ECONOMIC ANALYSIS OF ATOXIGENIC MITIGATION METHODS FOR AFLATOXIN IN CORN IN CENTRAL TEXAS

A Thesis

by

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ABSTRACT

Atoxigenics and crop insurance are available to producers to assist in preventing economic loss from aflatoxin contamination in corn. Atoxigenics are a newer technology available to farmers, and although professional opinion of this biotechnology encourages its use, an economic analysis has not been performed to determine if the atoxigenics are overall economically beneficial to the producer when combined with crop insurance.

The objective of this paper is to perform an economic analysis on the decision to use available atoxigenic treatments on a corn crop, and evaluate the economic outcome at different crop insurance levels for corn producers in Central Texas. This paper will use a risk based partial budget simulation model combined with an aflatoxin contamination simulation model to complete a risk analysis on the decision to use atoxigenic mitigation methods. Field level data on aflatoxin contamination levels is from Bell County, Texas.

A representative farm was simulated with and without atoxigenic treatments and each case was simulated across a range of crop insurance options available to corn producers in Bell County. A total of 50 scenarios were simulated and compared based on net revenue.

Results show atoxigenics do provide a monetary benefit to producers. When the atoxigenic treatment was compared to no atoxigenic treatment, both with no insurance, the simulated average net revenue was higher by $8-$10 per acre for the treatment scenario. When crop insurance was simulated, with and without atoxigenic treatments,

results indicated the current RMA insurance premiums were too high for treatment scenarios. The current RMA premiums did not account for the decreased risk of insurance payout amount and frequency associated with the use of atoxigenics.

Current RMA premiums were replaced with fair premiums equal to the simulated mean indemnity payment for all crop insurance options. When the treatment scenario was compared to the no treatment scenario, under the set of most efficient crop insurance options, atoxigenic treatment provided the producer with an additional net monetary benefit of $8-$16 per acre.

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1. INTRODUCTION

1.1 General Overview

Mycotoxins are chemical compounds produced by fungi that grow on organic substances, and one of the most agriculturally important mycotoxins is aflatoxin. Aflatoxins are primarily produced by the strains *Aspergillus flavus* and *Aspergillus parasiticus*, these species are found in the soil and as they grow on their food source aflatoxin is produced and builds up (Horne et al. 1991). Consumption of aflatoxin leads to detrimental effects in humans and animals. Aflatoxins are classified as a group 1 carcinogen for humans by the International Agency for Research on Cancer (IARC 1993).

In the United States (US), the corn producer bears a local market discount when aflatoxin contaminated corn is sold at the grain elevator. In Texas, over 2 million acres of corn are harvested which produces 280 million bushels of corn, and contributes approximately $1.4 billion to the state's economy annually (NASS 2013a). Texas also consistently provides the appropriate environment for aflatoxin accumulation; extreme drought followed by humidity.

There are atoxigenics; non aflatoxin producing strains of *A. flavus*, that can be applied to the corn plant to assist in preventing aflatoxin contamination. The atoxigenic, combined with crop insurance indemnities, can alleviate producer's economic loss caused by aflatoxin however it is difficult to predetermine the aflatoxin severity in any given growing season. Additionally, separate aflatoxin test results are used in local corn market discounts and in crop insurance indemnity calculations, creating the risk of lack of insurance coverage.

This thesis will outline the background information necessary to describe the many variables which influence aflatoxin in corn, as well as include a review of past similar studies and the theory underlying the economic analysis. Finally, the methodology used in building the economic model will be described and the results and conclusions of the analysis will be presented.

1.2 Statement of the Problem

Atoxigenics and crop insurance are available to producers to assist in preventing economic loss from aflatoxin contamination in corn. The problem surrounding these tools is a lack of economic analysis to assist farmers in making the most informed and economically reasonable decisions concerning their individual production practices. Atoxigenics are a newer technology available to farmers, and although professional opinion of this biotechnology encourages its use, an economic analysis has not been performed to determine if the atoxigenics are overall economically beneficial to the industry when combined with other tools such as crop insurance.

1.3 Objective

The objective of this paper is to perform an economic analysis of the decision to use available atoxigenic treatments on a corn crop, and evaluate the economic outcome at different crop insurance levels for corn producers in Central Texas. This paper will use a risk based partial budget simulation model combined with an aflatoxin contamination simulation model to complete a risk analysis on the decision to use atoxigenic mitigation methods. Field level data on aflatoxin contamination levels is from Bell County, Texas. The current study should assist the decision maker by considering the risk of aflatoxin infection, infection level, aflatoxin test discrepancies, cost of the atoxigenic, cost of the insurance, indemnity payments, and stochastic market prices and local yields.

