to 2017.

Taking the logarithm of the yield function (equation 7) results in a log-linear regression equation:

$$\ln Y_t = \beta_0 + \beta_1 \ln Y_{t-1} + \beta_2 \ln P_{t-1} + \beta_3 \ln Qstock_{t-1}$$

$$+\beta_4 DrySP12_t + \beta_5 WetSP12_t + \beta_6 t + \varepsilon \tag{8}$$

Based on economic theory, one would expect yield of alfalfa to be increasing in the lagged price of alfalfa and in the variable time. A higher price in last year would encourage the farmers to add inputs to improve the yield. The technology improvement over time may have positive impact on alfalfa yield.

Data

Data to estimate this yield function come from the USDA Quick Stats website (https://quickstats.nass.usda.gov/). The time variable t takes on values from 1 to 38 representing from year 1980 to 2017. The purpose of time variable here is detecting whether the technological improvements have improved alfalfa yields over time.

The variables WetSP12 and DrySP12 are based on the 12-month SPI as of December of each year (Guttman 1999). Thus, it measures how much wetter or drier that calendar year is than normal (how much it deviates from long term averages). The SPI takes on negative values for drier than normal years and positive values during wetter than normal year.

The Drought and Moisture Measure was constructed as follows:

a) a dummy variable DRY = 1 if the SPI12 is negative, = 0 otherwise

b) a dummy variable WET = 1 if the SPI12 is positive, = 0 otherwise

c) The variable DrySP12 = DRY * ABS(SPI12) (this variable signals both whether or not the year was drier than normal and also how much drier)

d) the Variable WetSP12 = WET * SPI12 (this variable signals both whether or not the year was wetter than normal and also how much wetter)

Estimation and Results

First, using all the data needed in the logarithmic function of yield, a linear regression was applied in Excel with an Ordinary Least Squares routine. There are only 38 observations and 6 independent variables. The regression estimates are given in Table 3 below with an Adjusted R Square value of 0.81.

Table 3. Econometric Estimates of Alfalfa Yield in Arizona

Variable Name	Parameter Estimate	P-value	Standard Error
Intercept	1.57	0.0001	0.36
log of lagged Yield	0.30	0.04	0.14
log of lagged real P	-0.02	0.31	0.02
log of lagged December Alfalfa Stock on Farm	-0.005	0.71	0.01
Drought Measure	-0.002	0.75	0.01
Excessive Moisture Measure	-0.02	0.04	0.01
Time trend	0.003	0.0029	0.001
R Square	0.84		
Durbin's h	-2.73	0.0032	

The estimated parameter coefficients of Lagged yield, Excessive Moisture Measure and variable Time are significant at the 5% level. The estimated parameter coefficients of the Drought Measure, log of lagged real alfalfa price, and log of lagged December Alfalfa Stock on Farm were not statistically significant, however.

The estimated parameter coefficients in this logarithmic function of yield function represent elasticities. The elasticity of alfalfa yield with respect to its last year's yield is 0.3, which is inelastic.

A 1% increase of alfalfa yield this year will approximately increase next year's alfalfa yield by 0.3%. The elasticity of alfalfa yield with respect to Excessive Moisture Measure is -0.02, which is also inelastic. A 1% increase of Excessive Moisture Measure will approximately decrease alfalfa yield by 0.02%. The elasticity of alfalfa yield with respect to time is 0.003, which indicates a very small amount of increase of alfalfa yield year by year. (See Figure 4 below)

