ECONOMIC IMPACTS OF CROP BIOTECHNOLOGY IN A RISKY COTTON PRODUCTION SYSTEM: AN APPLICATION TO THE HIGH PLAINS OF TEXAS

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Abstract

Developments in crop plant biotechnology can shift crop production functions, changing the profitability and optimal enterprise selection in a farm plan. Cotton production on the High Plains of Texas will be affected by crop biotechnology. Representative farm modeling was used to estimate the effects on profitability and enterprise selection due to expected biotechnological advances in major crops at the farm level. Biotechnology is estimated to significantly contribute to the profitability of farms in the High Plains of Texas. Likewise, such developments can be expected to result in increased cotton acreage in the region.

Introduction

Modification of the genetic scheme of crop plants has been the focus of a long and growing list of crop production research strategies. Crop plant productivity can be significantly affected by environmental factors, pests and diseases, soil characteristics, and the structural design of the plants themselves. Biotechnological approaches can lead to transgenic crop plants that can optimize the exploitation of specific environments. The flexibility of genetic approaches and techniques permits researchers to address many varied problems in agricultural crop production. Biotechnology can affect crop plant production by influencing yields, quality characteristics, or costs. Each of these areas of crop production can be influenced either by altering the expected levels or by adjusting the variation from expected levels.

Producers seeking to achieve maximum profit will optimize revenue and so, they seek to optimize the yield. Clearly, yields cannot be totally controlled by the producer, but producer decisions along with external events, such as weather, crop disease, and insects, determine crop yields. These external events, which the producer has no prior knowledge of or control over, present the producer with the problem of uncertainty regarding crop yields, and therefore, revenue. Because of the simultaneous decisions on revenue and costs required to obtain maximum profit, uncertainty about the revenue received for the crop affects the expected level of profit through uncertainty of revenues and uncertainty of costs.

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Information is used to form the producer’s expectation of yield levels. This information is often used to form either an objective or a subjective evaluation of the risk involved in the production of the crop. Therefore, the producer's objective becomes the maximization of expected profit through optimization of expected yields and revenue, given the risk associated with production of the crop and the risk attitude of the producer. Costs of crop production are jointly determined with expected revenue. As a result, the producer wishing to achieve the maximum profit minimizes costs of production with respect to the expected level of revenue. Therefore, a producer has control of three means to guide profit toward its maximum: increase the expected level of yields, reduce the production risk involved, or lower production costs.

To assess the feasibility of continued biotechnology research on crop plants grown in the High Plains of Texas (HPT) and to help recognize the crops most economically amenable to developments in genetic engineering, a need exists to evaluate the economic impacts of genetically engineered crop varieties on the profitability of agricultural operations in the region. The objective of this study was to estimate the impacts on farm profitability and enterprise selection given expected biotechnological advances in crops grown in the HPT.

The HPT consists of a fifty-five county region in northwest Texas. The region includes part of the Panhandle, the South Plains, and much of the Rolling Plains. Much of the HPT, the segment in which most regional crop production takes place, lies in a zone classified as semiarid. The semiarid climate is the basis for the low and sporadic rainfall experienced throughout most of the region. Much of the HPT relies upon irrigation water taken from the Ogalalla Aquifer. Upland cotton, grain sorghum, winter wheat, and corn are the primary field crops produced in the HPT. Most of the production of these four crops in Texas takes place in the HPT. Cotton production for 1993 in the HPT was 3.8 million bales, making up 23 percent of total national cotton production. Regional production of grain sorghum was 56 million bushels, representing 10 percent of grain sorghum production in the United States. Of the 2.4 billion bushels of all wheat produced nationally, the HPT produced .29 percent or 70 million bushels. HPT production of corn in 1993 was 131 million bushels. This was approximately 2 percent of corn production in the United States (USDA, various). Completion of this study required the HPT to be disaggregated into three areas. The three areas are designated as subregions. The names of the subregions are the Transition Subregion, the Southern High Plains Subregion, and the Northern Low Plains Subregion.

