Grain Sorghum International Trade: U.S.-Mexico Simulation and Estimation Model

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Abstract

An econometric international supply/demand/trade simulation and forecast sorghum model in a partial equilibrium framework is built in this research paper to quantify the effects of key exogenous variables on the U.S.-Mexico sorghum trade. A forecast baseline is also established by using the validated model and values of exogenous variables provided by FAPRI to project the level of endogenous variables over the period of 2009 to 2017. Impacts of plausible alternative scenarios for key exogenous variables are simulated from 2009 to 2017.

Key Words: Sorghum, International Trade, Simulation, Estimation

Introduction

In the United States, sorghum is the most prominent of the three minor feed grains (sorghum, barley and oats), providing averaged nearly $1,497 million cash receipts per year in 2006-2008 to U.S. farmers (NASS-USDA). Sorghum has a variety of uses including food for human consumption and feed grain for livestock and industrial applications such as ethanol production (Stroade and Boland, 2003).

In the U.S., sorghum is mainly used for animal feed. In 2007-2008, feed and residual use of sorghum averaged nearly 192 million bushels and accounted for 75 percent of total sorghum use (ERS-USDA). However, in recent years, corn has become the main substitute for sorghum as animal feed due to its superior nutritional properties (Stroade and Boland, 2003). Furthermore, increased levels of productivity of corn resulted in relatively lower prices, reducing the price gap between corn and sorghum and making corn a strong substitute for sorghum. As a result, the demand of sorghum as feed in the United States has been steadily declining over time.

Another major component of total sorghum consumption is exports. The United

States is the largest exporter of sorghum, accounting for about 60 percent of world trade in 2008 (FAS-USDA). Mexico is the major market of U.S. sorghum is part because its feeding industry is accustomed to feeding sorghum and its corn imports have been limited by the Mexican Government policies (Hoffman et al. 2007). In 2008, Mexico imports constituted nearly seventy percent of the total U.S. exports (FAS-USDA).

The United States is the largest producer of grain sorghum in the world, accounting for averaged 18% of total world production in recent years from 2004 to 2008. However, the production of sorghum in the United States has declined during the past decade. This drop may be due to factors like the competition from other crops (especially corn), decreasing planting area, and government domestic and trade policies on agriculture and trade.

Declining area planted to sorghum is another factor resulted in decreasing production. As more area is devoted to corn and other crops providing farmers with higher returns, area planted to sorghum in the United States has declined over time. Sorghum is typically grown in regions that experience fequent droughts because the crop is more tolerant than corn to hot and dry conditions. The top five States producing sorghum are Texas, Kansas, Oklahoma, Nebraska, and Colorado, as of 2008. Texas and Kansas planted more than three fourths of all U.S. sorghum acreage in 2008 (NASS-USDA). However, these States appear to be shifting some of their sorghum area into corn production. For example, between 1980 and 2005, the combined sorghum area in Kansas and Nebraska declined by 3.6 million acres, shifting mostly to corn area, which increased by about 2.7 million acres during the period (Hoffman et al. 2007).

Since Mexico is the key export market for U.S. sorghum, the recent changes that have taken place in Mexico are crucial to help understanding the reduced import level. Mexico has been a traditional sorghum trading partner of the U.S. since the 1980's and this relation grew even deeper after the implementation of NAFTA in 1994. NAFTA has led to greater integration in the North American feed grain markets. However, due to special concerns of Mexican negotiators, longer implementation periods were negotiated for tariff liberalization of some feed grains. For example, the opening of the Mexican market occurred instantly for sorghum, but took 14 years for corn. Therefore, although corn is considered a better input than sorghum from an animal nutrition standpoint, government supported corn prices and differentiated trade treatments limited the use of corn for feeding animals in Mexico (Garcia-Vega and Williams, 1996). Consequently, sorghum enjoyed a clear advantage as animal feed with respect to corn over the years in Mexico. However, under NAFTA, Mexican corn tariffs were scheduled to be phased down and disappear in 2008. As corn tariffs were reduced and then eliminated, Mexican feedstock users have been shifting to imported U.S. corn, away from U.S. sorghum imports (Hoffman et al. 2007).

Because of a rapidly eroding domestic market and shrinking demand overseas, the U.S. sorghum sector needs to develop markets, domestic or foreign, to survive as an industry. Recently though, the high prices for crude oil, the U.S. government energy policies, and the consequent increasing demand of ethanol have dramatically expanded the demand for corn, for most ethanol production in the United States currently uses corn as the feedstock. The proportion of corn used for feed, seed and industrial (F.S.I.), mostly ethanol, kept expanding over the past several years, rising from 20 percent in 2000/01 to 30 percent in 2008/09 (USDA, 2009). In addition, continued increases are projected for corn used to produce ethanol over the next ten years, although the pace slows from the rapid gains of the past several years (USDA, 2009). However, ethanol can also be made from grain sorghum within some technical limitations and depending on relative prices. Consequently a growing demand for sorghum as a feedstock for ethanol production is also possible.

Growth of livestock industry has been a driving force behind the growing demand of sorghum in international feed grain markets, especially in regions unable to meet their own feed needs. The growing livestock industry has become the major factor in determining sorghum utilization in Mexico. However, production constraints, especially limited area, kept Mexico from expanding production as rapidly as use, and then the increased consumption has been met by sorghum imports while they were cheaper than corn. That situation has been changing in recent years.

In the phase of potential changes from sorghum supply and demand in domestic market and quota eliminations on corn import under NAFTA, this research paper seeks to build an econometric international supply/demand/trade simulation and forecast sorghum model in a partial equilibrium framework to accurately and appropriately estimate the impact of those relevant variables that have effects on the future demand for U.S. sorghum. Then Simulate impacts of plausible scenarios for key exogenous variables, including the price of corn, the increasing demand from the ethanol industry, etc. Finally, forecast for some key endogenous variables (i.e., sorghum's price in Mexico, sorghum area planted), and the forecast values of endogenous variables will be estimated from 2009 to 2017.

Literature Review

Earlier studies on U.S.-Mexico trade tend to focus on the analysis of the overall feed grain market, or on certain high profile sectors such as corn and sugar. Relatively little research has been done to evaluate the likely effects that freer U.S. – Mexico trade has had on the future sorghum demand. Thus, this literature review summarizes and analyzes literature that is relevant to this study. Its purpose is to provide an understanding of the relevant previous research efforts, and to present linkages with the research at hand.

Roy and Ireland (1975) developed a sorghum econometric model of simultaneous equations to identify and estimate the major structural relationships which influence annual sorghum prices in the domestic market. However, this model was constructed only based on the U.S. market, and it was conducted decades ago. Thus, a more comprehensive analysis based on the U.S.-Mexico sorghum market will be performed to provide more complete and updated results.