Figure 4. Yield of Alfalfa in Arizona
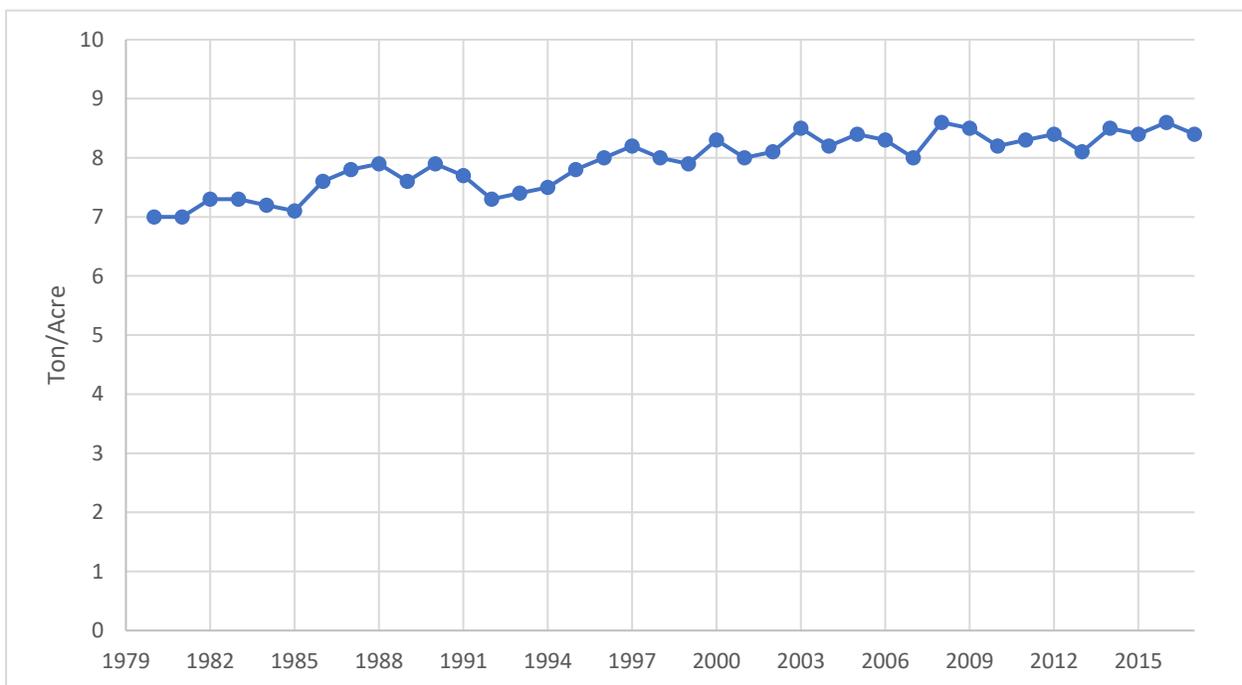
When analyzing time series data, testing for autocorrelation is important. Autocorrelation is a problem because its presence means that some useful information is missing from the model. Such information might explain the movement in the dependent variable more accurately. The LnY_{t-1} is an independent variable and LnY_t is dependent variable here. A test of autocorrelation between LnY_{t-1} and LnY_t is conducted in SAS. The null hypothesis here is that the error terms ε_{t-1} and ε_t are not correlated. Using PROC AUTOREG procedure in SAS, the Durbin's h statistic value

from the test is -2.73 and p-value is 0.0032, which indicates we reject the null hypothesis at 5%

level,

The Yule-Walker method (Greene 2012) was applied here to correct for first

order autocorrelation when the lag of the dependent variable, LnY_{t-1} is in the regression. Using

PROC AUTOREG procedure in SAS and dropping the lagged yield variable LnY_{t-1}, the Yule-

Walker method results a transformed regression R-Square of 0.79. The regression estimates using

Yule-Walker method are given in Table 4 below.

Table 4. Econometric Estimates of Alfalfa Yield in Arizona (Yule-Walker Method)

Variable Name	Parameter Estimate	P-value	Standard Error
Intercept	2.23	<.0001	0.19
log of lagged real P	-0.03	0.13	0.02
log of lagged December Alfalfa Stock on Farm	-0.006	0.67	0.01
Drought Measure	-0.0007	0.92	0.007
Excessive Moisture Measure	-0.017	0.08	0.009
Time t	0.0046	<.0001	0.0006

The estimated parameter coefficients of Drought Measure, Log of lagged real alfalfa price,

and Log of lagged December Alfalfa Stock on Farm are still not statistically significant after

correcting the first-order autocorrelation. All the estimated parameter coefficients have the signs

same as the original model. The estimated parameter coefficient of Excessive Moisture Measure

is only significant at 10% level. The estimated parameter coefficient of variable Time is significant

at 5% level and it is 0.0046, which is larger than 0.003 in the original model.

