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U.S. DEPARTMENT OF AGRICULTURE

Economic Research Service

Economic Research Report Number 327

November 2023

Producer Supply Response for Area Planted of Seven Major U.S. Crops

Brian R. Williams and Gayle Pounds-Barnett









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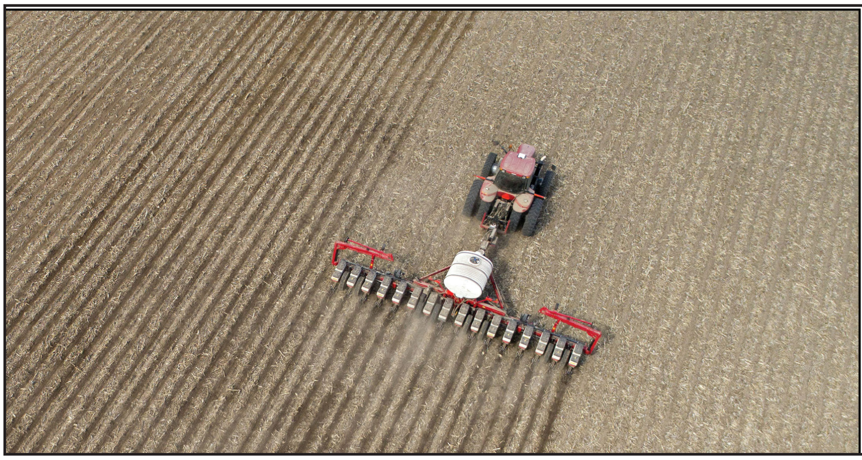

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Abstract

The U.S. Department of Agriculture's (USDA) Agricultural Baseline provides a 10-year outlook for seven major U.S. crops (corn, soybeans, wheat, sorghum, barley, oats, and cotton). The baseline plays an important role in predicting farm program expenditures in the President's annual budget proposal. To provide the best possible projections, it is necessary to frequently revisit the underlying models behind the baseline to ensure that they are theoretically consistent and produce realistic projections. This study examined the performance of the existing area planted equations for seven major U.S. crops in the baseline model relative to observed historical area planted values. It subsequently estimates a system of equations for the crops to produce price consistent supply (i.e., higher price increases the supply of the crop associated with higher prices but decreases other crop supplies). Projections created from the resulting price and net return elasticities are shown to be an improvement over the existing U.S. baseline equations.

Keywords: Supply response, program crops, area planted, crop price elasticities, seemingly unrelated regression, corn, soybeans, wheat, sorghum, barley, oats, cotton

About the Authors

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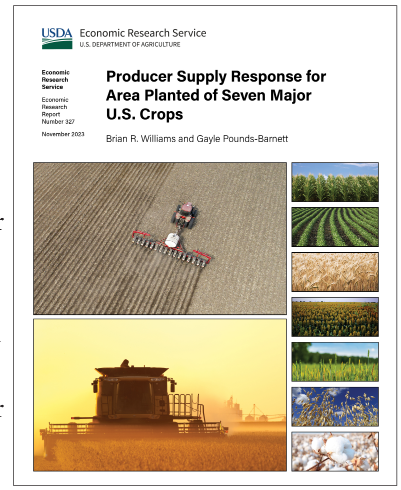

What Is the Issue?

Numerous studies have examined the accuracy of USDA projections, some of which looked at short-term projections, while others focused on longer term baseline projections. Recent studies evaluating the Agricultural Baseline's 10-year projections for U.S. harvested area show that wheat area harvested is frequently overestimated while soybean area is consistently underestimated. The researchers found that a simple time-series forecast improves baseline projections that extend beyond the first 3 years of the 10-year projections. Given the findings from prior research, significant potential exists for improvement in the underlying model for the USDA Agricultural Baseline's area planted projections. Updating the model with theoretically consistent estimations of own- and cross-price supply elasticities will provide a strong foundation for future USDA Agricultural Baseline modeling efforts.

What Did the Study Find?

Elasticities with respect to net returns and price for each crop as well as competing crops are estimated for area planted of seven major U.S. program crops—corn, soybeans, wheat, sorghum, barley, oats, and cotton. Each of the own-net returns elasticities (defined as percent change in area planted with a 1-percent increase in net returns) shares a positive sign while each of the cross-elasticities (the percent change in area planted of one crop with a 1-percent change in net returns for a competing crop) share a negative sign for all variables.

- Own- and cross-price elasticities are calculated from the elasticities with respect to net returns. The own-price elasticity for corn area planted is estimated to be 0.210. A 1-percent increase in soybean price will yield a 0.192-percent increase in soybean area planted while the own-price elasticity for wheat is 0.217.

- Each of the cross-price elasticities for area planted is negative. A 1-percent increase in soybean prices is associated with a decrease of 0.115 percent in corn area planted while a 1-percent increase in wheat prices reduces corn area planted by 0.013 percent. Similarly, a 1-percent increase in the price of corn will result in a 0.107-percent decline in projected soybean area planted while a 1-percent decrease in the price of wheat and sorghum will result in decreases of 0.125 and 0.148 percent in soybean area planted. Overall, when forecasted values using the reestimated results are compared with the existing baseline model, the elasticities estimated in this study represent an improvement in the accuracy of the projections.

ERS is a primary source of economic research and analysis from the U.S. Department of Agriculture, providing timely information on economic and policy issues related to agriculture, food, the environment, and rural America.

How Was the Study Conducted?

This study used national-level data from 1996 to 2021 to estimate a national supply response for seven major U.S. program crops using a seemingly unrelated regression in which the share of total area planted is estimated as a function of net returns. Results are used to calculate own- and cross-price elasticities. Yield data for each of the crops are collected from the USDA, Foreign Agricultural Service's Production Supply and Distribution (PSD) data portal. Planted area and producer price received data are collected from USDA, National Agricultural Statistics Service. Data on variable cost of production are collected from the USDA, Economic Research Service (ERS) Commodity Cost and Return Estimates.

Producer Supply Response for Area Planted of Seven Major U.S. Crops

Introduction

The U.S. Department of Agriculture's (USDA) Agricultural Baseline is a 10-year outlook for major crops and livestock commodities. Among the projections in the baseline are variables related to production, trade, and demand. The U.S. baseline projections play an important role in estimating farm program expenditures in the President's annual budget proposal and also can be used to support domestic and international marketing decisions throughout the agribusiness supply chain (Williams et al., 2022). Numerous studies have examined the accuracy of USDA projections, including Egelkraut et al. (2003); Isengildina et al. (2004); Irwin & Good (2004); Good & Irwin (2006); Irwin & Good (2015); Boussios et al. (2021); and MacLachlan (2021). Some, such as Egelkraut et al. (2003); Isengildina et al. (2004); and Good & Irwin (2006) looked at USDA's short-term projections, while others such as Irwin & Good (2015) and Boussios et al. (2021) focused on longer term baseline projections. More specifically, Boussios et al. (2021) evaluated the Agricultural Baseline's 10-year projections for U.S. harvested area. Their study showed wheat area harvested was frequently overestimated while soybean area was consistently underestimated. Corn area was also underestimated, but not as much as soybean area. They also found that a time-series forecast improved baseline projections beyond the first 3-year horizon for wheat and soybeans but was less successful at improving corn projections.

As Boussios et al. (2021) showed, potential exists for improvement in the USDA Agricultural Baseline's projections for area planted. The authors reexamined the current U.S. baseline model for projecting planted area and estimated the model as a function of net returns. An improved underlying model behind the USDA Agricultural Baseline projections using estimations of own- and cross-price supply elasticities provides a theoretically consistent starting point for the baseline process.