2. BACKGROUND

2.1 Affected Area

Aflatoxin is not a new issue in field crops, it has been around for centuries and affects mainly cereals, oilseeds, and tree nuts. The occurrence and level of aflatoxin contamination in crops varies among commodities, years, and regions, but aflatoxin occurrence is more likely under severe environmental stresses such as extreme drought and heat conditions, or damage by insects (Horne et al. 1991). Even in regions that are experiencing severe environmental crop stress, aflatoxin contamination will be randomly scattered throughout the region making estimation of total damage and economic losses difficult (Horne et al. 1991).

Estimates suggest that up to 25% of the world's food crops are affected to some degree by mycotoxin contamination (Horne et al. 1991). In developing countries, exposure to aflatoxins is widespread and starts before birth, which carries distinct negative impacts on human health (Gnonlonfin et al. 2013). In developed countries, the negative impacts of aflatoxin are felt from rejection in the market and animal health impacts. In the United States (US), Vardon and colleagues (2003) estimated the annual cost of aflatoxin contamination at about $500 million. Robens and Cardwell (2003) calculated additional annual costs of aflatoxin management in the US at $20-$50 million. Within the US, aflatoxin contamination appears to be more prevalent in the southeast and southwest. The Midwest does experience aflatoxin contamination, but historically not to the extent of the southern regions as extreme drought and heat are not as prevalent in the Midwest (Horne et al. 1991). In Texas, specific to corn, aflatoxin contamination is found in the Panhandle region and in the central Texas region, as seen in figure 2.1 (OTSC 2013a). Both regions are the main corn producing areas of the state.

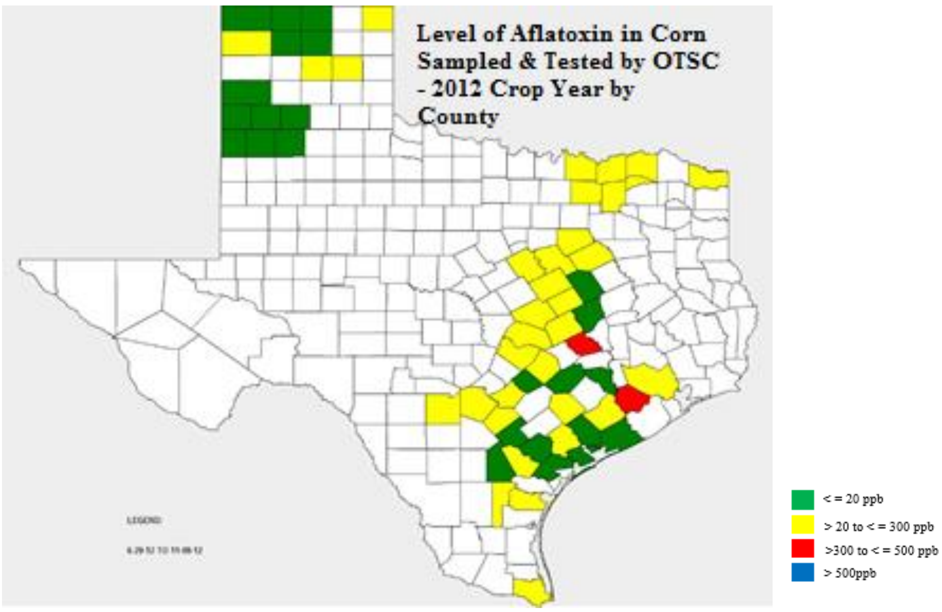

Figure 2.1. Common aflatoxin contamination regions in Texas (OTSC 2013a)

It is difficult to measure total economic losses from aflatoxin due to the range of affected industries. Aflatoxin contamination is economically detrimental not only to the producer, but also the downstream grain elevators, food and feed companies, and even further to people or animals who may consume contaminated food or feed.

2.2 Aflatoxin Regulations

Human and animal health concerns set precedent for regulation limits of aflatoxin levels in human food and animal feed products. The European Commission has set a total aflatoxin standard of 4 parts per billion (ppb) in food, more precautionary than any national or international standards currently existing (Lubulwa and Davis 1994). In the US, there are no regulatory limits prescribed by the Food and Drug Administration (FDA).The FDA has issued a Compliance Policy Guide listing aflatoxin action levels, which the US food and feed industries follow (FDA 2009). Table 2.1 explains these guidelines.

Table 2.1. FDA Action Levels for Aflatoxin (GIPSA 2013)

Listed below are the FDA action levels for aflatoxins in animal feeds.	
20 ppb	For corn and other grains intended for immature animals (including immature poultry) and for dairy animals, or when its destination is not known;
20 ppb	For animal feeds, other than corn or cottonseed meal;
100 ppb	For corn and other grains intended for breeding beef cattle, breeding swine, or mature poultry;
200 ppb	For corn and other grains intended for finishing swine of 100 pounds or greater;
300 ppb	For corn and other grains intended for finishing (i.e., feedlot) beef cattle and for cottonseed meal intended for beef cattle, swine, or poultry.