Methods

This work estimates the impacts of incorporating new biotechnologies into crop production agriculture by developing and analyzing the outcomes of representative farm plans. Three model farms representing three specific geographic and agronomic subregions of the HPT were specified. The three representative farm models were used to determine optimal levels of production and net returns for risky crop enterprises with and without biotechnological shifts in the crop production functions. Each representative farm was designed as closely as possible to the typical farm for each subregion and characterized by differing sets of available crop enterprises and differing farming techniques and practices.

Two models were developed for each representative farm to model alternative scenarios. The two scenarios were a baseline (Base) scenario and a biotechnology (BT) scenario. The Base scenario employs assumptions consistent with typical crop production practices currently used in the representative subregions. The Base scenario contains constraints on the number of acres planted to the given crops designed to emulate the effects of federal agricultural programs and local convention regarding crop plantings in each subregion. Acreage constraints were not included in the BT scenario. This difference was included to explore the impacts of historical commodity price supports versus the current trend toward elimination of agricultural subsidies.

Asymmetric quadratic programming was used to allow stochastic net revenues, resulting from stochastic crop yields, to be maximized subject to production constraints. The Base scenario quadratic programming model uses parameters relevant to the representative farm before the introduction of biotech-enhanced crops. This scenario models current circumstances with regard to crop production. The BT scenario uses parameters for the representative farm simulating the introduction of biotechnology-enhanced crops. The models of the BT scenario were formulated using estimated distributions for crop yield distributions resulting from biotechnological advances. Clearly, the selection of the crop yield distributions for each scenario is important. The crop yield distributions for the Base models were selected to closely model current actual crop yield series. The crop yield distributions for the BT scenario were elicited from a panel of experts who conduct biotechnology research in the area.

The information required to develop the representative farm models consisted of farm size, available crop enterprises, federal farm program details, crop yield statistics, cattle grazing fees, costs of production, and producer risk preferences. Representative farm size and crop base acreages are subregional averages taken from the 1992 Census of Agriculture. If the level of the enterprise was less than 2 percent of the total farm size, the enterprise was omitted from available enterprises for that representative subregion.

Federal farm program provisions were integrated into the representative farm models to capture the effects of farm subsidies. The models include federal price supports as they existed up through the 1995 crop season as legislated in the Food, Agriculture, Conservation, and Trade Act of 1990. The program yields for each representative farm were determined by soliciting a subjective judgment of the county average from Farm Service Administration employees in a sampling of counties in each subregion.

Wheat production in each of the representative subregions is generally a multi product enterprise of grain and cattle grazing. Therefore, revenue from cattle grazing is included in the representative farm models. Gross revenue from grazing totaled $60.75 per acre for irrigated wheat and $17.36 per acre for dryland wheat. Certainly, grazing availability is not a known quantity as is assumed in the models, however, such an estimate is sufficient for the purposes of this study.

Production costs were subtracted from gross revenues to give profit or net return per acre in the representative farm models. Variable and fixed production costs were determined from Texas Crop Enterprise Budgets. Budget entries from the Panhandle, the South Plains, and the Rolling Plains districts were combined to match as closely as possible the production costs of the representative subregions.

As mentioned above, the Base scenario uses actual historical crop yields to estimate expected crop yield distributions. Determination of the expected crop yield distributions for each representative subregion was made by considering the historical crop yield series of each county in a representative subregion. A geographically weighted average of crop yields across counties gave equal weight to each county in the representative subregion. The expected crop yield distributions used in the Base models were derived from a historical period of twenty-two growing seasons from 1972 through 1993. The historical crop yield series were taken from USDA Crops County Data. The expected crop yield levels used in the Base models were the continuations of the crop yield trends present in the historical data.

The variations from expected levels of crop yields and relationships between yields of each crop were needed for the Base models. For each crop yield series, these numbers were calculated as the expected variance of the detrended crop yield series and the expected covariance of the detrended crop yield series with the other detrended crop yield series.

The BT scenario used crop yield distributions altered to reflect the impacts of output enhancing biotechnology.