Williams and Garcia-Vega (1996) used an econometric simulation model of Mexican livestock, meat, and feed markets, to analyze various scenarios of U.S.-Mexico trade liberalization over the 1986 to 1991 period of unilateral elimination of Mexican trade barriers. However, the data used in this analysis considered only the pre-NAFTA period of Mexican unilateral trade liberalization. Also, the model was developed for examining the effects of the unilateral elimination of Mexican trade barriers on the Mexican livestock, meat, and feed industries.

Pandrangi and Malaga (2005) conducted a study to make an attempt to estimate the parameters of an import demand function for the U.S. sorghum in Mexico. However, a relatively simple model in the form of a single equation was used in this paper. It is expected that the model could be improved by the use of simultaneous equations methods.

Duch-Carvallo and Malaga (2009) developed a partial equilibrium econometric and simulation international trade model for sorghum based on the U.S. and Mexico sorghum markets. Alternative scenarios on critical variables were also simulated. Although the authors also confirmed that Mexican poultry production and U.S. corn price are meaningful variables, this research has no projection for these two critical factors.

Method and Data

This section describes the structure of a partial equilibrium international sorghum trade model and provides detailed information about data, model estimation and validation. This econometric model is composed of nine functional relationships and eight identities. As a result, it determined seventeen endogenous variables. All these econometric equations are estimated simultaneously, using Seemingly Unrelated Regression (SUR). The functional forms are chosen based on modern trade theory, the expected effects of each of the explanatory variables on the respective endogenous variables and the results of empirical tests.

The algebraic formulations of the necessary components of this partial equilibrium econometric model are described here.

Exporter (the U.S.). The components of domestic sorghum supply are specified as beginning stocks and total sorghum production. While beginning stocks in the U.S. is taken as an exogenous variable, total sorghum production is recognized as the product of harvested acreage times the average yield, which is considered exogenous to the model. Additionally, the total area planted in the U.S. is divided into three behavioral equations, corresponding to Kansas, Texas and other states. Kansas and Texas are the leading sorghum-producing states in the U.S., it is reasonable that estimate sorghum acreage planted in these two states separately from the others. Therefore, the U.S. supply of sorghum in any time period t can be specified as:

(1) $APK_t^{US} = f(APK_{t-1}^{US}, PS_{t-1}^{US}, WAHK_t^{US}/WAPK_t^{US}, X_1),$

(2) $APT_t^{US} = f(APT_{t-1}^{US}, PS_{t-1}^{US}, CAHT_t^{US}/CAPT_t^{US}, X_2),$

(3) $APO_t^{US} = f(APO_{t-1}^{US}, PS_{t-1}^{US}, PW_{t-1}^{US}, X_3),$

(4) $AP_t^{US} = APK_t^{US} + APT_t^{US} + APO_t^{US},$

(5) $AH_t^{US} = f(AP_t^{US}, X_4),$

(6) $QS_t^{US} = AH_t^{US} * YD_t^{US} + BSK_t^{US}.$

Where:

Subscripts t and t-1 refer to current and previous year; APK = sorghum area planted in Kansas (thousand ha); PS = real domestic farm sorghum price (in US dollars/bu); WAHK = wheat area harvested in Kansas(thousand ha); WAPK = wheat area planted in Kansas(thousand ha); APT = sorghum area planted in Texas(thousand ha); CAHT = cotton area harvested in Texas(thousand ha); CAPT = cotton area planted in Texas(thousand ha); APO = sorghum area planted in all the other states(thousand ha); PW = real domestic farm wheat price(in US dollars/bu); AP = sorghum area planted in the U.S. (thousand ha); AH = sorghum area harvested in the U.S. (thousand ha); $X_n =$ exogenous variables such as rain, input costs, n=1,2,3,4; QS = quantity of sorghum supplied in the U.S. (thousand Mton); YD = sorghum yield in the U.S.(Mton/ha); BSK = beginning stocks of sorghum in the U.S(thousand Mton).

In Kansas and Texas planted area equations, area ratios are included to take into account the effects of competing crops in each state. Given the timing of cotton planting and harvesting and its strong dependency on weather conditions, it has been observed (and confirmed by sorghum producers) that Texas cotton producers may switch into sorghum after a bad weather outcome affects their planted cotton. This makes the ratio between harvested over planted cotton areas a meaningful variable to be considered in the estimation of Texas sorghum planted area. Similarly, for Kansas, the ratio between harvested wheat over planted wheat area seems to have the same effect on sorghum planting decisions. Therefore, the area ratios of harvested area over planted area are incorporated into the respective area planted equation.

The components of total U.S. sorghum demand include: sorghum demand from the U.S. feed industry, demand for feed, seed and industrial uses (F.S.I.), and demand for ending stocks. The behavioral equation for sorghum utilized for feed domestically will be determined first as it takes the greatest share of total sorghum consumption, while the other two components will be taken as exogenous variables. Then sorghum demand for feed in the U.S. and total domestic sorghum consumption are given as:

(7) $QF_t^{US} = f(PS_t^{US}/PC_t^{US}, PoulPD_t^{US}, X_5),$ and

(8) $QD_t^{US} = QF_t^{US} + QI_t^{US} + ESK_t^{US}.$

Where:

QF = quantity of sorghum used for feed in the U.S. (thousand Mton); PC = real domestic farm corn price(in US dollars/bu); PoulPD = poultry production in the U.S. (thousand Mton); $X_5 =$ exogenous variables; QD = total quantity of sorghum demanded in the U.S. (thousand Mton); QI = quantity of sorghum needed for industry use in the U.S. (thousand Mton); ESK = ending stocks of sorghum in the U.S(thousand Mton).

Sorghum utilization for feed clearly depends on the domestic market sorghum price in each period and the market price of corn, as sorghum substitute. The U.S. feed industries' decisions about making alternative grain to use depend on their relate prices. However, in order to avoid multicollinearity while gaining efficiency, the ratio of these two prices is used instead of using them individually.

The excess supply of sorghum in the U.S. is defined as the difference between the quantity demanded of sorghum and the quantity supplied of sorghum. This relation is expressed as:

(9) $ES_t^{US} = QS_t^{US} - QD_t^{US}.$

Where:

ES = excess supply of sorghum in the U.S(thousand Mton).

Importer (Mexico). Mexican sorghum production each year is determined as the area planted times a technologically and climatically determined crop yield. And the sorghum area planted in Mexico is introduced as a function of lagged dependent variable, lagged real domestic farm sorghum price and other exogenous variables. Therefore, the sorghum area planted in Mexico and the Mexican sorghum supply in any time period *t* can be specified as:

(10) $AP_t^{MX} = f(PS_{t-1}^{MX},\ AP_{t-1}^{MX}, X_6)$,

(11) $AH_t^{MX} = f(AP_t^{MX}, X_7)$, and

(12) $QS_t^{MX} =\ YD_t^{MX} * AH_t^{MX} +\ BSK_t^{MX}$.

Where:

AP = sorghum area planted in Mexico(thousand ha); PS = real Mexican farm sorghum price(in Mexican pesos/Mton); AH = sorghum area harvested in Mexico(thousand ha); $X_{6,7}$ = exogenous variables such as weather, input costs; QS = quantity of sorghum supplied in Mexico(thousand Mton); YD = sorghum yield per unit of area in Mexico(Mton/ha); BSK = beginning stocks of sorghum in Mexico(thousand Mton).