Many of the existing estimates for the supply response for row crops were estimated long ago. Most notably, Chavas and Holt (1990) estimated producer acreage allocation decisions under an expected-utility maximization framework for corn and soybeans while Lin et al. (2000) estimated the response of planted acreage to price changes under the 1996 Farm Bill. Prior to 1996, planting decisions were heavily influenced by agricultural policy and commodity programs. However, since 1996, farm bills largely decoupled farm payments from producer planting decisions. As a result, producers base planting decisions on markets rather than policy.

Prior to the 1996 Farm Bill, producer decisions were heavily swayed by farm policy; however, the bill removed most planting restrictions. The exception was a program called normal flex acreage (NFA). As part of the 1990 Farm Bill, NFA allowed producers to grow any approved crop on up to 15 percent of their base acreage; a system in which decisions are market-based rather than policy-driven. Lin et al. (2000) used a limited set of data to understand producers' planting decisions from 1991 to 1995 based upon NFA. Using State-level planting decision data from the NFA, Lin et al. (2000) estimated regional own- and cross-price elasticities for seven major field crops as a function of net returns.

The agricultural industry underwent numerous structural changes since the passage of the 1996 Farm Bill. Acreage for crops such as soybeans increased steadily during the last three decades, while other crops such as wheat experienced steady acreage declines. The advent of biofuels substantially increased demand for corn and a subsequent upward shift in prices of many program crops. Biofuel byproducts such as distiller's grains caused structural changes among feed grains. These major structural changes presented a need for an updated study on the land allocation decisions modern producers made.

A number of studies examined producer land allocation decisions since the passage of the 1996 Farm Bill, but none looked at more than a few of the program crops in their analysis. Huang and Khanna (2010) looked at the implications of climate change on U.S. crop yield and area planted for corn, soybeans, and wheat while controlling for climate change and socioeconomic factors. Similarly, Lin and Dismukes (2007) estimated an acreage supply response under risk for corn, soybeans, and wheat and then used their results to investigate the implications of countercyclical payments on area planted. Lin and Dismukes (2007) also focused their research on the North Central U.S. region rather than the entire country.

While several researchers looked at acreage response to price and net returns, a need exists for a more comprehensive look at a broader subset of crops. This report builds upon the work of Lin et al. (2000) by updating their estimates of the supply response for seven major U.S. program crops while using data on area planted from 1996 to 2021. That was an era in U.S. agriculture when producer planting decisions were less susceptible to policy influence and more driven by market conditions.

The U.S. Baseline Model

Three sets of Agricultural Baseline projections are released each year: the USDA; the Food and Agricultural Policy Research Institute (FAPRI); and the Organisation for Economic Co-operation and Development's Food and Agriculture Organization (OECD-FAO).

The USDA's International Baseline projections provide information on the supply, demand, and trade for major agricultural commodities for major exporting and importing countries and regions. The projections are based upon specific macroeconomic assumptions, normal weather, and no domestic or external policy shocks to the agricultural markets.[1] The USDA baseline models incorporate a partial-equilibrium model with judgment-based estimates from an interagency committee that spans USDA agencies. The United States is among the 44 country-specific models included in the international baseline which includes information on the supply and demand of 7 major program crops in addition to livestock products. Among the supply-side variables for the crops included in the U.S. model are area planted, area harvested, yield, production, and stocks.[2] Like the USDA, FAPRI also uses a partial equilibrium model to construct 10-year baseline projections. Public documentation is limited; however, FAPRI releases an annual report[3] that includes model, policy, macroeconomic, and other assumptions. The OECD-FAO also releases an annual Agricultural Outlook that consists of a combination of expert judgment and the Aglink-Cosimo modeling framework. Aglink-Cosimo is a partial equilibrium model that "simulates market balances and prices"[4] for regional and global models.

The current USDA, U.S. Baseline model estimates planted area as a function of lagged planted area for each of the previous 3 years, the current year's prices for each respective crop and competing crops, and 2 years of lagged price for each respective crop (y) and competing crops (x) (see equation 1 in appendix).

In some of the first research to investigate the supply response to crop prices, Nerlove (1956) found that a producer's expectations of prices influences planting decisions. Nerlove further argued that a farmer's price

[1] For more information see the International Baseline Documentation found online.

[2] See Hjort et al., 2018 for more information on the United States and other country-specific baseline modeling.

[3] The most recent FAPRI report can be found online.

[4] More information on OECD-FAO's modeling process can be found online.

expectation was not based solely on the previous year's price, but included expectation and adjustment coefficients based upon the farmer's perceived error in price forecasting, also known as the Nerlovian Model. The existing area planted projections are based upon an adaption of the Nerlovian Model. However, when most crop planting decisions are made, the price for that crop and competing crops is unknown. This is a deviation from the theoretical framework laid out by Nerlove (1956). The prices used are the producer price received for the crop being planted, which are unknown until after the crop is harvested. As a result, it would theoretically be incorrect for area planted to be a function of unknown prices at planting time. Figures 1, 2, and 3 show the existing baseline equations consistently over project the area planted for corn and soybeans and consistently under project the area planted for wheat.[5] Given the consistent over projection for corn and soybeans and consistent under projection for wheat, potential exists for a marked improvement in the equation systems from the U.S. baseline model.

Theoretical Framework

Farmers operate in a competitive market and choose among a variety of inputs and outputs to maximize expected net returns. According to Varian (1992) farmers follow a profit maximizing function in which a firm's net returns, or profit, is defined as the difference between revenue and costs. The resulting profit function takes the form shown in equation 2, where y is a vector of outputs, x is a vector of inputs, p_i is the expected price of crop i, y_i is the quantity of crop i, w_j is the price of input j, and x_j is the quantity of input j. The producer will maximize profits subject to the production constraints, giving a Lagrangian function[6] shown in equation 3.

Maximizing and solving the Lagrangian function results in the profit maximizing solutions shown in equations 4 and 5 in the appendix.

The optimal solutions for equations 4 and 5 indicate that planting decisions for each crop are influenced not only by the crop's own prices and input costs, but also by the prices and input costs of competing crops.

Empirical Model

This study used national-level data from 1996 to 2021 to estimate a national supply response for seven major U.S. program crops. Yield data for each of the crops are collected from the USDA, Foreign Agricultural Service's Production Supply and Distribution (PSD) data portal; planted area and producer price received are collected from USDA, National Agricultural Statistics Service. Data on variable cost of production are collected from the USDA, Economic Research Service's (ERS) Commodity Cost and Return Estimates. Prices and variable costs are deflated using the consumer price index with a base year of 2005.

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[5] The projections for "Current Baseline Model" in figures 1–3 are calculated using the underlying equations from the U.S. Baseline model and do not include input from the Interagency Agricultural Projection Committee (IAPC).

[6] A Lagrangian function is a method used to solve optimization problems by combining the maximization problem and constraints into one equation by including a multiplier. In this case, the multiplier is symbolized by .

Following Lin et al. (2000), a producer's expected net returns are the product of expected yield and expected price minus the expected variable cost. A producer's expected price is defined as the lagged real price for each respective crop while expected yield is calculated as a trend yield. Expected variable costs are the inflation-adjusted lagged costs reported in the USDA, ERS Commodity Cost and Returns Estimates.[7] Shares are calculated as the area planted divided by the sum of the area planted for each of the seven crops in this study.

Table 1 presents summary statistics of endogenous (shares of planted acreage) and exogenous (net returns and prices) variables. Several small differences are noted between each crop's share of area planted and the share of area harvested. Corn makes up the largest share of all area planted with 34.8 percent, followed by soybeans with 31.2 percent. Wheat has the third largest share of all area planted with 22.8 percent. The remaining four crops—sorghum, barley, oats, and cotton—each account for 5 percent or less.