Solution of the models for the BT scenario required information on expected crop yields, expected variation from expected levels of crop yields, and expected relationships between yields of each crop, similar to the Base models. However, the expected crop yields and expected variation were elicited from an expert panel. Once obtained, the expected crop yield levels and the variance of crop yield levels were incorporated into the representative models. The covariances between crop yields in the representative subregion are assumed to remain unchanged from the Base scenarios.

The expert panel was made up of thirteen scientists from biological and agricultural fields who are directly involved with some aspect of crop plant biotechnology. The expectations obtained from the panel members are for a twenty-year horizon. The panel survey was conducted in 1996, therefore, based upon the twenty-year time horizon, expectations produced from the panel are for the year 2016. Panel members were asked to return their expectations regarding total crop yields. Much of the expected difference between current crop yields and future crop yields was agreed by panel members to be influenced by biotechnology.

The Triangular Distribution Procedure (Young, 1983) was used to subjectively elicit expectations of crop yield distributions. Each panel member was asked to specify the most likely, maximum, and minimum expected crop yields for each crop in each representative subregion. Once the three estimates were obtained, the proper formulas were used to estimate the mean and variance of the response. The mean or expected crop yields and the variance of crop yields for each panel member were recorded from these formulas. Once elicited and transformed into expected crop yields and variances, the individual expectations of the panel members were aggregated to provide a single expectation of crop yields and variance of crop yields for each crop in each representative subregion. The expected crop yields and variance of crop yields were simply averaged across panel members to arrive at a single expected crop yield and a single variance of crop yields for each crop in each representative subregion.

The stochastic nature of the crop yields and resulting crop net returns in the representative farm models necessitated a measure estimating the level of producer risk aversion. The quadratic programming technique uses a standardized risk measurement to introduce producer risk preferences into the models. The risk aversion coefficient (RAC) is equal to the Arrow-Pratt absolute risk aversion coefficient divided by 2. The RAC was used to express producer risk preferences. A wide array of risk aversion was tested for each model to establish a tight range in which the RAC of subregional crop producers would be expected to lie. The bounds of the range of coefficients were determined by an iterative process of refining the bounds of the acreage constrained Base models until the appropriate bounds were identified.

Results

The representative farm models were designed to maximize the representative producer's total net return or profit from crop production given constraints on available irrigation water, labor, land, and capital investment, financial parameters, economic relationships, and institutional regulations. The decision variables were the acreages allocated to production of each crop.

A general model was developed for each subregion-scenario combination and solved for three different levels of risk aversion. Therefore, each model set consisted of three models, each with a different level of risk aversion. The upper and lower bounds on the range of producer risk aversion are different for each representative subregion. The range of producer risk aversion was equally divided to produce three risk aversion coefficients (RAC), the set of which remains unchanged for each representative subregion no matter the scenario.

Each of the three Base models having different RACs give identical results except for risk premiums (RP). Given that the crop enterprise acreages are preimposed on the representative producer, the producer's level of risk aversion makes no difference as to enterprise selection. However, the risk premiums vary according to the level of risk aversion.

The representative farm in the Transition Subregion consists of 858 total acres of cropland with a maximum of 700 irrigable acres. Available crop enterprises were irrigated cotton, dryland cotton, irrigated sorghum, dryland sorghum, irrigated wheat, dryland wheat, and corn.

The total acres in the optimal solution used for crop production was 858 for all models. Irrigated cotton enterprise showed a decline in acreage under the BT scenario, however, slight in the middle of the range of RAC and more dramatic closer to each bound (Table 1). Dryland cotton was eliminated from the farm in the BT scenario. Most of the enterprise acreages leaving cotton production shifted to dryland sorghum in the Transition Subregion. Expected net return (ENR) in the BT scenario increased sharply across RAC levels. Because the RP decreased across RAC levels, the tradeoff between risk and return was improved over the Base scenario.

The representative farm in the Southern High Plains Subregion consisted of 921 total acres of cropland with a maximum of 400 irrigable acres. Available crop enterprises were irrigated cotton, dryland cotton, irrigated sorghum, dryland sorghum, and dryland wheat.