Feed demand in Mexico is affected primarily by the number of animals to be fed in inventory and feed prices. In Mexico during the estimation period, as it was confirmed by Pandrangi and Malaga (2005), corn is considered as sorghum's main competing feed in terms of producers' choice of what feed to use. Consequently, the model to be estimated includes corn price to account for the existing competing nature between these two products. Finally, the Mexican sorghum demand for feed and total domestic sorghum consumption in time period *t* is specified as:

(13) $QF_t^{MX} = f(PS_t^{MX}/PC_t^{MX}, PoulPD_t^{MX}, X_7),$ and

(14) $QD_t^{MX} = QF_t^{MX} + ESK_t^{MX}.$

Where:

QF = quantity of sorghum used for feed in Mexico(thousand Mton); PoulPD = poultry production in Mexico(thousand Mton); X_7 = exogenous variables; QD = total quantity of sorghum demanded in Mexico(thousand Mton); ESK = ending stocks of sorghum in Mexico(thousand Mton).

The excess demand in an importing country like Mexico is the sum of domestic demand minus domestic supply. This relation is given by:

(15) $ED_t^{MX} = QD_t^{MX} - QS_t^{MX}.$

Where:

ED = excess demand of sorghum in Mexico(thousand Mton).

International Market. The market equilibrium for grain sorghum between Mexico and the U.S. is determined by equating the excess supply of the United States (ES_t^{US}) to the excess demand of Mexico (ED_t^{MX}) plus the total quantity demanded of the rest of the world (ROW). The excess supply and excess demand of sorghum are determined as indicated in the previous sections. Thus,

(16) $ES_t^{US} = ED_t^{MX} + ROW.$

In order to better understand the Mexican sorghum market and accomplish some of the objectives of this study, a Mexican sorghum price transition equation is developed. Thus, the sorghum price in Mexico is specified as a function of sorghum price in the U.S. and the exchange rate between Mexican pesos and U.S. dollars. At this time, this price behavioral equation can be written in the following way:

$$(17) \quad PS_t^{MX} = f\ (PS_t^{US}, ER_t).$$

Where:

ER = the exchange rate between U.S. dollars and Mexico pesos at time period *t* in terms of pesos per U.S. dollars.

In addition, validation of the model uses Theil's inequality coefficient, with the proportions of inequality U^M, U^S and U^C. Therefore, if validated, this econometric model allows for the forecast and simulation of future plausible scenarios on exogenous variables. Such exogenous variables include: U.S. corn price, U.S. sorghum yield, U.S. sorghum export to the rest of the world, sorghum demand from U.S. ethanol industry, poultry industry in Mexico and the exchange rate between U.S. dollars and Mexico pesos.

Data Sources

The estimation period that was used to estimate U.S.-Mexican sorghum demand, supply, and price equations generally consists of thirty-four years (1975-2008). Data on production variables for both countries were obtained from PS&D. Prices of corn and sorghum in Mexico were obtained from SAGARPA. Prices of corn and sorghum in the U.S. were obtained from ERS – USDA. Prices of corn and sorghum for both countries were deflated to prices of 2000. Projections for exogenous variables were obtained from FAPRI.

Empirical Results

In this section, details about the results of the international grain sorghum model estimations, baseline projections and simulations are presented. The estimation results for the set of behavioral equations modeling U.S. sorghum supply and demand, based on annual data over the period 1975-2008, are presented below in Table 1. Overall, the U.S. sorghum supply and demand equations showed acceptable goodness of fit as indicated by the R^2 statistics. And all estimated parameters showed the expected signs and were statistically significant.

Equation (1.1) indicates an inverse relation existing between sorghum area planted in Kansas and the ratio of wheat harvested to planted area in that state. This result is consistent with previous hypothesis that wheat and sorghum are competing crops in that part of the country. Moreover, the negative coefficient of the ratio of cotton area harvested to cotton area planted in Texas in equation (1.2) confirms that more sorghum is planted when the cotton harvested ratio declines. With regard to U.S. sorghum supply estimation, a variable that was evaluated but removed for lacking of statistically significance was input costs. The reason it was not found significant might be due to the fact that changes in input costs are less likely to affect sorghum farmers' planting decisions.

On the other hand, the prices of sorghum and corn, which is the substitute for sorghum in the U.S., are used in a ratio format in this equation, is an attempt to reduce the serious multicolinearity problem existing between them. A dummy variable was included to capture the lack of effect of some external unobservable factors like abnormally good or bad weather in a given year.

Table 2 presents the results of estimating the parameters of Mexican sorghum supply and demand equations. All estimated parameters showed the expected signs and were statistically significant. In order to improve the overall estimation results, two dummy variables were introduced in equation (2.1) to account for the peso depreciation period and adverse weather conditions for the period from 1975 to 1980. Both dummy variables were found to be significant in this model for sorghum area planted in Mexico. For the Mexican sorghum feed use equation (2.4), a zero-one dummy variable for 1991was included to account for the effect of abnormally occurrence of bad weather during the year 1991.

Table 3 provides a summary of the econometric results for this behavioral relation. As illustrated on Table 3, Mexico's sorghum price is positively related to the U.S. sorghum price transformed into real Mexican pesos, which is also consistent with previous expectations.

The international estimation/simulation sorghum model was validated using the Theil's inequality coefficient, with its proportions of inequality $\mathrm{U^M}$, $\mathrm{U^S}$ and $\mathrm{U^C}$ corresponding to characteristic sources of the simulation error. The ideal distribution of the Theil's inequality coefficient over the three proportions is $\mathrm{U^M} = \mathrm{U^S} = 0$, and $\mathrm{U^C} = 1$. A summary of these validation statistics is provided in table 4. As suggested by the results, it is considered that this model established is suitable for further projections and simulations.

Baseline Projections

Baseline projections for the endogenous variables are predicted over the period of 2009 to 2017. The projections were run using the validated model and values of exogenous variables provided by FAPRI. The baseline values of the endogenous variables serve as a benchmark to measure the effects of plausible alternative scenarios developed in the next section. Table 5 lists the FAPRI's projected values of key exogenous variables used in this study from 2009 to 2017.

In addition, figures 1 through 9 below depict the observed versus the predicted and baseline projected values of key endogenous variables through the entire regression period as additional information on the overall fitness of this model. Overall, it is considered that this model generates very reasonable baseline projections for the 2009-2017 period, considering the historical pattern of the data and assuming most likely conditions would still hold in the future.