Expected net returns are highly variable between the crops in the study as well as between years. Corn has the highest mean expected net return with a U.S. average of $604.17 per hectare[8] over the study period, followed by sorghum and soybeans. Oats has the lowest expected net return with producers expecting an average of $111.89 per hectare during the study period. Additional information on operating costs for each crop can be found in figures A.5 and A.6 and a graphical representation of net returns over time can be found in figure A.7.

Table 1

Descriptive statistics for share, net returns, and price for seven U.S. program crops

	Mean			
Commodity	**Share of area planted (percent)**	**Mean area planted (thousand hectares)**	**Net return (U.S. dollars/hectare)**	**Real price (U.S. dollars/metric ton)**
Corn	34.8	34,775	$604.17	$121.89
Soybean	31.2	31,102	$544.89	$280.06
Wheat	22.8	23,139	$241.62	$155.86
Sorghum	3.0	3,127	$589.26	$115.86
Barley	1.6	1,209	$297.41	$160.56
Oats	1.4	1,465	$111.89	$141.77
Cotton	5.1	5,140	$222.54	$1,258.25

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Acreage response is estimated as a system of equations where the dependent variable is the percentage of total acreage planted to each crop; the independent variables are the expected net returns for each crop as well as the expected net returns for competing crops. Equation 6 shows where S_y is the percent of total area planted to crop y, NR_y is the expected net return for crop y, NR_x is the expected net return for crop x, and a_y and b_{yx} are coefficients to be estimated. The coefficient byx can be interpreted as the change in the share of crop y with a change in the expected net return for crop x.

[7] Variable costs include cash expenditures on seed, fertilizer, chemicals, custom services, fuel, repairs, irrigation costs, and hired labor. They are calculated using the reported total operating cost plus hired labor costs and subtracting interest on operating capital. For more detailed information, see the ERS Commodity Cost and Returns Estimates documentation found online.

[8] Metric units are used to remain consistent with units used in the USDA Agricultural Baseline as well as in the USDA PSD database.

As outlined by Barten and Vanloot (1996) and Lin et al. (2000), symmetry constraints are imposed on the estimation such that the change in the share of crop *x* with a one-unit change in the net returns of crop *y* is equal to the change in the share of crop *y* with a one-unit change in the net returns of crop *x*. This is specifically defined in equation 7 in the appendix.

In addition, linear homogeneity constraints or adding-up conditions are imposed so that the sum of all coefficients across a crop sum to zero as shown in equation 8. This constraint is imposed so that an equal percent change in net returns for two competing crops does not change the share of each crop's planted area.

Following Lin et al. (2000), a seemingly unrelated regression model is used to estimate the parameters. The resulting coefficients can then be transformed into elasticities with respect to net returns and price elasticities. The elasticities with respect to net returns are calculated as shown in equation 9, where γ_{yx} is the percent change in the share (or area) of crop *x* with a percent change in the net returns of crop *y*, δ_y is the mean share of crop *y*, and π_x is the mean net return for crop *x*.

The price elasticity can be calculated from the elasticity with respect to net returns using a regression analysis with the log of net returns as the dependent variable and the log of price as the independent variable as shown in equation 10. The resulting coefficient gives the percent change in net returns with a 1-percent change in price.

The price elasticity can then be calculated as the product of the elasticity with respect to net returns and the regression coefficient for the respective crop as shown in appendix equation 11. An out-of-sample prediction was used to test the fit of the model. The model described was reestimated while omitting 1 year of data. The omitted year was then combined with that year's actual data to predict area planted. This out-of-sample prediction was conducted for each year from 2017 to 2021.

Findings

Elasticities with respect to net returns for each crop as well as competing crops were estimated for area planted of seven major program crops in the United States. Each of the own-net returns elasticities share a positive sign while each of the cross-elasticities share a negative sign for all variables. As shown in table 2, the elasticity with respect to net returns for corn area planted is estimated to be 0.127, meaning that a 1-percent increase in net returns for corn will result in a 0.127-percent increase in corn area planted. A 1-percent increase in net returns for soybeans will result in a 0.134-percent increase in soybean area planted while the own-net return elasticity for wheat area planted is 0.139. Barley has the highest own-elasticity with respect to net returns with a 0.987-percent increase in barley area planted with a 1-percent increase in barley net returns. Sorghum follows with an own-elasticity of 0.406 for area planted. Oats and cotton round out the remaining U.S. program crops estimated with own-net returns elasticities of 0.326 and 0.067, respectively, for area planted.

The estimated elasticities with respect to net returns show that U.S. corn area planted will decrease by 0.080 percent with a 1-percent increase in soybean net returns while a 1-percent increase in wheat net returns will reduce corn area planted by 0.008 percent, holding everything else constant. Similarly, a 1-percent increase in sorghum net returns will reduce corn area planted by 0.301 percent and a 1-percent increase in cotton net returns will decrease corn area planted by 0.161 percent.

Table 2
Area planted elasticity of net return for seven U.S. program crops

	Elasticity with respect to a 1-percent increase in the net returns						
Commodity	Corn	Soybean	Wheat	Sorghum	Barley	Oats	Cotton
Corn	0.127	-0.080	-0.008	-0.301	–	–	-0.161
Soybean	-0.065	0.134	-0.080	-0.104	–	–	-0.019
Wheat	-0.002	-0.026	0.139	–	-0.802	-0.704	-0.022
Sorghum	-0.026	–	–	0.406	–	–	–
Barley	–	–	-0.069	–	0.987	–	–
Oats	–	–	-0.021	–	–	0.326	–
Cotton	-0.009	-0.001	-0.005	–	–	–	0.067

Note: Cross elasticities that are left blank were not estimated due to minimal overlap between crop areas of the two crops.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Own- and cross-price elasticities are calculated from the elasticities with respect to net returns as described above. As shown in table 3, all elasticities for area planted are inelastic, with barley the sole exception. The own-price elasticity for corn area planted is estimated to be 0.210, meaning that a 1-percent increase in corn price will result in a 0.210-percent increase in corn area planted. This is higher than the own-price elasticities of 0.160 and 0.170 found by Chavas and Holt (1990), and Lin and Dismukes (2007), respectively; but lower than the reported elasticity of 0.293 estimated by Lin et al. (2000) and 0.510 estimated by Huang and Khanna (2010) as shown in table 5. A 1-percent increase in soybean price will yield a 0.192-percent increase in soybean area planted, which is lower than estimates of 0.269 found by Lin et al. (2000); 0.450 found by Chavas and Holt (1990); 0.300 found by Lin and Dismukes (2007); and 0.487 found by Huang and Khanna (2010). The own-price elasticity for wheat is 0.217, which is lower than the 0.340 elasticity reported by Lin et al. (2000), Westcott et al. (2000), and 0.250 reported by Lin and Dismukes (2007) but higher than that reported by Huang and Khanna (2010). Barley has the highest own-price elasticity at 1.651 while sorghum has an own-price elasticity of 0.576. A 1-percent increase in the price of oats will result in a 0.695-percent increase in oats area planted while a 1-percent increase in cotton prices is estimated to increase cotton area planted by 0.155 percent. The own-price elasticity for cotton represents the second largest deviation in elasticity from Lin et al. (2000), with their cotton elasticity three times higher than the estimate found in this research.