The total acres in the optimal solution used for crop production was 921 for all models. Across the range of RAC, the irrigated cotton enterprise increased under the BT scenario to the maximum allowable irrigated acres (Table

2). Dryland cotton also increased to fill the remainder of total farm acreage. Therefore, only cotton enterprises made up the Southern High Plains representative farm under the BT scenario. Sorghum and wheat acreages sustained the losses and decreased to zero in all cases. These enterprise selections explain the constant but increased ENR across the RAC range. Like the Transition model, because the RP decreases across RAC levels, the tradeoff between risk and return was improved over the Base scenario.

The representative farm in the Northern Low Plains Subregion consisted of 566 total acres of cropland with a maximum of 200 irrigable acres. Available crop enterprises were irrigated cotton, dryland cotton, dryland sorghum, and dryland wheat.

The total acres in the optimal solution used for crop production was 566 for all models. Across the range of RAC, the dryland cotton enterprise increased under the BT scenario to account for the total farm acreage (Table 3). Irrigated cotton decreased to zero acres in the farm plan. Therefore, the representative farm in the Northern Low Plains consisted of only the dryland cotton enterprise under the BT scenario. Making room for the increased dryland cotton acreage, dryland wheat and dryland sorghum exited the representative farm plan under the BT scenario. ENR in the BT scenario increased sharply across RAC levels. However, unlike the other two subregional models, because the RP increased across RAC levels, the tradeoff between risk and return was not necessarily improved over the Base scenario.

Changes in enterprise selection on the representative farms from the Base scenario to the BT scenario provide an idea of possible acreage shifts into and out of each subregion because of biotechnology developments. Acres of irrigated cotton slightly decrease, but continue around 200 acres on the Transition farm, decrease from 22 acres to zero acres in the Northern Low Plains farm, and increase about 25 percent in the Southern High Plains farm from around 320 acres to 400 acres. Irrigated cotton acreage increases would continue on the Southern High Plains farm if not constrained by the limit on irrigation water use. Acres of dryland cotton fall from 60 acres to zero acres in the Transition farm, however, acreage increases about 100 acres and 300 acres in the Southern High Plains and Northern Low Plains farms, respectively.

Conclusions

This study brings together both theoretical and empirical methods of economic analysis to address the crop productivity impacts of plant stress and biotechnology, as they affect the decision-making behavior of economic agents. The analysis of the representative farm models formulated in this research shows that increases in producers' expected net revenues and in the expected levels of payoff that account for producers' risk preferences are anticipated to accompany advances in crop biotechnology that affect the crops grown in the HPT. Likewise, for the higher levels of risk aversion, developments in crop biotechnology are expected to reduce producers' risk premiums for each subregion except the Northern Low Plains Subregion, where risk premiums increase only slightly. At lower levels of risk aversion, risk premiums are expected to, at worst, increase only slightly. Therefore, introduction of biotechnology advances can be expected to reduce the proportion of expected net revenues represented by the risk premiums for each subregion. These results have consequential and timely implications.

Producers, historically relying on federal farm programs for some protection against risk, are finding that their reliance on these programs may be limited in the future. The current political climate surrounding the federal farm support program, the FAIR Act of 1996, calls for decreased program payments to producers. Total withdrawal of agricultural subsidization by the federal government may become a reality early in the twenty-first century. Under such conditions, many farmers will be forced to seek alternative risk management strategies. Expected biotechnological progress such as that examined in this study could allow farmers to realize added benefits from risk management. Depending upon the time frame of actual elimination of farm subsidies and the urgency to find a risk management tool to replace the subsidies, realization of such benefits could speed the rate of adoption of biotechnology enhanced crops.

Expected net revenues will increase because of biotechnology. The increases estimated in this study provide some idea of the expected benefits of biotechnology. The expected benefits will not be wholly realized by producers. The estimated benefit must be divided among the different levels of the marketing chain, including the developer of the biotechnology and crop producers. Estimates of benefits, however, allow the calculation of the maximum rent that farmers would be willing to pay for the technology. An estimation of the rent could aid companies and institutions in developing investment analyses and so, budgeting of research funding for biotech products.