According to baseline projected results, domestic sorghum supply would keep stable during the period from 2009 to 2017. Although U.S. sorghum feed use decreases over time, total U.S. sorghum consumption would not change much. That might be due to increased sorghum industrial use. Although U.S. real sorghum price increased from 2005 to 2007, it dropped in 2008. And it would keep this decreasing trend from 2009 to 2017. As historical data indicated, U.S. sorghum exports to Mexico reached its maximum around the year 2000. Until 2008, this exports level kept decreasing. It is expected that sorghum exports to Mexico would slightly increase over the projected period. However, it would never go back to the exports level in 2000. Additionally, sorghum supply and demand in Mexico are projected to increase from 2009 to 2017. Since Mexican sorghum price is closely related to sorghum price in the U.S., it would also decrease over the projected period.

Model Simulations and Forecasts

Results of the forecasts are listed in table 6. Five scenarios were analyzed using the established supply/demand/trade simulation model. These include: a) 10% higher/lower than FAPRI data of U.S. corn price; b) 10% higher/lower than FAPRI data of Mexican poultry production; c) a 5% annual increase in sorghum yield in the U.S.; d) a 5% annual increase/decrease in U.S. sorghum export to the rest of the world; and e) the increases in U.S. ethanol industry demand. The endogenous variables selected for the analysis are U.S. sorghum supply, U.S. sorghum exports to Mexico and U.S. real sorghum price. The simulated results are compared to the respective baseline projections. Some important implications resulting from the forecast and simulation analysis include the following:

1. The scenario analysis for U.S. corn price changes indicates that it will have a relatively larger impact on sorghum exports to Mexico, with the impacts on domestic sorghum supply and price being smaller. For instance, as a result of 10% above the FAPRI projections of U.S. corn price, sorghum exports to Mexico are estimated to be in average about 10% higher than would be the case without corn price change, and U.S. sorghum supply and price are estimated to increase by an average of about 6% and 5% per year below the baseline values respectively.

2. In contrast, the poultry production in Mexico has the most potential to affect the U.S. sorghum exports level to that country. According to the simulation results, 20% change with respect to the FAPRI projections of Mexican poultry

production could result in an about 40% change in sorghum exports to Mexico in 2009. By the year 2017, the change is 46% compared to the case without Mexico poultry production changes.

3. Annual 5% growth in U.S. sorghum yield would stimulate U.S. sorghum exports to Mexico to a large extent. However, this change would result in a decrease in the U.S. sorghum price.

4. Another scenario assumes 5% annual increase/decrease in sorghum exports to ROW, which may be possible considering current conditions would hold in the future. However, according to the simulation analysis, it would have not much impact on U.S. sorghum supply, exports to Mexico, or sorghum price.

5. The simulation results indicate that increasing 100% sorghum demand from its ethanol industry over 2009 level may have small impacts on U.S. sorghum supply, exports to Mexico and real price. Therefore, to have large impacts on the U.S. sorghum market, a much larger demand from the ethanol industry would be needed. This could be achieved through a specific mandate type of policies.

Future Research

This research paper describes the international sorghum market with emphasis on the North American market (US and Mexico). One limitation of this research is that the estimation of the demand side only includes Mexico as an importer. Future research in this area could expand the number of importers by incorporating countries such as the European Union and Japan, given their growing importance in recent years. The high disaggregation will allow the market structure of most of the countries participating in the international sorghum market to be adequately captured.

Perhaps an even more interesting aspect to explore is to evaluate the impacts on U.S. sorghum market resulting from ethanol industry with policy changes. In this research paper, it was assumed that the ethanol industry would be mandated to double that average amount of last six years' consumption levels based on its 2009 baseline level for the period 2009-2017. However, the results do not show much effect. Future research could endogenize the ethanol sorghum demand or try with alternative scenarios so that the model developed in this paper could be used to draw more accurate implications regarding potential governmental interventions to encourage sorghum production in the U.S.

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Table 1. Summary of the Econometric Results of the Structural Equations of U.S. Sorghum Supply and Demand

U.S. Supply

$$APK_t^{US} = 1768.883 + 0.597APK_{t-1}^{US} + 1.577PS_{t-1}^{US} - 1513.55\,WAHK_t^{US}/WAPK_t^{US} + \varepsilon_t \quad (1.1)$$

(4.03) (5.04) (2.45) (-3.21) Rsq = 0.58

[0.003] [-0.876]

$$APT_t^{US} = 1352.179 + 0.324APT_{t-1}^{US} + 6.975PS_{t-1}^{US} - 1421.34\,CAHT_t^{US}/CAPT_t^{US} + \varepsilon_t \quad (1.2)$$

(4.83) (3.32) (5.91) (-4.01) Rsq =0.84

[0.013] [-0.778]

$$APO_t^{US} = -42.825 + 0.754APO_{t-1}^{US} + 13.29PS_{t-1}^{US} - 256.927PW_{t-1}^{US} + \varepsilon_t \quad (1.3)$$

(-0.25) (8.83) (3.16) (-2.1) Rsq =0.79

[0.022] [-0.635]

$$AP_t^{US} = APK_t^{US} + APT_t^{US} + APO_t^{US} \quad (1.4)$$

$$AH_t^{US} = -58.776 + 0.878AP_t^{US} + \varepsilon_t \quad (1.5)$$

(-0.37) (27.92) Rsq =0 .77

[1.015]

$$QS_t^{US} = AH_t^{US} * YD_t^{US} + BSK_t^{US} \quad (1.6)$$

U.S. Demand

$$QF_t^{US} = 29852.13 - 390.514\,PS_t^{US}/PC_t^{US} - 0.633PoulPD_t^{US} + 1083.02DV + \varepsilon_t \quad (1.7)$$

(5.06) (-2.42) (-7.02) (1.13) Rsq =0.62

[-0.038] [-0.757]

$$QD_t^{US} = QF_t^{US} + QI_t^{US} + ESK_t^{US} \quad (1.8)$$

$$ES_t^{US} = QS_t^{US} - QD_t^{US} \quad (1.9)$$

*t values are in parentheses.
elasticities are in brackets.

Table 2. Summary of the Econometric Results of the Structural Equations of Mexican Sorghum Supply and Demand

Mexican Supply

$$AP_t^{MX} = 1036.83 + 0.347\,AP_{t-1}^{MX} + 0.226PS_{t-1}^{MX} - 1019.57DV_1 - 358.724DV_2 + \varepsilon_t \quad (2.1)$$

(3.69) (2.41) (2.41) (-3.72) (-2.29) Rsq = 0.66

[0.249]

$$AH_t^{MX} = 234.747 + 0.694AP_t^{MX} + \varepsilon_t \quad (2.2)$$

(1.16) (6.23) Rsq =0.37

[0.837]

$$QS_t^{MX} = YD_t^{MX}AP_t^{MX} + BSK_t^{MX} \quad (2.3)$$

Mexican Demand

$$QF_t^{MX} = 8139.8 - 5183.7\,PS_t^{MX}/PC_t^{MX} + 2.078PoulPD_t^{MX} + 2742.622DV + \varepsilon_t \quad (2.4)$$

(4.59) (-2.02) (6.69) (1.99) Rsq =0.61

[-0.538] [0.475]

$$QD_t^{MX} = QF_t^{MX} + ESK_t^{MX} \quad (2.5)$$

$$ED_t^{MX} = QD_t^{MX} - QS_t^{MX} \quad (2.6)$$

*t values are in parentheses.
elasticities are in brackets.