PRICE FLEXIBILITY EQUATION

Model

Thirdly, the price of alfalfa in Arizona is affected by a few similar and a few different factors from the previous regression equations. Similarly, the following function is estimated:

$$P_t = \beta_0 Q_t^{\beta_1} CornP_t^{\beta_2} MilkP_t^{\beta_3} CalfP_t^{\beta_4} Qstock_{t-1}^{\beta_5} FeedInv_t^{\beta_6} CowInvP_t^{\beta_7} Exp_t^{\beta_8} e^{\varepsilon} \qquad (9)$$

where β_i (i = 1 to 8) are the coefficients to be estimated, P_t is the price of alfalfa in Arizona in year t, Q_t is quantity of alfalfa production in Arizona in year t, $CornP_t$ is the national corn price in year t, $MilkP_t$ is the national milk price in year t, $CalfP_t$ is the national calf price in year t, $Qstock_{t-1}$ is the alfalfa stocks on farm in Arizona in the December of year t-1 (lagged one year), $FeedInv_t$ is the inventory of cattle on feed in Arizona in year t, $CowInv_t$ is the inventory of milk cow in Arizona in year t, Exp_t is the measure of export demand. t is time variable where t is from 1 to 38 representing year 1980 to 2017.

Taking the logarithm of the price flexibility function (equation 9) results in a log-linear regression equation:

$$\ln P_t = \beta_0 + \beta_1 \ln Q_t + \beta_2 \ln CornP_t + \beta_3 \ln MilkP_t + \beta_4 \ln CalfP_t$$

$$+ \beta_5 \ln Qstock_{t-1} + \beta_6 \ln FeedInv_t + \beta_7 \ln CowInv_t + \beta_8 \ln Exp_t + \varepsilon \qquad (10)$$

Based on economic theory, one would expect price of alfalfa to be decreasing in the quantity of alfalfa production and increasing with corn price, milk price, calf price, and the emerging export. The logic of using alfalfa stock as an independent variable is that the more stocks of hay farmers

possess at the end of the previous year, the less they will be willing to pay for new supplies of hay.

Data

Data to estimate this price flexibility function come from the USDA Quick Stats website (https://quickstats.nass.usda.gov/). The hypothesis of using national calf prices is that since alfalfa is used to feed cattle, then higher calf prices would signal higher derived demand for alfalfa. For the measure of export demand, here I choose a few different variables, such as the US hay exports in thousands of dollars, the stocks of cattle, goats, and sheep from main the alfalfa importing country, China, and the stock of cattle from other main alfalfa importing countries (Saudi Arabia, UAE, Japan, and South Korea). The data on US hay exports in thousands of dollars is from the Foreign Agricultural Service (FAS). The quantity of cattle and sheep are downloaded from the FAOSTAT website. As in the previous equation, I use annual data from year 1979 to 2017. Here we used the quantity of cattle and sheep in China as the measure of export demand.

Estimation and Results

First, using all the data needed in the logarithmic function of price flexibility, a linear regression was applied in Excel with an Ordinary Least Squares routine. There are 38 observations and 8 independent variables. One might expect that the emerging export market would have an impact on the price of alfalfa received in Arizona, but none of the measures of export demand I tried is statistically significant at 5% level. While applying different variables as the export measure in three models, the estimated parameter coefficients of other variables don't shift a lot. Three different versions of regression estimates are given in Table 5 below.

Table 5. Econometric Estimates of Alfalfa Price Flexibility in Arizona

Variable Name	Model 1		Model 2		Model 3	
	Parameter Estimate	P-value	Parameter Estimate	P-value	Parameter Estimate	P-value
Intercept	-2.66	0.18	-5.81	0.27	-7.96	5.99
Log of Alfalfa Production	-0.34	0.27	-0.34	0.28	-0.24	0.31
Log of AZ cattle on feed inventory	0.28	0.06	0.26	0.06	0.26	0.12
Log of AZ milk cow inventory	0.54	0.10	0.64	0.01	0.59	0.26
Log of national milk price	0.52	0.01	0.50	0.01	0.48	0.17
Log of national corn price	0.34	0.0001	0.37	0.0001	0.35	0.08
Log of national calf price	0.25	0.02	0.29	0.02	0.29	0.11
Log of Lagged December Alfalfa Stock on farm	-0.11	0.07	-0.11	0.06	-0.10	0.06
Export Measures:						
Log of the US hay export value	0.06	0.51				
Log of China's cattle, sheep, and goat inventory			0.14	0.59		
Log of cattle inventory in SA, UAE, JPN, Korea					0.27	0.31

In model 1, the export measure I used is the US hay export value. The estimated parameter coefficients of Log of Alfalfa Production, Log of AZ milk cow inventory, and Log of the US hay export value are not statistically significant here. The estimated parameter coefficients of Log of Arizona cattle on feed inventory and Log of alfalfa stocks on farm in previous December is not significant at 5% level but it is significant at 10% level. The estimated parameter coefficients of Log of national milk price, Log of national corn price, and Log of national calf price are significant at 5% level.