In Texas, the FDA action levels are observed, as seen in table 2.1, with the addition of corn testing between 20-50 ppb may be distributed when destined for wildlife, and corn testing between 300-500 ppb requires a blending permit issued by the Office of the Texas State Chemist (OTSC), or must be destroyed (OTSC 2011). Grain testing greater than 500 ppb may not enter commerce and a record of disposition shall be submitted to the OTSC (Herrman 2011).

Aflatoxin testing is mandatory for exported corn. According to the 1990 Farm Bill, all corn exported from the US is required to be tested to determine whether it exceeds an acceptable level of aflatoxin contamination (GIPSA 2013). For domestic use, the FDA action levels are observed in commodity production and purchasing, and aflatoxin testing services are regulated by the United States Department of Agriculture's (USDA) Grain Inspection, Packers and Stockyards Administration (GIPSA). A Memorandum of Understanding (MOU) was agreed upon between FDA and the Federal Grain Inspection Service (FGIS). The MOU includes a requirement of a report to the FDA, on a lot-by-lot basis, for each lot of grain/rice/processed products that exceeds the 20 ppb FDA action limit (GIPSA 2013).

2.3 Aflatoxin Testing Methods

Multiple methods are available to test corn for aflatoxin. At the local elevator, two main types of screening methods are often used; blacklight tests and commercial test kits (Munkvold et al. 2012). The blacklight test is a quick visual screening, with the presence of a greenish gold fluorescence under the light indicating active *A. flavus*. Commercial test kits use immunoassay or ELISA techniques. Immunoassay analysis is based on the detection of specific proteins found in aflatoxins using antibodies to identify these proteins. Some tests are qualitative and determine only the presence or absence of aflatoxin, other tests can quantify the amount of aflatoxin present, in ppb. In the commercial kit testing process, 5 to 10 lb. samples of corn are collected, ground, then a small subsample is removed for the test kit (Munkvold et al. 2012).

Additionally, analytical laboratories use procedures such as thin-layer chromatography, mini columns, gas chromatography, or mass spectroscopy to determine aflatoxin levels. The laboratory procedures are highly quantitative and accurate (Munkvold et al. 2012). Large sampling variability still exists however, as the aflatoxin contamination is randomly distributed through kernels. The number of contaminated kernels in a sample and the level of contamination in a kernel can be highly variable. Multiple test results using the same testing method can be dramatically different for an individual load of grain (Munkvold et al. 2012).

2.4 Crop Insurance Procedures

The following information describes general terms and equations used in this paper for defining crop insurance and calculating quality adjustments and indemnity payments resulting from aflatoxin contamination in corn. The subsequent crop insurance information and calculations come from the Common Crop Insurance Policy published by USDA's, Risk Management Agency (RMA) (FCIC 2010). Bell County, Texas is the specific area used in the following examples as it is the region where field level data originated for the current study. In Bell County, corn producers have three insurance options available to them. These are yield protection (YP), revenue protection (RP), and revenue protection with harvest price exclusion (RPHPE) (RMA 2012).

YP, as defined by RMA, is a policy that insures producers against yield losses due to natural causes. The producer selects the percentage of average yield to insure, from 50-85%, and selects the percentage of projected price to insure from 55-100%. The selected percentages give the producer a production guarantee per acre. The projected price is determined in accordance with the Chicago Mercantile Exchange (CME) and is based on daily settlement prices for December corn futures contracts. If harvested production value, termed value of production to count (VPTC), is less than the insured production value, termed value of production guarantee (VPG), the producer is paid an indemnity based on the difference. The VPG is calculated by multiplying the acres insured, by the product of the production guarantee and projected price.

(1) VPG = acres insured * (production guarantee bushels/acre * projected price)

a. Production guarantee = average yield in bushels/acre * insured percentage

The VPTC is calculated by multiplying production to count (PTC) by projected price.

(2) VPTC = PTC * projected price

(3) Indemnity = VPG – VPTC

PTC is considered all production from insured acreage, but PTC can be discounted for several reasons, including a reduction in the quality of the corn. Aflatoxin contamination is one cause of quality reduction in corn. When aflatoxin is present at or above 20 ppb, the producer receives a reduction in value (RIV) at the local grain elevator. The RIV is based on the level of aflatoxin contamination, determined at each local grain elevator, and used to calculate a discount factor (DF), which is employed to calculate a quality adjustment factor (QAF). The QAF is utilized in adjusting the PTC for crop insurance indemnity calculations.

(4) RIV= Set by the local elevator

(5) DF= RIV/local market price

(6) QAF= 1-DF

PTC= actual total production in bushels * QAF

When a QAF is used to discount PTC, depending on the percentage of yield insured, crop insurance indemnities can possibly cover aflatoxin contamination costs in corn. For corn that is not sold, and kept in storage or to feed to livestock instead, a DF is used from table 2.2 below to calculate crop insurance indemnities. For insurance purposes, corn destined for storage must be tested for aflatoxin by an approved testing facility, prior to going in storage.