Each of the cross-price elasticities for area planted is negative. A 1-percent increase in soybean prices is associated with a decrease of 0.115 percent in corn area planted; a 1-percent increase in wheat prices will reduce corn area planted by 0.013 percent. Similarly, a 1-percent increase in the price of corn will result in a 0.107-percent decline in projected soybean area planted; a 1-percent decrease in the price of wheat and sorghum will result in decreases of 0.125 and 0.148 percent, respectively, in soybean area planted. Changes in the price of corn have only a small impact on wheat area planted with a cross-price elasticity of -0.004; 1-percent increases in soybean and cotton prices will reduce wheat area planted by 0.037 and 0.051 percent, respectively. Table 4 shows a 1-percent increase in the price of corn will reduce sorghum area planted by 0.042 percent. A 1-percent increase in the price of wheat is expected to reduce oats area planted by 0.032 percent, barley area planted by -0.107 percent, and cotton area planted by 0.007 percent. Cotton area planted is relatively unresponsive to changes in the price of corn and soybeans with cross-price elasticities of -0.014 and -0.002, respectively.

Table 3
Area planted price elasticities for seven U.S. program crops

	Acreage elasticity with respect to a 1-percent change in price						
Commodity	Corn	Soybean	Wheat	Sorghum	Barley	Oats	Cotton
Corn	0.210	-0.115	-0.013	-0.032*	–	–	-0.024*
Soybean	-0.107	0.192	-0.125	-0.008*	–	–	-0.004*
Wheat	-0.004	-0.037	0.217	–	-0.269*	-0.137*	-0.051
Sorghum	-0.042	–	–	0.576	–	–	–
Barley	–	–	-0.107	–	1.651	–	–
Oats	–	–	-0.032	–	–	0.695	–
Cotton	-0.014	-0.002	-0.007	–	–	–	0.155

*Elasticities have been weighted by multiplying the elasticity by the percent of counties in which the two crops have overlapping area.

Note: Cross elasticities that are left blank were not estimated due to minimal overlap between crop areas of the two crops.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Table 4
Area planted own-price elasticities for seven U.S. program crops relative to previous studies

	Acreage own-price elasticity				
Commodity	This study	Lin et al. (2000)	Huang and Khanna (2010)	Chavas and Holt (1990)	Lin and Dismukes (2007)
Corn	0.210	0.293	0.510	0.160	0.170
Soybean	0.192	0.269	0.487	0.450	0.300
Wheat	0.217	0.340	0.067	–	0.250
Sorghum	0.576	0.550	–	–	–
Barley	1.651	0.282	–	–	–
Oats	0.695	0.442	–	–	–
Cotton	0.155	0.466	–	–	–

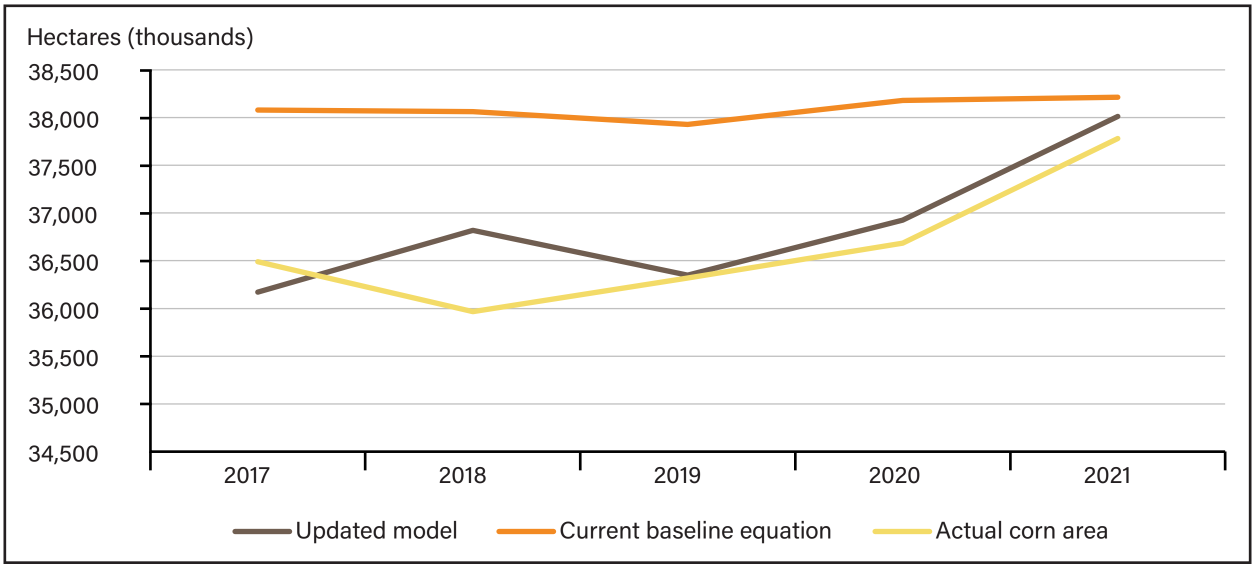
Note: Elasticities that are left blank were not estimated.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

The estimated own- and cross-price elasticities were used to forecast area planted projections for each year where expected prices were assumed to be the previous year's producer price received. For some crops, the area in which two crops overlap and compete with one another for area can be small relative to the total area of that crop. As a result, changes in the prices of crops in which there is little overlap can have a disproportional impact in total area planted. For example, in 2021, 101 counties in the United States had both corn and sorghum planted out of a total of 3,112 counties where at least one of the commodities in this study were grown. Those 101 overlapping counties in which both corn and sorghum were planted accounted for only 7.5 percent of all corn area in the United States. Using this information, weights were created based upon the proportion of area planted that overlaps between the crops at a county level. For the corn and sorghum example, the cross elasticity is weighted by multiplying the cross-price elasticity by 0.075. Using this weighting method, cross-price elasticities for corn with sorghum and cotton, for soybeans with cotton and sorghum, and between wheat and barley and oats are calculated. As shown in figure 1, forecasted or projected corn area planted tracks closely with historical observed values. Forecasted soybean area planted also tracks closely with historical observed values as shown in figure 2. Soybean forecasted values deviate slightly more from observed values than corn or wheat but still follow trends similar to those of the observed historical values.

To test the model fit, the elasticities were reestimated while omitting 1 year of data for each year from 2017 to 2021. These model results are used to create out-of-sample predictions that are then compared to projections made using the existing baseline equation described in equation 1. The projections using the out-of-sample forecasting are included in figures 1–3. Overall, when comparing the forecasted values shown in figures 1, 2, and 3 to the existing baseline model in which corn and soybeans area planted are consistently overestimated and wheat area planted is consistently underestimated, it is apparent that the elasticities estimated in this study represent an improvement in the accuracy of the projections as well as a move toward a model that is theoretically consistent. Appendix figures A.1–A.4 show observed area planted as well as forecasted area planted using elasticities from this research as well as the existing baseline equations for oats, barley, sorghum, and cotton.