The estimated parameter coefficients in this logarithmic function of price flexibility represents elasticities. The elasticity of alfalfa price with respect to national milk price is 0.52, which is inelastic. A 1% increase of national milk price will approximately increase Arizona alfalfa price by 0.52%. The elasticity of alfalfa price with respect to national corn price is 0.34, which is also inelastic. A 1% increase of national corn price will approximately increase Arizona alfalfa price by 0.34%. The elasticity of alfalfa price with respect to national calf price is 0.25, which is also inelastic. A 1% increase of national calf price will approximately increase Arizona alfalfa price by 0.25%. The elasticity of alfalfa price with respect to lagged December alfalfa stock on farm is -0.11, which is also inelastic. A 1% increase of lagged December alfalfa stock on farm will approximately decrease Arizona alfalfa price by 0.11%. All the three estimated parameter coefficients have the signs one would expect from economic theory.

In model 2, the export measure I used is the inventory of China's cattle, sheep, and goat. In model 3, the export measure I used is the cattle inventory in SA, UAE, JPN, and Korea. The estimated parameter coefficients of other variables in model 2 and model 3 differ a little from model 1 but there are no significant changes. None of the export measures are statistically significant. Several other different export measures had been tested also, but none of those proved statistically significant either. It is hard to quantify the actual export of alfalfa from Arizona since we only have the data of total alfalfa hay exports from USA in total. There is no state level data of alfalfa hay exports.

A Durbin-Watson test was done in SAS to test for autocorrelation. The null hypothesis here is LnAlfPrice has no first-order autocorrelation. The first-order Durbin-Watson statistic output from SAS

shows a DW=2.097 and p-value < DW is 0.229. The first-order Durbin-Watson test is not statistically

significant at 5% level. Thus, the hypothesis of no first-order autocorrelation cannot be rejected.

DECEMBER ALFALFA STOCK EQUATION

Model

The LnAlfQ is an exogenous variable and the estimated parameter coefficient of LnAlfQ is not statistically significant in the price flexibility equation. The estimated parameter coefficient of Log of alfalfa stocks on farm in the previous December is not significant at 5% level but it is significant at 10% level. A few factors may have impact on alfalfa stock. A December alfalfa stock equation is estimated:

$$QStock_{t-1} = \beta_0 Q_{t-1}^{\beta_1} FeedInv_{t-1}^{\beta_2} CowInvP_{t-1}^{\beta_3} CornFutureP_t^{\beta_4} P_{t-1}^{\beta_5} Exp_{t-1}^{\beta_6} e^{\varepsilon} \qquad (11)$$

Where β_i (i = 1 to 6) are the coefficients to be estimated, $Qstock_{t-1}$ is the alfalfa stocks on farm in Arizona in the December of year t-1 (lagged one year), Q_{t-1} is quantity of alfalfa production in Arizona in year t-1, $FeedInv_{t-1}$ is the inventory of cattle on feed in Arizona in year t-1, $CowInv_{t-1}$ is the inventory of milk cow in Arizona in year t, $CornFutureP_t$ is the US corn futures price in September in year t, P_{t-1} is the Arizona alfalfa price in year t-1, Exp_{t-1} is the measure of export demand in year t-1, here I use the US alfalfa hay export values. All these variables are same from price flexibility equation except variable $CornFutureP_t$. t is from 1 to 38 representing year 1980 to 2017.

Taking the logarithm of the December alfalfa stock function (equation 11) results in a log-linear regression equation:

$$\ln \text{QStock}_{t-1} = \beta_0 + \beta_1 \ln Q_{t-1} + \beta_2 \ln\text{FeedInv}_{t-1} + \beta_3 \ln\text{CowInv}_{t-1}$$

$$+ \beta_4 \ln CornFutureP_t + \beta_5 \ln P_{t-1} + \beta_6 \ln\text{Exp}_{t-1} + \varepsilon \qquad (12)$$

Based on economic theory, one would expect on farm stock of alfalfa to be increasing in the quantity of alfalfa produced and the US corn future prices, and the inventory of cattle on feed and milk cow in Arizona. The price of alfalfa may have complex effects. On one hand a higher price creates and incentive to sell alfalfa, lowering stocks. On the other hand, a higher alfalfa price may signal higher prices in the future for alfalfa, creating and incentive to cattle producers to hold greater stocks.