Table 2.2. Discount Factors for Aflatoxin (RMA 2012)

Aflatoxin Range	DF
0.1-20.0 ppb	0.000
20.1-50.0 ppb	0.100
50.1-100.0 ppb	0.200
100.1-200.0 ppb	0.300
200.1-300.0 ppb	0.400
300.1 & above	.500 or 1.000*

*.500 for production that was in on-farm storage and was later sold, was in on-farm storage and was transported to commercial storage and later sold, was fed, was utilized in any other manner, or was sold to other than a disinterested third party. If product is destroyed in a manner acceptable to RMA, the DF will be 1.000

Revenue protection (RP), as defined by RMA, provides protection against loss of revenue due to a production loss, price decline or increase, or a combination of both. The producer selects the amount of average yield to insure, from 50-85%, and projected price and harvest price are set at 100% of the amounts determined by RMA through the CME futures contracts. The amount of insurance protection is based on the greater of the projected price or the harvest price. If harvested production multiplied by harvest price, termed value of production to count (VPTC), is less than the amount of insurance protection, termed revenue production guarantee (RPG), the producer is paid an indemnity based on the difference. The indemnity is calculated based on the difference RPG and the VPTC. The RPG is calculated by multiplying acres insured, by the product of guaranteed production in bushels/acre and the higher of either projected price or harvest price. The VPTC is calculated by multiplying PTC by the harvest price. The PTC may be discounted for several reasons, including aflatoxin contamination.

(1) RPG = acres insured * (production guarantee bu/acre * max(projected price, harvest price)

a. Production guarantee = average yield in bu/acre * insured percentage

(2) VPTC = PTC * harvest price

(3) Indemnity = RPG - VPTC

If revenue protection with harvest price exclusion is chosen, the producer is insured in the same manner as revenue protection, except the RPG is based on the projected price only.

2.5 Aflatoxin Mitigation Methods

Current mitigation methods against aflatoxin include; best management practices (BMP), *Bacillus thuringiensis* (Bt) corn, and atoxigenics such as Afla-Guard ® and AF-36. The mitigation methods have all assisted in decreasing the severity of aflatoxin, but methods have not been found that prevent aflatoxin altogether.

Corn production BMPs are described by the OTSC through collaboration with the feed and grain industry and Texas A&M research and extension (OTSC 2013a). The BMPs include description of preharvest and postharvest practices. Preharvest; hybrid selection, planting time, crop management, and harvest methods are critical components. During harvest, field segregation, adjustment of combine settings, grain moisture, and drying time are all control points for aflatoxin. Mycotoxins can also increase postharvest during storage. Bin preparation, placement of clean and contaminated corn, aeration, monitoring, and pest control are all important practices that can help prevent aflatoxin buildup during storage. Additionally, postharvest it is critical to follow approved sampling and testing methods to achieve the most consistent aflatoxin test results, reduce testing error and therefore reduce economic loss.

In addition to BMPs, Bt corn plays a key role in reducing aflatoxin contamination. Bt stands for *Bacillus thuringiensis*, which is a bacterium found in the soil that naturally produces proteins toxic to some insects Bt corn is resistant to some pests. It is not resistant to aflatoxin, but the pest resistance decreases kernel wounds on the plants caused by insects, which decreases the chance of fungal infection via kernel wounds (Peairs 2013).

The atoxigenic, or bio control, mitigation methods available to corn producers in Texas are Afla-Guard® and AF-36. Both are commercial preparations of different strains of the fungus, *Aspergillus flavus*, but neither of the strains produce aflatoxin and are labeled as atoxigenic strains. AF-36 is heat killed wheat seed which is colonized by the fungus, and it is produced by Arizona Cotton Research and Protection Council with Double CT LLC as the Texas distributor. Afla-Guard® is hulled barley seed coated with spores of the fungus and is produced by Syngenta Crop Protection, Inc. and available from dealers who sell their product (Isakeit 2009). The described atoxigenic mitigation methods are main components of the present study.

The atoxigenics work similarly, using competitive exclusion of aflatoxin producers as the mechanism for aflatoxin reduction (Isakeit 2009). Efficacy studies of AF-36 and Afla-Guard ® have been conducted independently. Cotty (2008) conducted a commercial field test in multiple Texas counties in 2008 to determine the ability of AF-

36 to reduce aflatoxin contamination in corn. AF-36 was applied to fields during various growth stages from V7 growth stage to tasseling, with control fields used for non-treatment comparisons. Overall, aflatoxin was reduced between 80-90% on average in the commercial field tests, with a 93-95% reduction on average achieved when AF-36 was applied between V7-V10 growth stages (Cotty 2008). Dorner (2010) conducted a 2 year study to determine the efficacy of Afla-Guard ® in reducing aflatoxin contamination in corn. Dorner's study was also carried out in Texas, in 2007 and 2008. In 2007, the mean concentration of aflatoxin contamination in treated fields was reduced by 85% compared to control fields not treated with Afla-Guard ®. In 2008, the mean concentration was reduced by 88% (Dorner 2010).