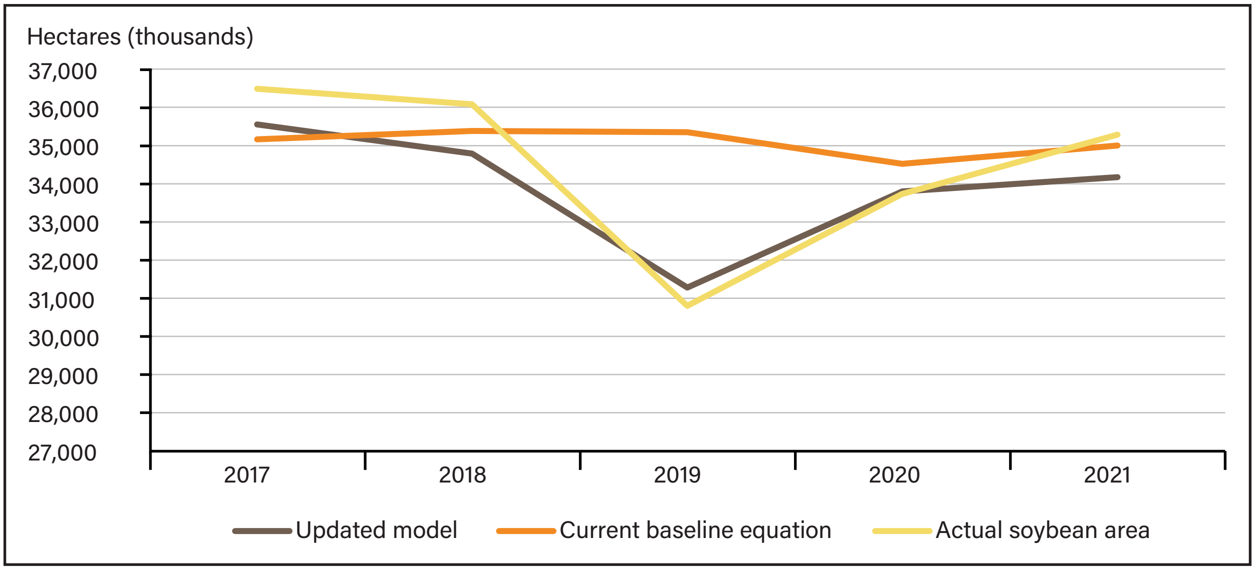
Figure 1
U.S. area planted for corn consistently projected higher than actual area planted



Note: Projections for the updated model are out-of-sample estimates.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

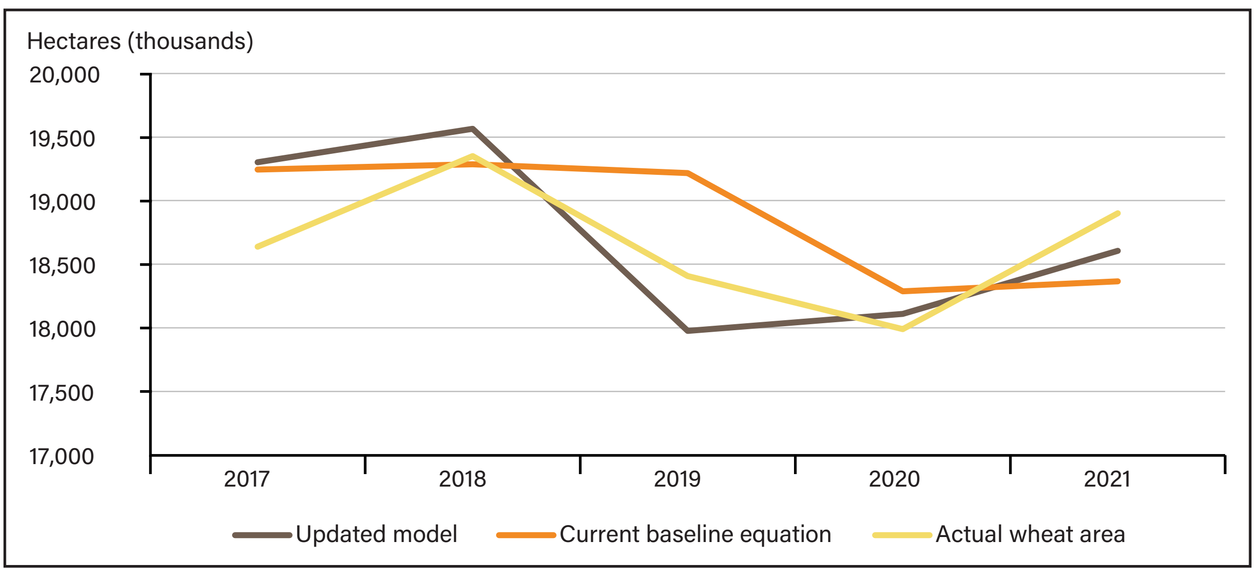
Figure 2
U.S. area planted for soybean consistently projected higher than actual area planted



Note: Projections for the "updated model" are out-of-sample estimates.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Figure 3
U.S. area planted for wheat consistently projected lower than actual area planted

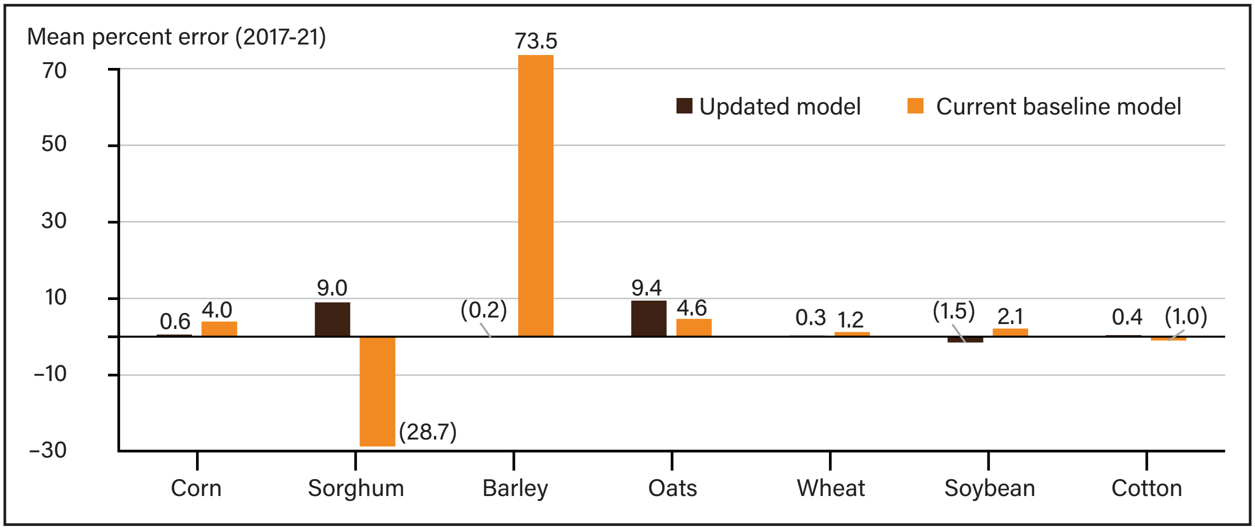


Note: Projections for the "updated model" are out-of-sample estimates.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

In another measure of model fit, the authors calculated the percent difference or error between the out-of-sample projections and the observed values for 2017–21. Figure 4 shows the mean difference between both the updated model and the existing baseline equations and the actual observed area planted for each of the seven crops. With the exception of oats, the updated model represents an improvement over the existing model. Barley has the largest improvement in terms of the mean percent error over the 5-year period, moving from an overestimation of 73.5 percent to a mean underestimation of just 0.2 percent. The mean error for corn is reduced from 4.0 percent to 0.6 percent while the mean error for soybeans is improved from 2.1 percent to -1.5 percent. A detailed breakdown of the error in each year is shown in appendix table A.2.

Figure 4
Mean percent error from 2017 to 2021 for the updated model and the existing baseline equations using out-of-sample forecasting



Note: Out-of-sample forecasts were calculated by reestimating elasticities while omitting 1 year of data for each year from 2017 to 2021. Results are compared to projections made using the existing baseline equations.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Conclusions

The U.S. Department of Agriculture's (USDA) Agricultural Baseline provides a 10-year outlook for major U.S. crops and plays an important role in predicting farm program expenditures in the President's annual budget proposal. This study examines the area planted equations in the U.S. baseline model and estimates a system of equations to produce theoretically consistent own- and cross-price elasticities of supply for seven U.S. crops.