Data

Data to estimate this December alfalfa stock function mostly come from the USDA Quick Stats website (https://quickstats.nass.usda.gov/). The data are similar with the data from the price flexibility equation and are lagged one year. The September US corn futures prices come from a finance website (https://www.investing.com/commodities/us-corn-historical-data).

Estimation and Results

First, using all the data needed in the logarithmic function of December alfalfa stock, a linear regression was applied in Excel with an Ordinary Least Squares routine. There are only 38 observations and 6 independent variables. The regression estimates are given in Table 6 below with an R Square value of 0.62.

Table 6. Econometric Estimates of December Alfalfa Stock in Arizona

Variable Name	Parameter Estimate	P-value	Standard Error
Intercept	-11.68	0.02	4.53
Log of Lagged Alfalfa Production	1.97	0.01	0.71
Log of Lagged AZ cattle on feed inventory	0.29	0.52	0.39
Log of Lagged AZ milk cow inventory	-0.49	0.67	0.81
Log of September US Corn Futures Price	0.42	0.04	0.19
Log of Lagged Alfalfa Price	-0.62	0.05	0.30
Log of Lagged US Hay export value	-0.11	0.59	0.21
R Square	0.62		
Durbin-Watson	2.21	0.46	

The estimated parameter coefficients of Log of Lagged AZ (Arizona) cattle on feed inventory, Log of Lagged AZ (Arizona) milk cow inventory, and Log of Lagged US Hay export value are not statistically significant here. The estimated parameter coefficients of Log of Lagged Alfalfa Production, Log of September US Corn Futures Price, and Log of Lagged Alfalfa Price are statistically significant at 5% level.

The estimated parameter coefficients in this logarithmic function of December alfalfa stock function represent elasticities. The elasticity of December alfalfa stock with respect to Arizona alfalfa production is 1.97, which is elastic. A 1% increase of Arizona alfalfa production will approximately increase Arizona December alfalfa stock by 1.95%, which has the sign as expected. The elasticity of December alfalfa stock with respect to next year's September US Corn Futures

Price is 0.42, which is inelastic. A 1% increase of next year's September US Corn Futures Price will approximately increase Arizona December alfalfa stock by 0.42%. The elasticity of December alfalfa stock with respect to Arizona alfalfa price is -0.62, which is inelastic. A 1% increase of Arizona alfalfa price will approximately decrease Arizona December alfalfa stock by 0.62%.

The December alfalfa stock is time series data, so a test of autocorrelation is conducted here. A Durbin-Watson test is done in SAS. The null hypothesis here is LnQstcok has no first-order autocorrelation. The first-order Durbin-Watson statistic output from SAS shows a DW=2.50, p-value < DW is 0.8, and p-value > DW is 0.2. The first-order Durbin-Watson test is not statistically significant at 5% level. Thus, the hypothesis of no first-order autocorrelation in LnQstcok cannot be rejected.

THREE-STAGE LEAST SQUARES (3SLS) METHOD

In a multivariate regression model, the errors in different equations might be correlated. In this case, the efficiency of the estimation might be improved by taking these cross-equation correlations into account.

The three-stage least squares method (Zellner & Theil 1992) refers to a method of estimation that combines system equations, sometimes known as seemingly unrelated regression (SUR), with a two-stage least squares estimation. It is a form of instrumental variables estimation that permits correlations of the unobserved disturbances across several equations, as well as restrictions among coefficients of different equations, and improves upon the efficiency of equation-by-equation estimation by taking into account such correlations across equations. Unlike the two-stage least squares (2SLS) approach for a system of equations, which would estimate the coefficients of each structural equation separately, the three-stage least squares method estimates all coefficients simultaneously. Each equation of the system using 3SLS method is assumed at least just-identified. Equations that are under-identified are disregarded in the 3SLS method.