Table 3. Summary of the Econometric Results of the Sorghum Price Relation Results

$$ES_t^{US} = ED_t^{MX} + ROW \quad (3.1)$$

$$PS_t^{MX} = 273.375 + 1.307PS_t^{US}ER_t + \varepsilon_t \quad (3.2)$$

(1.22) (7.71) Rsq = 0.70

[0.021]

*t values are in parentheses.
elasticities are in brackets.

Table 4. Validation Statistics for International Estimation/Simulation Sorghum Model

Variables	Bias (U^M)	Var (U^S)	Covar (U^C)	Theil's U
APK_t^{US}	0.00	0.10	0.89	0.054
APT_t^{US}	0.00	0.02	0.98	0.062
APO_t^{US}	0.00	0.00	1.00	0.092
AP_t^{US}	0.00	0.00	1.00	0.052
AH_t^{US}	0.00	0.00	1.00	0.069
PS_t^{US}	0.00	0.08	0.92	0.052
QF_t^{US}	0.00	0.06	0.94	0.112
QS_t^{US}	0.00	0.04	0.96	0.052
QD_t^{US}	0.00	0.09	0.91	0.057
ES	0.03	0.07	0.91	0.200
AP_t^{MX}	0.00	0.09	0.91	0.062
AH_t^{MX}	0.00	0.23	0.76	0.095
QF_t^{MX}	0.02	0.30	0.68	0.091
QD_t^{MX}	0.02	0.42	0.56	0.083
QS_t^{MX}	0.00	0.19	0.81	0.079
ED	0.01	0.06	0.92	0.200
PS_t^{MX}	0.00	0.09	0.91	0.100

Table 5. FAPRI's Projected Values of Key Exogenous Variables

Market Year	U.S. Sorghum Yield (MT/HA)	Real Corn Price ($/Bu.)	Ethanol Use (1000 MT)	Export to ROW (1000 MT)	Mexican Poultry Production (1000 MT)
2009	4.05	3.12	866	2796	2711
2010	4.07	2.97	834	2724	2777
2011	4.09	2.95	773	2827	2856
2012	4.10	2.93	772	2812	2914
2013	4.12	2.93	813	2863	2964
2014	4.13	2.87	895	2860	3016
2015	4.15	2.84	948	2898	3073
2016	4.16	2.75	1005	2916	3129
2017	4.18	2.70	1044	2988	3185

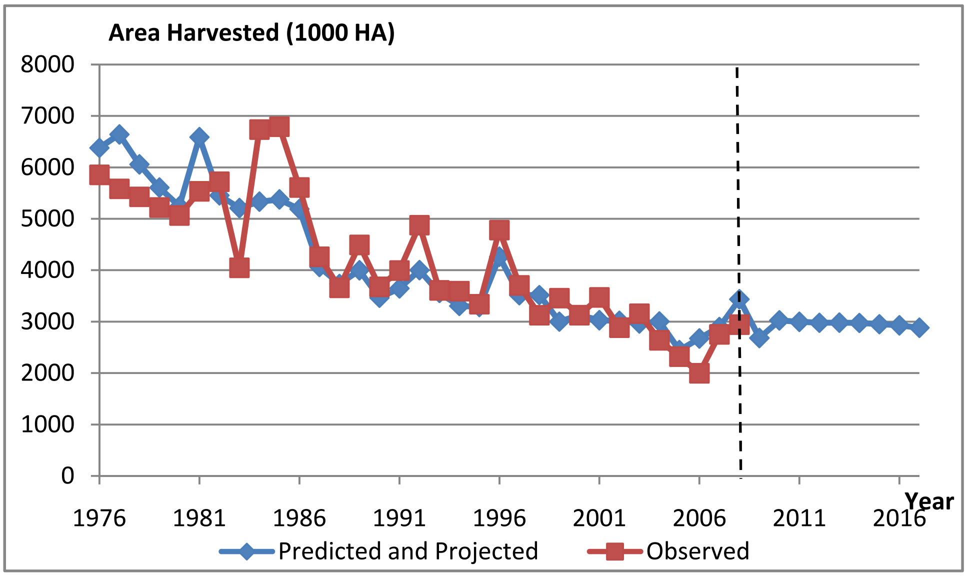

Figure 1. Observed vs. Predicted and Baseline Projected Values of U.S. Sorghum Area Harvested

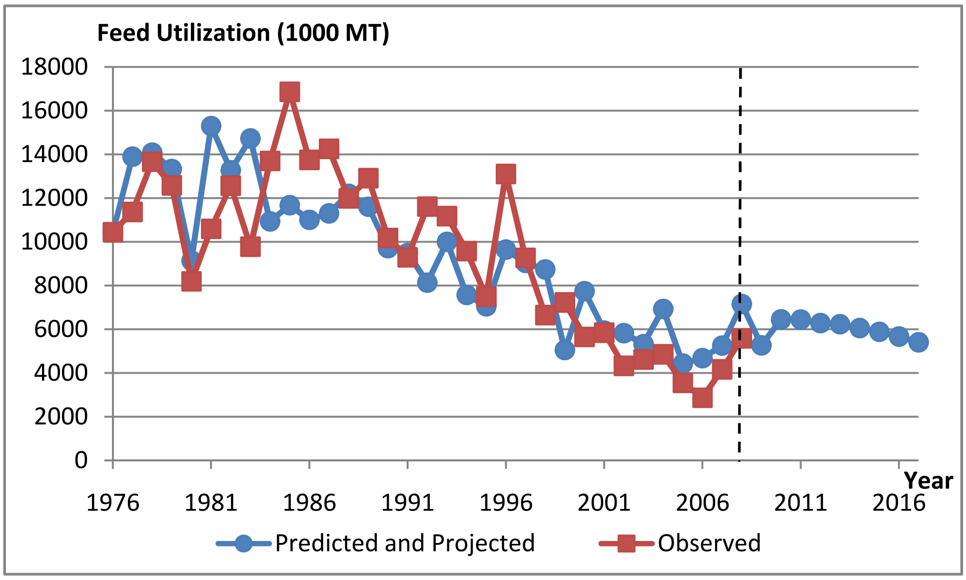

Figure 2. Observed vs. Predicted and Baseline Projected Values of U.S. Sorghum Feed Use