Using national-level data from 1996 to 2021, a national supply response is estimated using a seemingly unrelated regression where the share of total area planted is a function of net returns. Results are used to calculate own- and cross-price elasticities. Each of the own-price elasticities share a positive sign while each of the cross-elasticities share a negative sign for all variables.

Using the new elasticities, out-of-sample predictions were then compared to projections made using the existing baseline equation. They show that the new elasticities estimated in this study represent a theoretically consistent improvement in the accuracy of the projections. Given the improved projection accuracy, the resulting price elasticities from this research will be incorporated into the U.S. baseline model by replacing the model described in equation 1.

Although the model represents an improvement over the existing U.S. baseline equations, unanswered questions remain. Room for model improvements still exists for future exploration. The own-price elasticity is three times higher in this study than what had been found in prior studies. Boll weevil damage had considerably reduced cotton area during a portion of the study period. The sample period for this study encompassed the latter part of the U.S. Boll Weevil Eradication Program. This, in combination with factors related to drought, warrants further research efforts. Although this research examines planted area for the major U.S. program crops, not all crops have a consistent relationship between area planted and area harvested. For example, abandonment for some crops is heavily influenced by weather. Other crops with alternative uses, such as wheat, serve a dual purpose of grazing and grain and can be influenced by multiple factors. Additional research into these topics would complement this study and improve the literature on long-term baseline modeling efforts.

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Appendix

Equation 1

$$Area_{yt} = F\,(Area_{y,t-1}\,,\ Area_{y,t-2}\,,\ Area_{y,t-3}\,,\ Price_{y,t}\,,\ Price_{y,t-1}\,,\ Price_{y,t-2}\,,\ Price_{x,t}\,,\ Price_{x,t-1}\,,\ Price_{x,t-2})$$

Equation 2

$$\pi = \sum p_i y_i - \sum w_j x_j$$

Equation 3

$$L = \sum p_i y_i - \sum w_j x_j + \lambda F\,(y,x)$$

Equation 4

$$x_j^* = f_j\,(p,w)$$

Equation 5

$$y_i^* = f_i\,(p,w)$$

Equation 6

$$S_y = a_y + b_y NR_y + \sum_{7}^{x=1} b_{yx} NR_x$$

Equation 7

$$b_{yx} = b_{xy}$$

Equation 8

$$\sum_y b_{yx} = 0$$

Equation 9

$$\gamma_{yx} = \frac{\partial S_y}{\partial NR_x}\frac{NR_x}{S_y} = \frac{b_{yx}}{\delta_y} * \pi_x$$

Equation 10

$$\ln\,(NR_y) = \alpha_y + \beta_y \ln\,(p_y)$$

Equation 11

$$\varphi_{yx} = \gamma_{yx} * \beta_x$$

Table A.1

System of equation regression coefficients in response to share of area planted by crop

	Planted area	
	Estimate	Standard error
	Corn	
Intercept	34.0648**	0.5843
Corn net returns	0.0073**	0.0016
Soybean net returns	-0.0042**	0.0013
Wheat net returns	-0.0003	0.0011
Sorghum net returns	-0.0015	0.0008
Cotton net returns	-0.0014*	0.0005
	Soybean	
Intercept	30.5746**	0.7252
Corn net returns	-0.0042**	0.0013
Soybean net returns	0.0077**	0.0029
Wheat net returns	-0.0033	0.0020
Cotton net returns	-0.0002	0.0006
	Wheat	
Intercept	23.5658**	0.6563
Corn net returns	-0.0003	0.0011
Soybean net returns	-0.0033	0.0020
Wheat net returns	0.0131**	0.0021
Barley net returns	-0.0053**	0.0008
Oats net returns	-0.0042**	0.0009
Cotton net returns	-0.0005*	0.0002
	Sorghum	
Intercept	2.9885**	0.1281
Corn net returns	-0.0015	0.0008
Soybean net returns	-0.0006*	0.0003
Sorghum net returns	0.0021**	0.0008
	Barley	
Intercept	1.2485**	0.2221
Wheat net returns	-0.0053**	0.0008
Barley net returns	0.0053**	0.0008

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	Planted area	
	Estimate	Standard error
	Oats	
Intercept	1.9709**	0.1344
Wheat net returns	-0.0042**	0.0009
Oats net returns	0.0042**	0.0009
	Cotton	
Intercept	5.7761**	0.2233
Corn net returns	-0.0014*	0.0005
Soybean net returns	-0.0002	0.0006
Wheat net returns	-0.0005*	0.0002
Cotton net returns	0.0015**	0.0004

* Significant at the 5-percent level.

** Significant at the 1-percent level.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Table A.2

Percent error from observed area for each year from 2017 to 2021 for the updated model and the existing baseline equations using out-of-sample forecasting

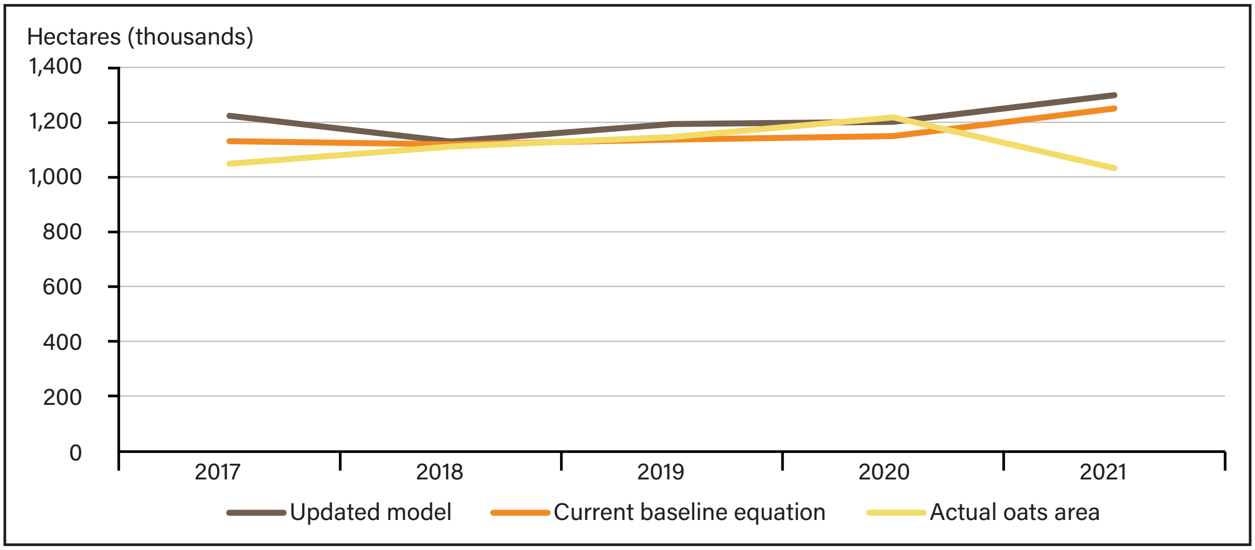
	Corn		Sorghum		Barley		Oats	
	Updated	Existing	Updated	Existing	Updated	Existing	Updated	Existing
2017	(0.9)	4.4	8.5	(21.3)	(17.9)	92.7	16.7	7.9
2018	2.4	5.8	0.3	(27.3)	4.0	79.6	1.7	0.7
2019	0.1	4.4	1.5	(22.7)	3.4	64.1	4.1	(0.8)
2020	0.7	4.1	30.1	(26.2)	0.9	64.5	(1.3)	(5.7)
2021	0.6	1.2	4.4	(45.7)	8.6	66.6	25.9	21.1