There are five models discussed above: acreage response equation, yield equation, alfalfa production equation, price flexibility equation, and December alfalfa stock equation. The five equations below are run together using 3SLS in SAS.

$$\ln A_t = \beta_0 + \beta_1 \ln A_{t-1} + \beta_2 \ln P_{t-1} + \beta_3 \ln CP_{T-1} + \beta_4 D + \varepsilon \qquad (13)$$

$$\ln Y_t = \beta_0 + \beta_1 \ln Y_{t-1} + \beta_2 \ln P_{t-1} + \beta_3 \ln Qstock_{t-1}$$

$$+ \beta_4 DrySP12_t + \beta_5 WetSP12_t + \beta_6 t + \varepsilon \qquad (14)$$

$$\ln \text{AlfQ}_t = \beta_0 + \beta_1 \ln \text{A}_{t-1} + \beta_2 \ln \text{P}_{t-1} + \beta_3 \ln \text{CP}_{T-1} + \beta_4 \text{D}$$

$$+\beta_5 \text{DrySP12} + \beta_6 \text{WetSP12} + \beta_7 t + \varepsilon \tag{15}$$

$$\ln \text{P}_t = \beta_0 + \beta_1 \ln \text{Q}_t + \beta_2 \ln \text{CornP}_t + \beta_3 \ln \text{MilkP}_t + \beta_4 \ln \text{CalfP}_t$$

$$+\beta_5 \ln \text{Qstock}_{t-1} + \beta_6 \ln \text{FeedInv}_t + \beta_7 \ln \text{CowInv}_t + \beta_8 \ln \text{Exp}_t + \varepsilon \tag{16}$$

$$\ln \text{QStock}_{t-1} = \beta_0 + \beta_1 \ln \text{Q}_{t-1} + \beta_2 \ln \text{FeedInv}_{t-1} + \beta_3 \ln \text{CowInv}_{t-1}$$

$$+ \beta_4 \ln CornFutureP_t + \beta_5 \ln \text{P}_{t-1} + \beta_6 \ln \text{Exp}_{t-1} + \varepsilon \tag{17}$$

The five variables LnA, lnYield, LnAlfPrice, LnAlfQ, and InlagAlfQstock are endogenous variables in 3SLS.

The independent variables lnlagA, lnrlagP, LagLnCP, DeCouple, lnlagYield, DrySP12, WetSP12, t, lnFeedInv, lnCowInv, lnPMilk, lnPCorn, lnCalfP, LnHayEXP, LnLagAlfQ, lnLagFeedInv, lnLagCowInv, lnSepCornFuture and LnLagHayEXP are instrumental variables here.

The model is recursive. First, acreage is determined based on lagged alfalfa price and other factors. Second, yield is also hypothesized to be a function of lagged alfalfa price. Lagged price is meant to capture farmers' expectations of the realized price they receive once they sell their alfalfa. Acreage and yield combine to generate production. Next, the price of alfalfa is hypothesized to depend on the quantity of alfalfa produced that year in addition to December stocks of alfalfa on-farm in Arizona in the previous year. Finally, end-of year stocks depend on current-year production and other variables.

Alfalfa production equation is LnAlfQ = LnAcre + LnYield. All variables in acreage response

equation and yield equation are therefore included in the production equation. Cross equation restrictions are imposed so that the predictive value of will equal the sum of the predicted values of LnAcre and LnYield.

The output of 3SLS procedure in SAS shows the cross-model covariance and correlation matrix. See the table 7 and table 8 below:

Table 7. Cross model Covariance and Correlation in the 3SLS model

Cross Model Covariance					
	lnA	**lnYield**	**lnAlfQ**	**lnAlfPrice**	**InlagAlfQstock**
lnA	0.002556	0.000262	0.002413	0.000926	0.002313
lnYield	0.000262	0.000689	0.000894	0.001297	0.000055
lnAlfQ	0.002413	0.000894	0.003444	0.002703	0.001869
lnAlfPrice	0.000926	0.001297	0.002703	0.013643	-.002527
InlagAlfQstock	0.002313	0.000055	0.001869	-.002527	0.081038
Cross Model Correlation					
	lnA	**lnYield**	**lnAlfQ**	**lnAlfPrice**	**InlagAlfQstock**
lnA	1.00000	0.19728	0.81336	0.15686	0.16071
lnYield	0.19728	1.00000	0.58070	0.42313	0.00743
lnAlfQ	0.81336	0.58070	1.00000	0.39441	0.11189
lnAlfPrice	0.15686	0.42313	0.39441	1.00000	-0.07600
InlagAlfQstock	0.16071	0.00743	0.11189	-0.07600	1.00000

The system weighted MSE and system weighted R-Square measure the fit of the joint model obtained by stacking all the models together and performing a single regression with the stacked observations weighted by the inverse of the model error variances. The output of 3SLS procedure

in SAS shows a system weighted MSE of 3.47 and a system weighted R-Square of 0.6, which indicate the fit of the joint model is moderate.