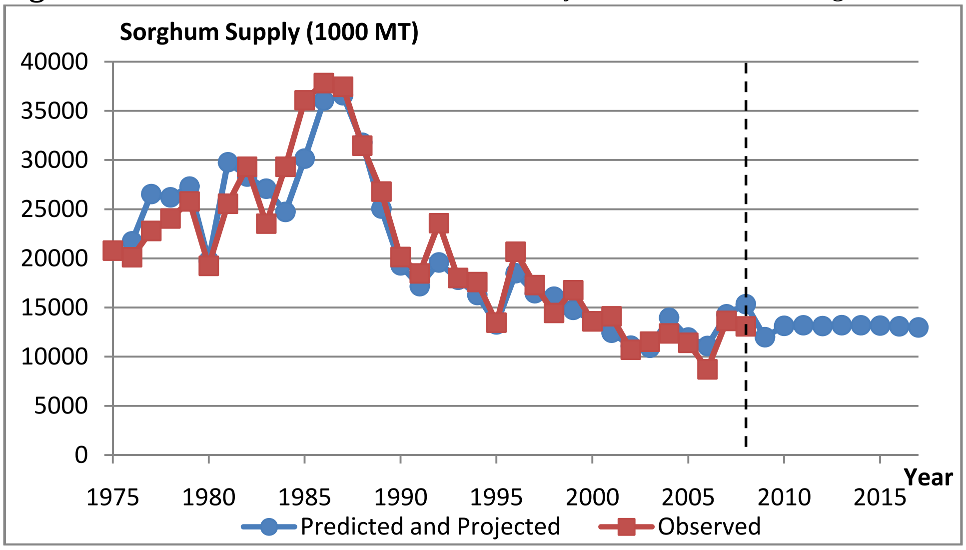

Figure 3. Observed vs. Predicted and Baseline Projected Values of Total U.S. Sorghum Supply

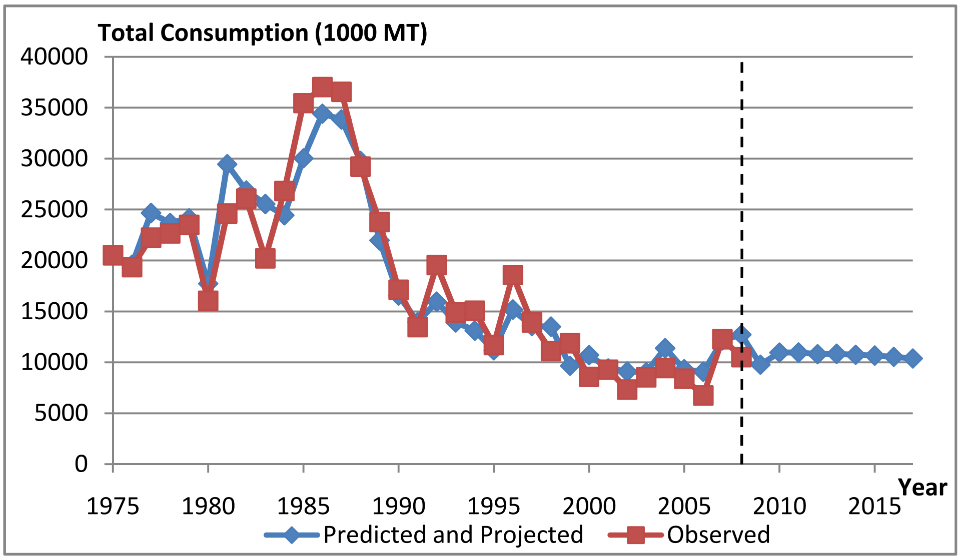

Figure 4. Observed vs. Predicted and Baseline Projected Values of Total U.S. Sorghum Consumption

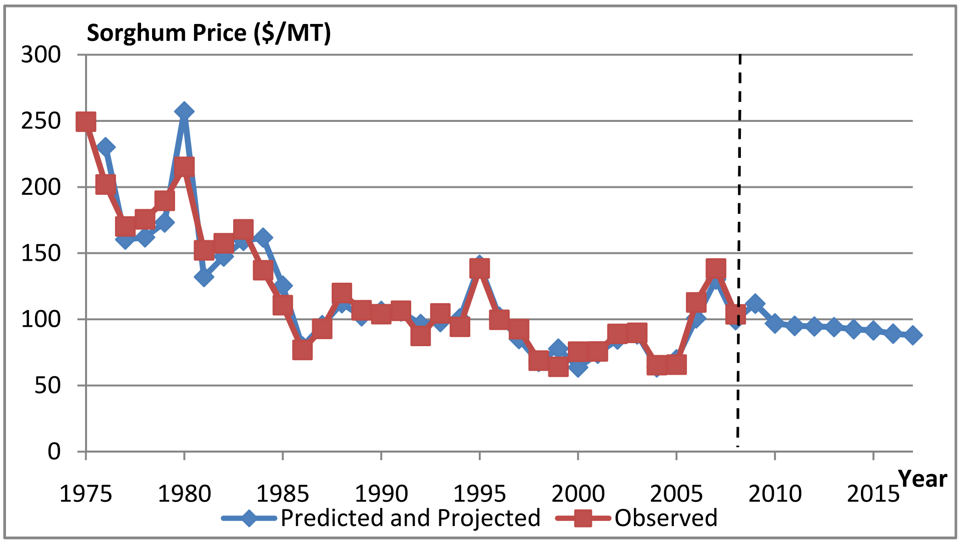

Figure 5. Observed vs. Predicted and Baseline Projected Values of U.S. Real Sorghum Prices

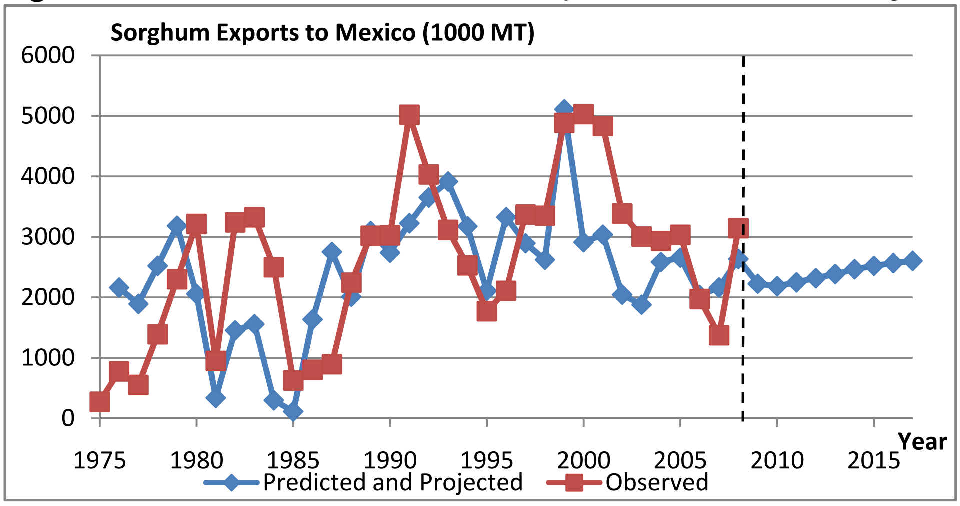

Figure 6. Observed vs. Predicted and Baseline Projected Values of U.S. Sorghum Exports to Mexico