2.6 Sources of Risk

The atoxigenics obviously work in decreasing the amount of aflatoxin contamination on an annual basis, but their cost combined with testing variability and sporadic aflatoxin contamination leaves the producer with multiple risky decisions that can affect net revenue. The following scenarios were described by personal communication with crop insurance experts in Central Texas. First, the decision to use the atoxigenics will impact net returns, due to the atoxigenic cost, the application cost, and the possible benefit the atoxigenic may provide. The decision to use atoxigenics is risky because it is difficult to predetermine if the year will be one with severe aflatoxin contamination, and the decision to use atoxigenics must be made prior to tasseling of the corn plant. If the producer chose to use atoxigenics, and the growing year resulted in ideal environmental conditions for corn, it is likely the overall level of aflatoxin contamination will be minimal and the atoxigenic would prove to be a net cost instead of a net benefit. Conversely, if the producer chose not to use atoxigenics and the growing year resulted in extreme environmental stress with large quantities of aflatoxin contamination, the absence of atoxigenics could force the producer to realize the full economic loss of the severe aflatoxin contamination.

Aflatoxin contamination test variability is a source of risk to the buyer and the seller because contamination is randomly distributed throughout kernels. The implications this creates are potentially detrimental to the buyer and seller. The sporadic contamination presents two unfavorable and inaccurate test result possibilities; a false positive or a false negative. If a false positive occurs, the lot of corn has tested higher for overall aflatoxin contamination than it actually has. If a false negative occurs, the lot of corn has tested lower for overall aflatoxin contamination than is actually has.

The possibility of inaccurate test results is also a source of risk with regard to reconciliation between any discounted value at the local grain elevator and crop insurance indemnity payments. The RIV, or market discount, is determined by the local elevator aflatoxin test, and the calculation for crop insurance indemnities is based on a separate test completed by an approved third party testing facility. The local elevator tests and pays based on truckloads of corn, and crop insurance tests and pays indemnities based on insured fields. An insurance adjustor is either sent out to the insured field to gather corn samples for an aflatoxin test, preharvest, or some corn is left standing postharvest or the local elevator purchasing corn will save samples from all tested loads.

Then the insurance adjustor will obtain these samples for the appropriate field or fields, combine the samples by field, and remove a subsample to test for aflatoxin contamination. The testing variability has the potential to discount producers at the local market price for aflatoxin contamination, then the insurance test could result in a less severe aflatoxin contamination level, and this could fail to trigger an indemnity payment for an already discounted market sale.

One method available to avoid the discrepancy in test results is the One Sample Strategy. The One Sample Strategy is a training and certification process for Texas grain elevators that allows aflatoxin tests done at certified local elevators to be the same test results used in crop insurance calculations (OTSC 2013c). Currently, 12 grain elevators in Texas are certified for this method and their aflatoxin test results can be used in crop insurance adjustments (OTSC 2013b). The ability to use one test for both outlets decreases the possible variation between two separate tests, but does not affect the issue of false positives or false negatives.

Producers and local elevators also have the choice on whether to test loads or fields of corn. If the year results in exceptionally favorable growing conditions, with higher than average yields, the producer may choose to decline an insurance aflatoxin test. The producer may do this to avoid the test fee, and because they know at the percentage of average yield they have insured, with an above average yield there would be inadequate disparity between the RPG/VPG and the VPTC to trigger an indemnity payment. A local elevator will usually only test an individual load of corn once, but because there is variability in kernel contamination a test result could be extremely high or low simply based on which kernels made up the sample used in the test. If a load of corn tests higher than 300 ppb at one elevator, it is common practice for that truck to drive to the next closest grain elevator and have the corn retested in attempt to obtain a test result lower than 300 ppb, and have the ability to make a sale to the elevator.

3. LITERATURE REVIEW

The biological background and research concerning mycotoxins and specifically aflatoxin is substantial. However, the literature discussing economic risk surrounding the incorporation of atoxigenic treatments into farming practices is very slim. One study has been found that discusses the cost-effectiveness of aflatoxin control methods, by Wu et al. (2008). Two additional studies explore the variability surrounding aflatoxin testing procedures in corn (Johansson et al. 2000, Park et al. 2007).

Wu and colleagues analyzed AF-36 in cottonseed, Bt corn, and Afla-Guard in peanuts to determine the dollar range of net benefit these aflatoxin control methods provide to producers of the respective crops. The paper analyzed the cost per acre associated with aflatoxin contamination through a price differential of lowest aflatoxin contamination, 20 ppb or what would be categorized as dairy feed, compared to higher contamination levels. The price differential was then related to the percentage of the total harvest that had aflatoxin levels above 20 ppb. The net benefit per acre was found using the percent efficacy of the control method in reducing aflatoxin levels to a point where growers receive the full price for their crop, multiplied by the cost of aflatoxin contamination, then deducting the cost of applying the respective control method.