Based on the results of the representative farm models, expected biotechnology developments will cause producers in the region to change their enterprise selections. Such changes in enterprise selection will precipitate shifts in the typical quantities of crops grown between subregions and even into and out of the region. Keep in mind that these shifts are expected to take place gradually over an extended period of time and therefore, might not be impeded by the rigidities of a shorter term.

Extrapolation from the farm models indicates that, adjustments in the Transition Subregion should be more easily made compared to the two southern subregions.

Wheat acreage will shift to sorghum and corn in the Transition subregion and cotton in the southern subregions. Northern farmers can shift to sorghum or corn production using their existing machinery and equipment. However, farmers in the southern subregions may require additional machinery and equipment for cotton production because much of the machinery for wheat production is generally not transferrable to cotton production.

A significant increase in cotton production will occur in the region. Cotton production will slightly shift away from the Transition Subregion and cotton acreages in the Southern High Plains and Northern Low Plains subregions will significantly increase. Such an increase in cotton production in these two subregions may require producers to make substantial investments in equipment and machinery used exclusively for cotton production. More cotton ginning capacity might also be required in the two southern subregions. The significant increase in cotton production in the region could affect the textile industry. Textile manufacturers may find increased opportunities for locating mills in the region. Such changes will impact the local economies in the two subregions.

Overall, biotechnology will encourage the increased production of dryland sorghum and cotton at the expense of wheat and irrigated sorghum acreages. The representative farm models indicate that acres of irrigated crops will tend to decrease under the BT scenario, especially at higher levels of risk aversion. Such a decrease in irrigated acreage may coincide with increased demand for water for uses other than agriculture. As a result of the increased non-agricultural demand, the cost of irrigation water could increase and further decrease its use in the crop production systems.

As was mentioned above, crop acreage shifts from one subregion to another, as well as, into and out of the HPT, will have impacts on the local economies in each subregion and the HPT as a whole. A logical extension from this work would be to assess the economic impacts to the subregional and regional economies of significant numbers of changing cropland acres. Such changes might be seasonal. The reduction of winter wheat acreages in the region could increase the demand for input supplies in the spring when preparations are being made for the alternative crops. Other changes might affect related industries. The increased cotton acreages in the Southern High Plains Subregion could increase the need for supporting industries such as the textile industry. Clearly, this study is only a beginning to the assessment of the economic consequences of biotechnology in the HPT. Approaches used in this study should be refined and strategies aimed at many related topics should be continued.

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Table 1. Optimal solutions for the Transition Subregion.

RAC	Irr Cotton		Dry Cotton		ENR		RP	
	Base	BT	Base	BT	Base	BT	Base	BT
	.... acres	....			.... dollars	....		
0	322	0	60	0	38,320	80,666	0	0
4.00e-05	264	249	60	0	37,636	78,912	18,704	17,621
8.00e-05	264	172	60	0	37,636	65,407	37,408	14,985

Table 2. Optimal solutions for the Southern High Plains Subregion.

RAC	Irr Cotton		Dry Cotton		ENR		RP	
	Base	BT	Base	BT	Base	BT	Base	BT
	.... acres	....			.... dollars	....		
0	318	400	419	521	40,831	79,972	0	0
7.50e-06	318	400	419	521	40,831	79,972	8,867	7,809
1.50e-05	318	400	419	521	40,831	79,972	17,734	15,618

Table 3. Optimal solutions for the Northern Low Plains Subregion.

RAC	Irr Cotton		Dry Cotton		ENR		RP	
	Base	BT	Base	BT	Base	BT	Base	BT
	.... acres	....			.... dollars	....		
0	22	0	258	566	26,906	65,094	0	0
6.50e-05	22	0	258	566	26,906	65,094	12,844	14,026
1.30e-05	22	0	258	566	26,906	65,094	25,688	28,052