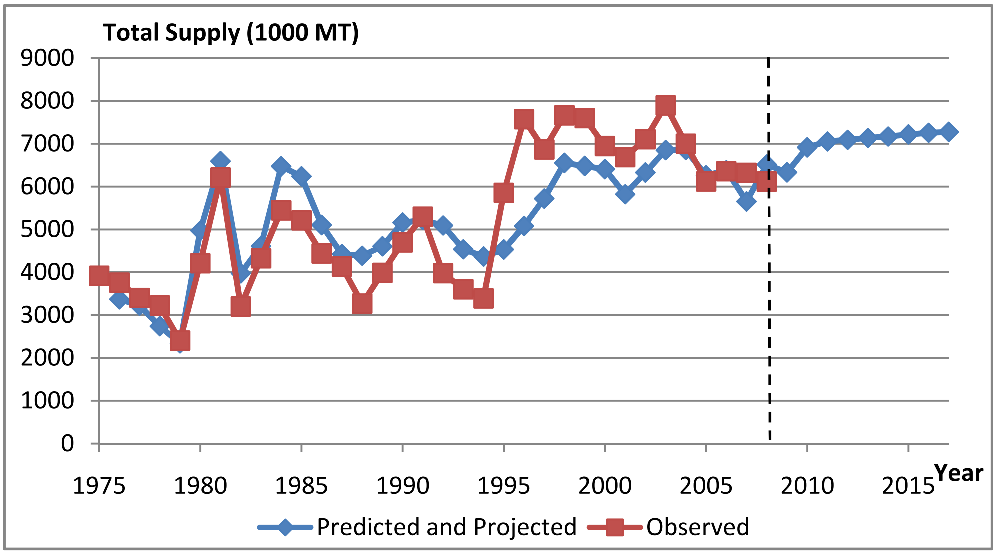

Figure 7. Observed vs. Predicted and Baseline Projected Values of Total Mexican Sorghum Supply

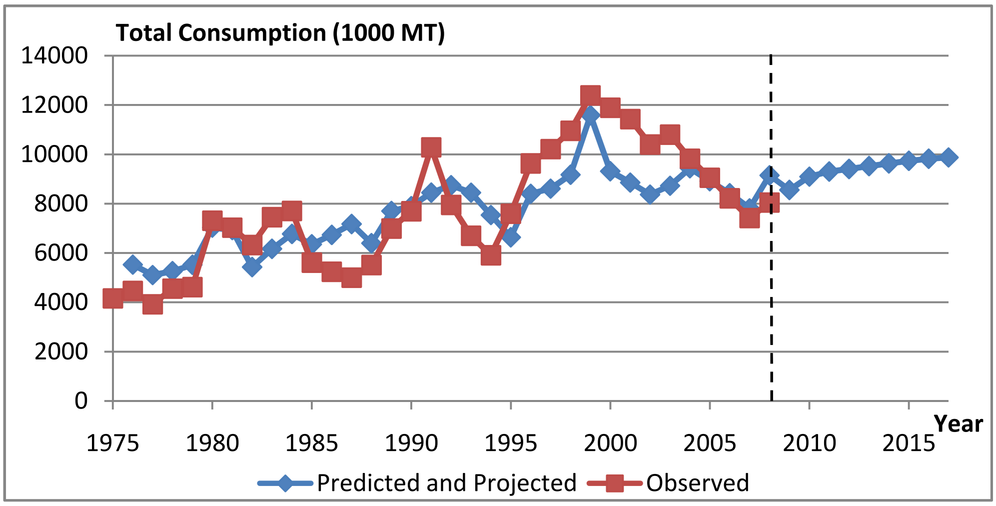

Figure 8. Observed vs. Predicted and Baseline Projected Values of Total Mexican Sorghum Consumption

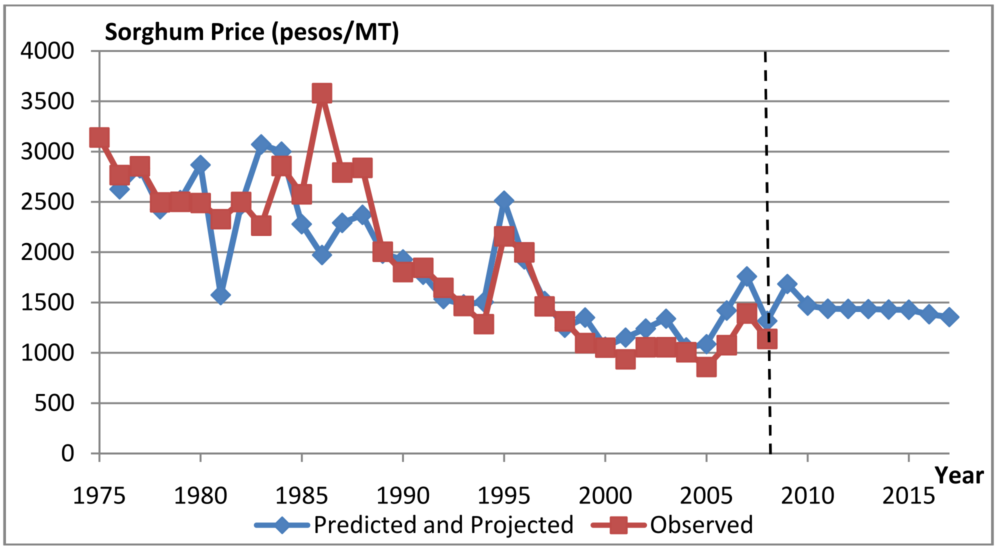

Figure 9. Observed vs. Predicted and Baseline Projected Values of Mexican Real Sorghum Price

Table 6. Baseline and Forecasts of U.S. Sorghum Supply, Exports to Mexico and Price under different scenarios