The results of Wu's paper estimated the net benefits of the atoxigenic control methods as follows: AF-36 in cottonseed to be between -$0.62 to $34 per acre and Afla-Guard in peanuts to be between -$16.50 to $49. Wu and colleagues described the negative values in the low end of the ranges as accounting for the fact that some years aflatoxin is not expected to cause a large problem, so the cost of application would slightly exceed the benefits. Wu et al. also note that expected benefits of applying AF-36, and expected cost, are likely to change over time based on the application frequency and cost of the atoxigenic. If AF-36 is applied annually, the year to year carryover effects have not yet been determined. Another point made in the paper, is the consideration of the cost of the atoxigenic in comparison to the total value of the crop production per acre. For example in Wu's research, the cost of AF-36 application represents only 3% to 12% of the total value of the cottonseed production, in years when aflatoxin would be naturally low.

Wu and colleagues present three case studies that demonstrate how cost-effectiveness of aflatoxin control methods can be evaluated, with a comparison of point estimates of expected benefits and costs. These estimates do not account for risk and uncertainty. By accounting for risk and uncertainty surrounding crop yields, market prices, aflatoxin contamination levels, and cost of the atoxigenic, probability distributions can be developed to better inform the producer about the potential economic costs and benefits associated with the use of atoxigenics. Incorporating risk and uncertainty into the analysis can provide a more realistic representation of the possible situations and outcomes of using these atoxigenic control methods (Richardson and Mapp 1976).

The following two studies demonstrate the variance surrounding aflatoxin testing in corn, the components that make up this variance, and the respective impact the components have on aflatoxin test results. Test variance is a key area of risk surrounding aflatoxin contamination, atoxigenic use, and the affect these have on a producer's bottom line.

In 2007, Johansson and colleagues published a study that estimated variance components of testing shelled corn for aflatoxin. Through regression analysis, mathematical equations were developed to model the relationship between aflatoxin concentration, and the total, sampling, sample preparation, and analytical variances. The mathematical expressions developed can be used to estimate the variance, dependent on sample size, subsample size, and number of aliquots for a specific aflatoxin concentration level when using a Romer mill and liquid chromatography (LC) testing procedure. LC is compatible for the Aflatest method, which is commonly used in Texas testing facilities. Two experiments were performed; one experiment was an unbalanced nested procedure to estimate the total variance, combined variance of sample preparation and analyses, and the sampling variance. The first experiment used 18 lots of corn, with a bulk sample size of 45.4 kg taken from each lot. Each bulk sample was divided into 32 test samples of 1.13 kg each and each test sample was comminuted in a Romer mill. Fifty gram subsamples were removed from the 32 samples and tested for aflatoxin concentration level.

The second experiment was designed to attain estimates of the analytical variance. The sampling variance represents the variability among replicate test samples taken from the same lot of shelled corn. Sample preparation variance represents the variability among replicate subsamples taken from the same sample comminuted in a suitable mill. The analytical variance represents the variability among replicate aliquots of extracts of a single subsample.

The variance estimates obtained from the two experiments were modeled, and general positive linear relationships were established between aflatoxin concentration level, testing procedure steps, and the total variance of an aflatoxin test. The mathematical relationships, specific to 1.13 kg samples and 50 g subsamples, were then modified to predict the variance for any given sample size. Equation 11 below, describes this modified mathematical relationship. Ĉ is the sample concentration level of aflatoxin in the load of corn. Ns is the sample size in kilograms, nss is the subsample size in grams, and na is the number of aliquots. The result of this equation, $S^2_{\hat{C}(t)}$, estimates the total variance in an aflatoxin test.

(11) $$s^2_{\hat{C}(t)} = \left[\left(\frac{12.95}{ns}\right)\hat{C}^{0.98}\right] + \left[\left(\frac{62.70}{nss}\right)\hat{C}^{1.27}\right] + \left[\left(\frac{0.143}{na}\right)\hat{C}^{1.16}\right]$$

With equation 11, a lot of corn with 20 ppb aflatoxin, using a 1.13 kg sample, Romer mill, 50 g subsamples, and LC analysis, the total, sampling, sample preparation, and analytical variances were 274.9 (CV=82.9%), 214.0 (CV=73.1%), 56.3 (CV=37.5%), and 4.6 (CV=10.7%) respectively (Johansson et al. 2000). In conclusion, and consistent with testing for aflatoxins in other commodities, sampling contributes the most variability, followed by sample preparation, then analysis.