	Wheat		Soybean		Cotton	
	Updated	Existing	Updated	Existing	Updated	Existing
2017	3.6	3.3	(2.6)	(3.6)	0.3	(13.0)
2018	1.1	(0.3)	(3.6)	(1.9)	(0.0)	(14.6)
2019	(2.3)	4.4	1.6	14.8	(2.0)	(4.7)
2020	0.7	1.7	0.2	2.3	0.3	10.6
2021	(1.6)	(2.8)	(3.2)	(0.8)	3.5	16.5

Note: Numbers in parentheses are negative.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

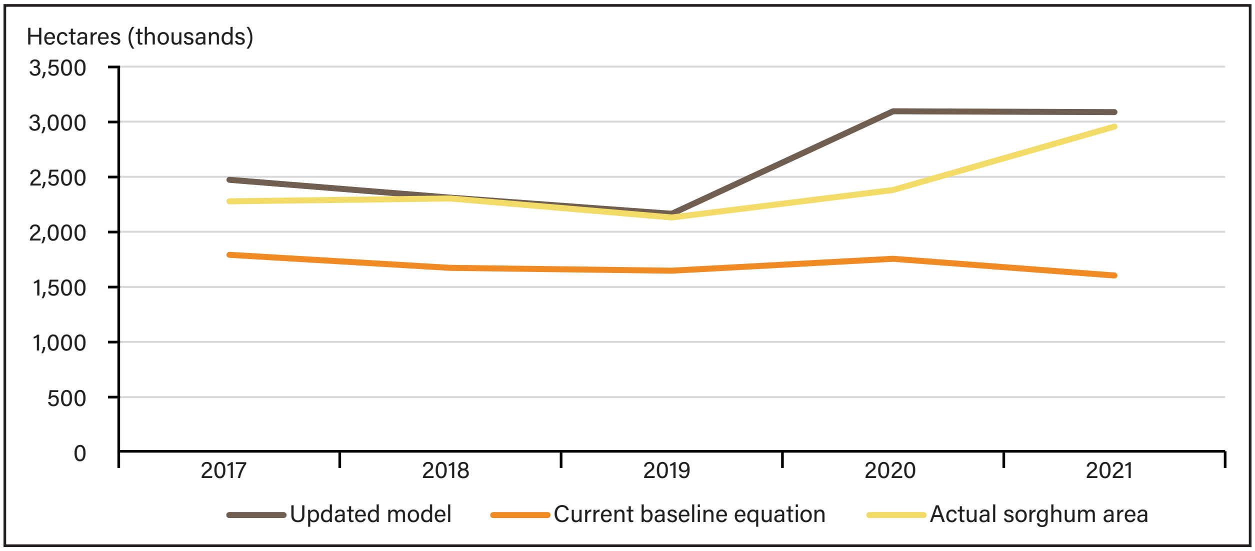
Figure A.1
Forecasted oats area planted compared with observed area planted



Note: Projections for the updated model are out-of-sample estimates.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Figure A.2
Forecasted sorghum area planted compared with observed area planted

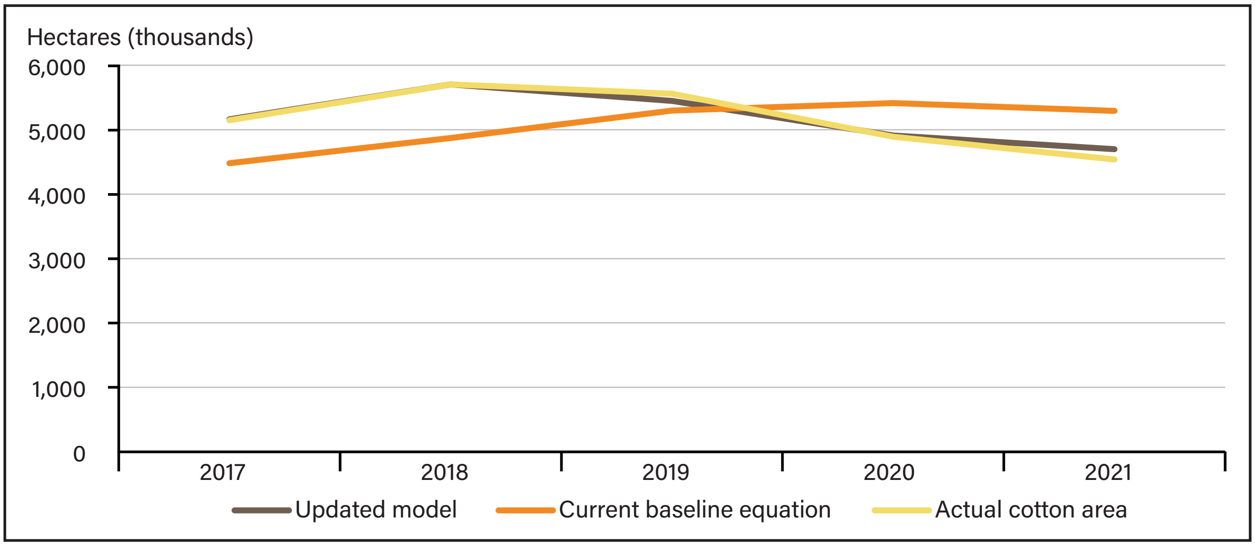


Note: Projections for the updated model are out-of-sample estimates.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Figure A.3

Forecasted cotton area planted compared with observed area planted

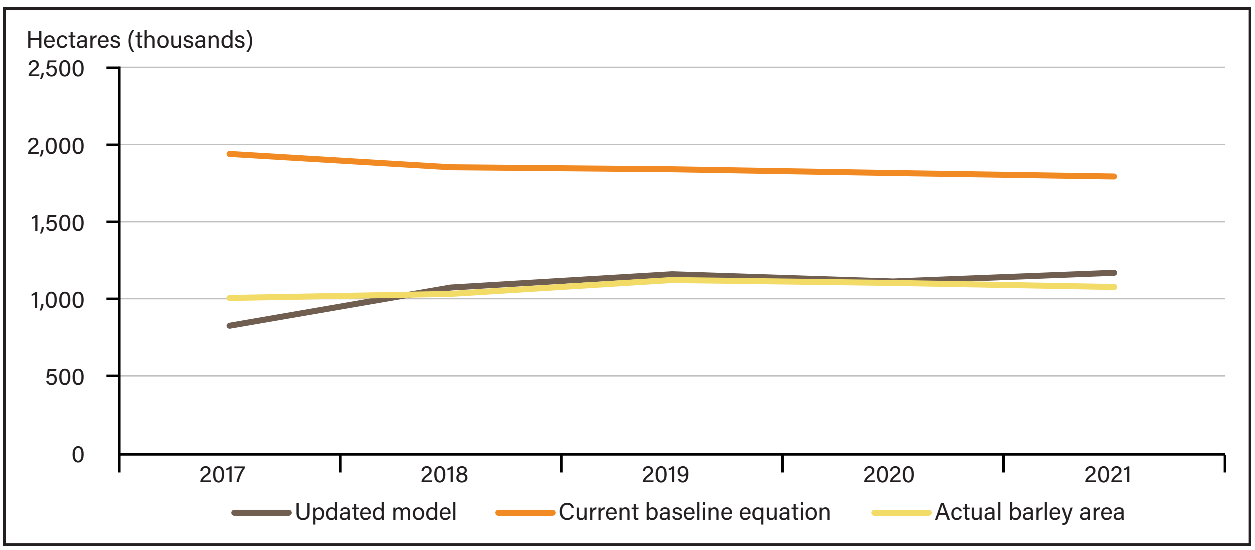


Note: Projections for the updated model are out-of-sample estimates.

Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Figure A.4

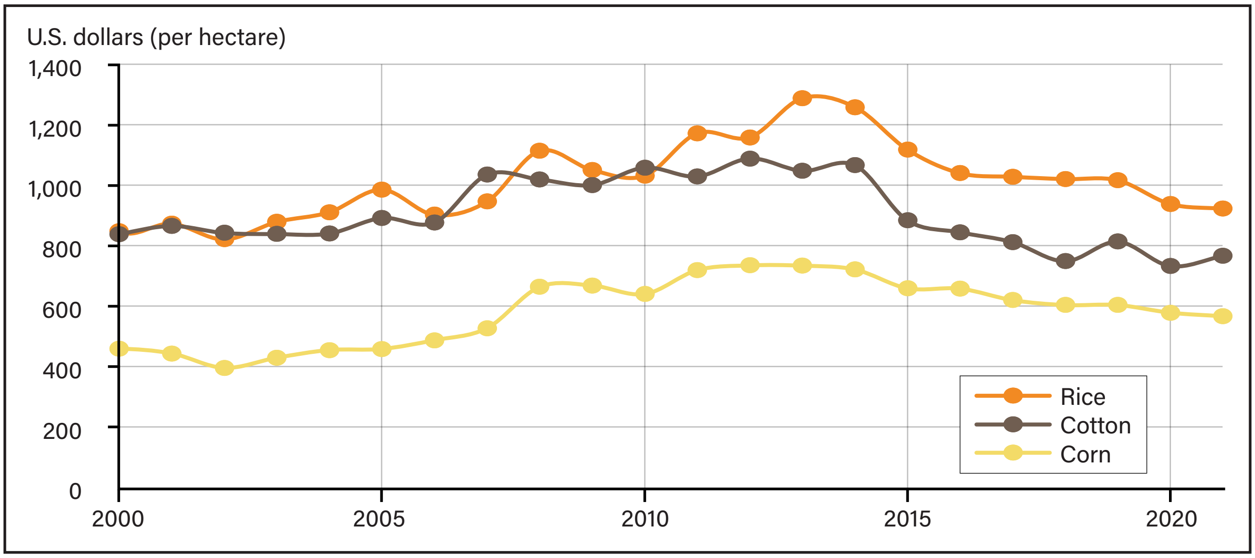
Forecasted barley area planted compared with observed area planted



Note: Projections for the updated model are out-of-sample estimates.

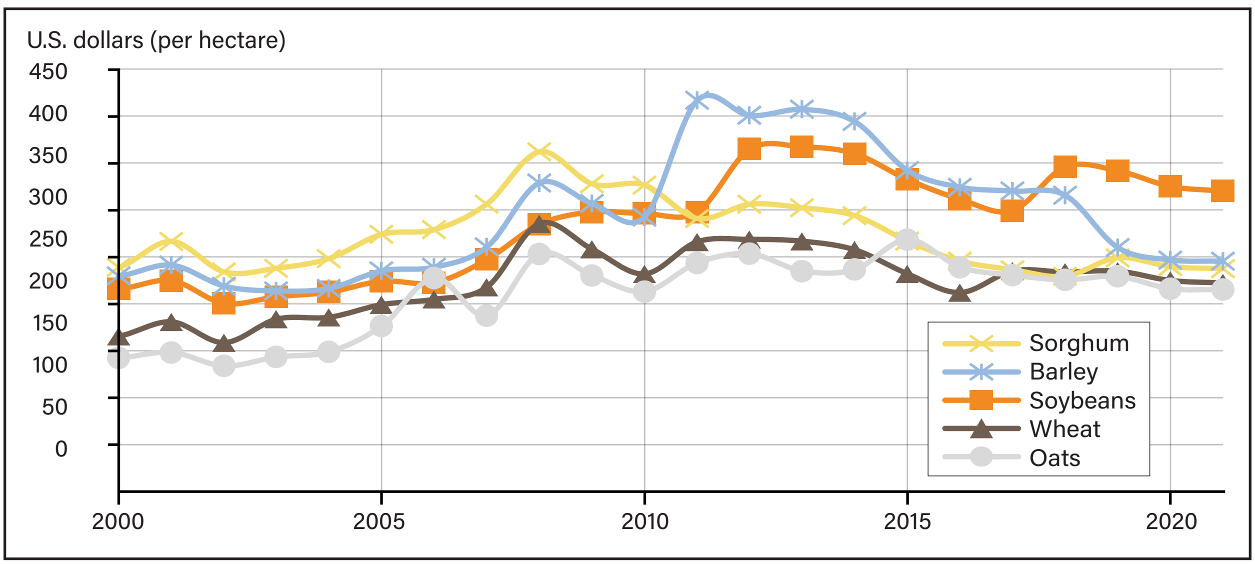
Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.

Figure A.5
Real operating cost for corn, rice, and cotton, U.S. dollars per hectare



Source: USDA, Economic Research Service calculations based on data from USDA, Economic Research Service's Commodity Cost and Return Estimates.

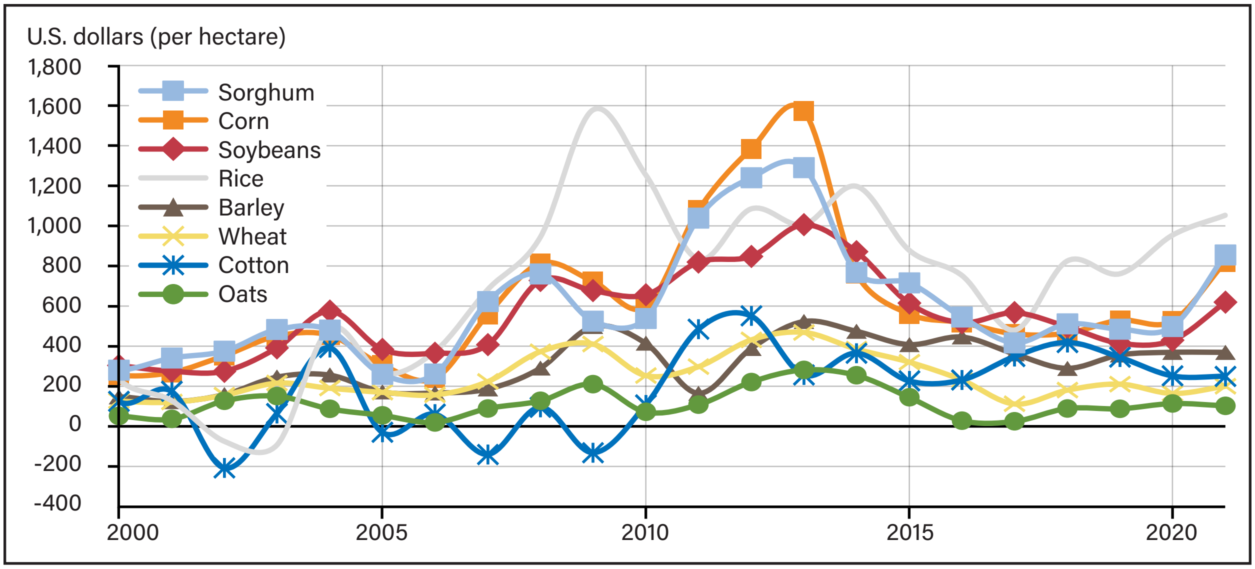
Figure A.6
Real operating cost for soybeans, wheat, sorghum, barley, and oats, U.S. dollars per hectare



Source: USDA, Economic Research Service calculations based on data from Economic Research Service's Commodity Cost and Return Estimates.

Figure A.7

Net return by crop, U.S. dollars per hectare



Source: USDA, Economic Research Service calculations based on data from USDA, Foreign Agricultural Service's Production Supply and Distribution; USDA, National Agricultural Statistics Service; and USDA, Economic Research Service's Commodity Cost and Return Estimates.