Comparison of OLS and 3SLS

Compared the results of parameter estimates and p-values from OLS method and 3SLS method, there are a few changes of estimates and p-values in some of variables but most of the parameter estimates and p-values stay the same. See the tables below.

Table 8. Comparison of Econometric Estimates of Alfalfa Acreage Response in Arizona

	OLS		3SLS	
Variable Name	Parameter Estimate	P-value	Parameter Estimate	P-value
Intercept	2.32	0.004	2.33	0.002
log of lagged Acreage	0.73	<.0001	0.73	<.0001
log of lagged real P	0.18	0.002	0.17	0.002
log of lagged real CP	-0.14	0.013	-0.14	0.005
DeCouple	0.10	0.006	0.08	0.01

Table 9. Comparison of Econometric Estimates of Alfalfa Yield in Arizona

	OLS		3SLS	
Variable Name	Parameter Estimate	P-value	Parameter Estimate	P-value
Intercept	1.57	0.0001	1.46	<.0001
log of lagged Yield	0.30	0.04	0.32	0.014
log of lagged real P	-0.02	0.31	-0.02	0.35
Drought Measure	-0.002	0.75	-0.005	0.45
Excessive Moisture Measure	-0.02	0.04	-0.01	0.08
Time trend	0.003	0.003	0.003	0.001

From Table 8 and Table 9, we see parameter estimates and p-values in Alfalfa Acreage Response equation and Alfalfa Yield Equation are close when comparing them from OLS method and 3SLS method.

Table 10. Comparison of Econometric Estimates of Alfalfa Price Flexibility in Arizona

	OLS		3SLS	
Variable Name	Parameter Estimate	P-value	Parameter Estimate	P-value
Intercept	-2.66	0.18	-0.79	0.72
Log of Alfalfa Production	-0.34	0.27	-1.16	0.01
Log of AZ cattle on feed inventory	0.28	0.06	0.37	0.02
Log of AZ milk cow inventory	0.54	0.10	1.09	0.004
Log of national milk price	0.52	0.01	0.56	0.003
Log of national corn price	0.34	0.0001	0.29	0.003
Log of national calf price	0.25	0.02	0.34	0.004
Log of alfalfa stocks on farm in previous December	-0.11	0.07	0.01	0.92
Log of the US hay export value	0.06	0.51	0.08	0.38

In Table 10, the estimated parameter coefficient of Log of Alfalfa Production is not statistically significant in OLS method but is statistically significant at 5% in 3SLS method. The alfalfa's price flexibility with respect to output is -1.16 in 3SLS method, which is elastic. The own price elasticity of demand of alfalfa is the inverse of the price flexibility and is 0.86, implying inelastic demand. The elasticity of Arizona alfalfa price with respect to cattle on feed inventory on Arizona is 0.37 in 3SLS method, higher than 0.28 in OLS method. The elasticity of Arizona alfalfa price with respect to Arizona milk cow inventory is 1.09 in 3SLS method, higher than 0.54 in OLS

method. The elasticity of Arizona alfalfa price with respect to the national calf price on is 0.34 in

3SLS method, higher than 0.25 in OLS method. The estimated parameter coefficient of Log of

alfalfa stocks on farm in previous December is statistically significant at 10% level in OLS method

but is not statistically significant in 3SLS method.

Table 11. Comparison of Econometric Estimates of December Alfalfa Stock in Arizona

	OLS		3SLS	
Variable Name	Parameter Estimate	P-value	Parameter Estimate	P-value
Intercept	-11.68	0.02	-11.70	0.01
Log of Lagged Alfalfa Production	1.97	0.01	2.17	0.004
Log of Lagged AZ cattle on feed inventory	0.29	0.52	0.17	0.67
Log of Lagged AZ milk cow inventory	-0.49	0.67	-0.57	0.48
Log of September US Corn Futures Price	0.42	0.04	0.46	0.02
Log of Lagged Alfalfa Price	-0.62	0.05	-0.63	0.04
Log of Lagged US Hay export value	-0.11	0.59	-0.15	0.49

From Table 11, we see parameter estimates and p-values in December Alfalfa Stock equation

are close when comparing them from OLS method and 3SLS method.