Park and colleagues (2007) produced a similar study, determining the variability associated with testing shelled corn for aflatoxin using different analytical procedures in Louisiana in 1998. Their study compared analysis results of 100 lots of shelled corn from 10 elevators in Louisiana, to analysis results from the Louisiana Agricultural Chemistry (LAC) laboratory. Park and colleagues used two 4.5 kg samples, from each of 10 lots of shelled corn being processed at 10 different elevators in Louisiana. Each 4.5 kg sample was ground and two 50 g subsamples were then taken from each comminuted sample and tested for aflatoxin, one at the local elevator and one at the LAC laboratory. The Aflatest method was used in both the elevator laboratories and the LAC laboratory, and high-performance column liquid chromatography (HPLC) was used at the LAC laboratory only. Results showed using the Aflatest method, mean aflatoxin levels determined at elevator laboratories were significantly ($P<0.5$) lower from those obtained in the LAC laboratory, by 46.2%. Also, Aflatest method results were lower than values obtained by HPLC.

The variability associated with the aflatoxin test procedure was measured using the variance statistic. The total variance was determined as a sum of the sampling, sample preparation, and analytical variances. From regression analysis, the total variances for the Aflatest and HPLC methods were determined, in 1998 in Louisiana, and appeared to be a function of aflatoxin contamination. Equation 12 describes the total variance for the Aflatest method, and equation 13 describes the total variance for the HPLC method. C represents aflatoxin contamination level.

(12) $S^2_{tla} = 2.80 \text{ x } C^{1.282}$

(13) $S^2_{tlh} = 4.714 \text{ x } C^{1.203}$

Conclusions from Park and colleagues (2007) state the difference between local elevator aflatoxin test results and LAC laboratory results may be attributed to analyst technical ability, difficulty in providing careful attention to detail in a high throughput environment, and/or substandard laboratory facilities found at the elevators. In their experiment, Park and colleagues estimated the total variance level associated with HPLC and Alfatest methods to be 173.2 (CV=65.8%) and 130.7 (CV=57.2%), respectively. The main source comprising total variability for both the Aflatest and HPLC methods were the sampling and sample preparation steps of an aflatoxin testing procedure.

Estimating the true amount of aflatoxin in a lot of shelled corn is difficult because of the distribution of contaminated kernels in the lot (Johansson et al. 2000). Both studies (Johansson et al. 2000, Park et al. 2007) estimated a mathematical relationship to solve for the variance of an aflatoxin testing method, in an attempt to quantify the uncertainty associated with the distribution of contaminated kernels in a lot of corn. Johansson and colleagues (2000) created a general mathematical relationship that can be used to predict total variance for any sample size, subsample size, and aliquots taken, using a Romer mill and LC testing analysis. The LC testing analysis is used in the Aflatest analytical method. Park and colleagues developed a mathematical relationship specific to the aflatoxin testing methods, Aflatest and HPLC, and to aflatoxin test results from these methods in Louisiana in 1998. To compare the variance results of the mathematical relationships developed in each study, assume there is an estimated concentration of aflatoxin in a lot of corn of 20 ppb. Above, the results of total variance of each study have been listed, for the respective equations used in each study. Now if we apply the 20 ppb concentration, the weight of Park's et al. (2007) sample and subsample (4.5 kg and 50 g), assume 1 aliquot, and the Aflatest or LC method to the general variance equation 11 that Johansson et al. (2000) created, the result is 114.66 compared to 130.70 which is the variance determined by Park et al. (2007). The results are similar, based on a quick comparison between the two equations in the two respective studies.

The review of literature above describes the lack of economic analysis research on the integration of atoxigenics into corn farming practices. Additionally, the two latter studies performed by Johansson et al. (2000) and Park et al. (2007) demonstrate the large variance associated with aflatoxin testing and the contributing components to this variance. The large variance associated with aflatoxin testing increases the risk involved with aflatoxin contamination in corn. The use of atoxigenics cannot directly decrease this variance but it could decrease the overall aflatoxin concentration level in a field of corn. Both Johansson et al. (2000) and Park et al. (2007) concluded that there is a positive linear relationship between aflatoxin contamination levels and variance associated with aflatoxin tests. By decreasing overall aflatoxin contamination levels, the testing variance can be decreased, and therefore the risk associated with testing variance, and consequently net revenue, will be decreased.

4. THEORY

This section will serve to provide a foundation of the theory used behind the methodology for the present study's risk ranking analysis. Risk and uncertainty will be defined, along with a description of degrees of risk aversion. The subjective expected utility function will be discussed in addition to methods of conducting a risk ranking analysis with different efficiency criteria.

4.1 Risk and Uncertainty

Risk and uncertainty are characteristic of agricultural businesses. Both can be found throughout agriculture; in production yields, input costs, market prices, interest rates etc. These are all variables that the decision maker cannot control. Hardaker and colleagues (2004a) define uncertainty as imperfect knowledge, and risk as uncertain consequences, especially with regards to unfavorable outcomes. Anderson and Dillan (1992) state that while uncertainty is always present in decision making, risk is only present when uncertainty about the decision will affect the decision maker's (DM) wellbeing. To cope with these risky choices the decision maker must compare the available risky choices. There are several methods available to make this comparison. Clearly put, risk is the part of a business decision, the DM cannot control (Richardson 2008).