Variables	Scenarios	2009	2010	2011	2012	2013	2014	2015	2016	2017
U.S. Sorghum Supply (1000 MT)	**Baseline**	**11994.32**	**13147.58**	**13203.41**	**13135.01**	**13235.39**	**13233.71**	**13207.86**	**13141.38**	**13028.27**
	10% *above* the FAPRI U.S. corn price projection	11994.32 (0)	14064.52 (7.0%)	14075.63 (6.6%)	14043.85 (6.9%)	14170.67 (7.1%)	14178.34 (7.1%)	14159.33 (7.2%)	14094.81(7.3%)	13981.70 (7.3%)
	10% *below* the FAPRI U.S. corn price projection	11994.32 (0)	12230.64 (-7.0%)	12241.96 (-7.3%)	12128.84 (-7.7%)	12194.32 (-7.9%)	12177.33 (-8.0%)	12141.85 (-8.1%)	12071.89 (-8.1%)	11958.54 (-8.2%)
U.S. Sorghum Exports to Mexico (1000 MT)	**Baseline**	**2225.27**	**2180.56**	**2267.86**	**2352.51**	**2431.90**	**2520.00**	**2586.45**	**2637.65**	**2685.12**
	10% *above*	2290.02 (2.9%)	2419.59 (11.0%)	2519.24 (11.1%)	2620.07 (11.4%)	2710.01 (11.4%)	2802.36 (11.2%)	2872.17 (11.0%)	2926.67 (11.0%)	2977.23 (10.9%)
	10% *below*	2146.14 (-3.6%)	1926.07 (-11.7%)	1984.27 (-12.5%)	2049.18 (-12.9%)	2115.31 (-13.0%)	2197.34 (-12.8%)	2259.38 (-12.6%)	2306.16 (-12.6%)	2349.78 (-12.5%)
U.S Sorghum Price($/MT)	**Baseline**	**111.85**	**96.91**	**95.10**	**94.64**	**94.15**	**92.51**	**91.61**	**89.11**	**88.00**
	10% *above*	123.60 (10.5%)	100.90 (4.1%)	99.64 (4.8%)	99.01 (4.6%)	98.35 (4.5%)	96.63 (4.5%)	95.69 (4.5%)	93.13 (4.5%)	92.06 (4.6%)
	10% *below*	100.10 (-10.5%)	91.74 (-5.3%)	90.34 (-5.0%)	90.08 (-4.8%)	89.80 (-4.6%)	88.29 (-4.6%)	87.48 (-4.5%)	85.08 (-4.5%)	84.00 (-4.5%)
U.S. Sorghum Supply (1000 MT)	10% *higher* poultry production	11994.32 (0)	13429.71 (2.1%)	13514.46 (2.4%)	13471.10 (2.6%)	13588.96 (2.7%)	13599.59 (2.8%)	13582.34 (2.8%)	13523.01 (2.9%)	13414.94 (3.0%)
	10% *lower* poultry production	11994.32 (0)	12865.45 (-2.1%)	12892.37 (-2.4%)	12798.92 (-2.6%)	12881.83 (-2.7%)	12867.83 (-2.8%)	12833.39 (-2.8%)	12759.76 (-2.9%)	12641.60 (-3.0%)
U.S. Sorghum Exports (1000 MT)	10% *higher*	2678.11 (20.3%)	2696.25 (23.6%)	2808.83 (23.9%)	2911.19 (23.8%)	3004.08 (23.5%)	3104.60 (23.2%)	3182.82 (23.1%)	3245.28 (23.0%)	3303.59 (23.0%)
	10% *lower*	1772.43 (-20.3%)	1664.88 (-23.6%)	1726.90 (-23.9%)	1793.83 (-23.8%)	1859.72 (-23.5%)	1935.40 (-23.2%)	1990.08 (-23.1%)	2030.02 (-23.0%)	2066.66 (-23.0%)

U.S Sorghum Price($/MT)	10% *higher*	115.47 (3.2%)	98.67 (1.8%)	97.00 (2.0%)	96.49 (2.0%)	94.32 (1.9%)	94.30 (2.0%)	93.44 (2.0%)	90.93 (2.0%)	89.86 (2.1%)
	10% *lower*	108.23 (-3.2%)	95.11 (-1.9%)	93.53 (-1.7%)	93.15 (-1.6%)	92.70 (-1.5%)	91.10 (-1.5%)	90.22 (-1.5%)	87.75 (-1.5%)	86.66 (-1.5%)
U.S. Sorghum Supply (1000 MT)	5% annual increase in U.S. Sorghum Yield	11741.63 (-2.1%)	14320.28 (8.9%)	14472.74 (9.6%)	14701.69 (11.9%)	15046.32 (13.7%)	15310.11 (15.7%)	15487.51 (17.3%)	15676.69 (19.3%)	15739.29 (20.8%)
U.S. Sorghum Exports (1000 MT)	5% annual increase	2366.02 (6.3%)	2411.69 (10.6%)	2579.63 (13.7%)	2761.38 (17.4%)	2919.95 (20.1%)	3089.96 (22.6%)	3224.35 (24.7%)	3353.38 (27.1%)	3458.47 (28.8%)
U.S Sorghum Price($/MT)	5% annual increase	115.79 (3.5%)	90.43 (-6.7%)	88.76 (-6.7%)	86.90 (-8.2%)	85.23 (-9.5%)	82.46 (-10.9%)	80.72 (-11.9%)	77.33 (-13.2%)	75.63 (-14.1%)
U.S. Sorghum Supply (1000 MT)	5% annual *increase* of sorghum demand from ROW	11994.32 (0)	13147.58 (0)	13296.31 (0.7%)	13258.24 (0.9%)	13440.82 (1.6%)	13502.13 (2.0%)	13563.10 (2.7%)	13572.14 (3.3%)	13543.22 (4.0%)
	5% annual *decrease* of sorghum demand from ROW	11994.32 (0)	13147.58 (0)	13173.33 (-0.2%)	12998.37 (-1.0%)	13035.23 (-1.5%)	12944.87 (-2.2%)	12855.40 (-2.7%)	12712.43 (-3.3%)	12535.61 (-3.8%)
U.S. Sorghum Exports (1000 MT)	5% annual *increase*	2225.27 (0)	2125.01 (-2.5%)	2218.17 (-2.2%)	2266.10 (-3.7%)	2332.76 (-4.1%)	2389.79 (-5.2%)	2437.61 (-5.8%)	2461.35 (-6.7%)	2494.71 (-7.1%)
	5% annual *decrease*	2225.27 (0)	2198.55 (0.8%)	2341.89 (3.3%)	2435.51 (3.5%)	2545.56 (4.7%)	2643.75 (4.9%)	2734.14 (5.7%)	2800.14 (6.2%)	2877.16 (7.2%)
U.S Sorghum Price($/MT)	5% annual *increase*	111.85 (0)	98.07 (1.2%)	96.11 (1.1%)	96.42 (1.9%)	96.07 (2.0%)	94.98 (2.7%)	94.33 (3.0%)	92.23 (3.5%)	91.28 (3.7%)
	5% annual *decrease*	111.85 (0)	96.50 (-0.4%)	93.76 (-1.4%)	93.35 (-1.4%)	92.30 (-2.0%)	90.62 (-2.0%)	89.34 (-2.5%)	86.72 (-2.7%)	85.16 (-3.2%)
U.S. Sorghum Supply (1000 MT)	Increasing demand from U.S. ethanol industry	11994.32 (0)	13696.16 (4.2%)	13809.32 (4.6%)	13801.20 (5.1%)	13926.45 (5.2%)	13920.56 (5.2%)	13862.87 (11.6%)	13769.54 (5.0%)	13624.57 (4.8%)
U.S. Sorghum Exports (1000 MT)	Increasing demand	1911.77 (-14.1%)	1959.53 (-10.1%)	2054.54 (-9.4%)	2156.63 (-8.3%)	2255.46 (-7.3%)	2366.99 (-6.1%)	2442.21 (-5.6%)	2503.30 (-5.1%)	2554.51 (-4.9%)

U.S Sorghum Price($/MT)	Increasing demand	118.88 (6.3%)	100.36 (3.6%)	98.79 (3.9%)	98.01 (3.6%)	97.19 (3.2%)	95.10 (2.8%)	94.10 (2.7%)	91.40 (2.6%)	90.26 (2.6%)