The comparison of OLS methods and 3SLS methods indicates the residuals in the five

equations might be correlated. The 3SLS method takes these cross-equation correlations into

account and has a higher efficiency of the estimation. For the simulation in next chapter, the results

from 3SLS method are applied.

EFFECTS OF FALLOWING

Surface water supplies for alfalfa in Central Arizona come mainly from the Colorado River and the Gila River systems. There are predictions that the Colorado River is going to have a water shortage in the next few years and Arizona will be affected with the "junior" priority water rights that CAP (Central Arizona Project) holds (Bickel et al., 2018). Alfalfa farms in Central Arizona may have to fallow alfalfa acreage, switch to other crops that require less water or increase use of groundwater.

Bickel et al. (2018) considered impacts of alfalfa acres being fallowed in Central Arizona on the local economy. They considered land fallowing scenarios that assumed reductions in alfalfa acreage that would ranges from 10% to 20% of state alfalfa acreage. Their study employed a fixed-price, input-output model that:

> "assumes firms are "price-takers" where the market price that producers receive is determined by national (and world) markets. As such, it does not assume that the price of crops changes in response to localized production changes. More specifically, the baseline model assumes that livestock and dairy producers in Pinal County can obtain feed and forage crops from outside the county at the same, constant, regional price. To the extent that local production shocks increase local prices, the model will understate negative impacts on county feed and forage purchasers (p. 44)."

The econometric results of this study suggest that the price of alfalfa would in fact increase in response to reduction in Arizona alfalfa production. In year t, if a water shortage were to cause

10% of Arizona alfalfa acreage to be fallowed, alfalfa production would also fall by 10% (assuming constant yields). The price flexibility of demand for alfalfa with respect to Arizona alfalfa production was estimated to be -1.16. Assuming other factors are held constant, a 10% drop in Arizona alfalfa production in year t would increase the Arizona alfalfa price by 11.6% in year t. Our acreage response equation suggests that an increase in price in year t would encourage greater production in year t + 1. The acreage response elasticity is low, though, 0.17. If lagged price increase 11.6% under normal circumstances, this would encourage an expansion of alfalfa acreage (all else equal) in year t + 1 and put downward pressure on price in t + 2. However, if the acreage constraint on alfalfa were still binding in year t + 1, then the price increase would be maintained.

Given a large shift in water rights and supplies, it is possible that this would cause a structural shift in the regression equations of this model. The 11.6% increase in response to a 10% supply reduction might be viewed as a reasonable upper bound estimate of short-run price increases. Measuring long-run impacts are beyond the scope of the current study.

SUMMARY AND CONCLUSIONS

This study explored the alfalfa market in Arizona. Alfalfa acreage response, yield, price flexibility, and December alfalfa stock models were estimated to check the importance of different relevant factors in the alfalfa market. In the alfalfa acreage response model, alfalfa acreage in Arizona with respect to its own price is inelastic (0.17) and with respect to its competing crop price index is also inelastic (-0.14). These small elasticity values indicate the response of Arizona alfalfa production to changes in prices is very small. Alfalfa is more like a perennial crop with three to seven years of life and this makes it difficult for farmers to switch from it before its life ends. Also, many dairy farms in Arizona grow their own alfalfa to feed their cows. In the alfalfa price flexibility model, Arizona alfalfa price with respect to Arizona alfalfa production is elastic (-1.16). Arizona alfalfa price with respect to cattle and calf inventories and milk and corn prices were inelastic. This study found no significant special effects of the growth in the alfalfa export market on Arizona's alfalfa prices. In the end-of-year December alfalfa stock model, the alfalfa stock was shown to be elastic with respect to its production in the same year.

Econometric models usually require sufficient data. There are lots of missing values in some variables prior to 1980, so this study dates only from 1980 to 2017. There are monthly price data on alfalfa but only annual data on acreage and yield. The econometric models built in this paper could be easily applied to other states or regions. An advantage of multi-state analysis is that it would increase the statistical power of analyses.

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