4.2 Risk Classifications

Each DM will view risk differently, and this will affect the decisions they make. Generally, individuals are considered risk averse, risk neutral, or risk loving (Nicholson and Snyder 2012). Risk averse implies the DM has a utility function that expresses decreasing marginal utility of income or wealth, but more wealth or utility is still preferred to less. (Hardaker et al. 2004a). A risk averse individual will prefer a level of income that is certain compared to a risky income that has the same expected value. Additionally, a risk averse person will be willing to pay a certain amount of wealth to avoid the risk involved in a gamble, and the greater the variability in the gamble, the more the person would be willing to pay to avoid the risk (Nicholson and Snyder 2012). In agriculture, it is assumed that the majority of farmers are risk averse (Hardaker et al. 2004a) and the current study is based on this assumption.

Within these three risk classifications, there are degrees of risk aversion. One corn producer can be more risk averse than another and appropriate degree classification of risk aversion is crucial to accurate risk analysis. One way to determine the degree of risk aversion is to measure the curvature of the individual's utility function. Since the utility function is defined only up to a positive linear transformation, this measure is difficult to attain. Arrow (1965) and Pratt (1964) proposed degree of risk aversion be measured by an absolute risk aversion coefficient (ARAC) or $R_a(w) = U''(W)/U'(W)$. This equation implies the DM is more willing to take on risk, the ARAC decreases, as the level of wealth increases. According to Hardaker and colleagues (2004a) the degree of risk aversion is more important than the choice of the utility function, in risk ranking analyses.

The ARAC allows researchers to make comparisons between risk aversion levels but the ARAC does not account for currency differences between countries. The inability of the ARAC to be robust across currencies obviously limits the comparison power. To supplement this issue, Arrow (1965) and Pratt (1964) revised the ARAC by multiplying it by W to create the relative risk aversion coefficient (RRAC).

$$ARAC = U''(W)/U'(W) \qquad RRAC = ARAC * W$$

The RRAC has the same advantages of the ARAC, with an additional advantage that its outcome variable does not change when using a different unit of measurement (Meyer and Meyer 2006). RRAC is an elasticity of U(W), allowing it to have the usual advantages of using elasticity instead of slope when measuring the effect of change in a variable.

The ARAC is a local measurement of risk aversion, and at different levels of wealth the degree of risk aversion will vary (Hardaker et al. 2004). Arrow (1965) and Pratt (1964) also defined three classifications as to how the degree of risk aversion varies with increasing levels of wealth. A utility function will display either constant, increasing, or decreasing absolute risk aversion if the $R_a(W)$ remains constant, increasing, or decreasing, respectively, with an increase in risk (Jehle and Reny 2001). The three classifications are decreasing absolute risk aversion (DARA), which defines the DM as less averse to small risks at higher levels of wealth. Increasing absolute risk aversion (IARA), which states the more wealth a DM has the more risk averse they will be. Thirdly, constant absolute risk aversion (CARA), states the DM does not change their risk aversion level with an increase in wealth.

4.3 Subjective Expected Utility

For each DM, there exists a utility function that is based on the DM's expectations about risk and their subjective view on the probability of the risky alternatives taking place. The subjective probabilities led Hardaker et al. (2004a) to conclude there is a subjective expected utility (SEU) function for each DM. The SEU is defined as, $SEU = U(w_i) = \Sigma(P_i * U(w_i))$, with $U(w_i)$ being the utility of wealth in state i and P_i being the probability of that wealth in state i occurring. If for a set of risky outcomes, one can determine or elicit the probabilities of each outcome and the amount of wealth each outcome would provide, the most efficient option would be the one that provides the most utility to the DM. The theory of this method would require a unique utility function be developed for each individual DM, and if the probabilities are subjective based on the DM's expectations about risk, the process of accurately obtaining these SEU functions is tedious and unrealistic.

4.4 Certainty Equivalents

Instead of the direct approach above, the certainty equivalents (CE) method can be used to rank risky alternatives. Hardaker et al. (2004a) describes a CE as a sum of money that would make the DM indifferent between a certain amount of money and a risky payoff. In the figure below the assumed utility function, U(W), shows diminishing marginal utility based on the concept of satiation and suggests the DM's utility curve is risk averse. If the CE method is used to rank a risky alternative, the risk averse DM will prefer a risky prospect to a sure thing only if the CE of the former is greater than the actual value of the latter. Figure 4.1 depicts this; a risk averse DM was offered gamble "A" with a 50/50 chance of winning \$h or losing \$h. The utility of current wealth is $U(W_0)$ which is also the expected value of the current wealth because it is certain. The expected utility, if the DM participates in the gamble, is EU(A). $EU(A)=1/2U(W_0+h) + 1/2U(W_0-h)$ and this also equals the $U(CE_a)$. This states the certain wealth of CE_A provides the same expected utility as does participating in the gamble. The DM prefers to keep their current wealth instead of taking the gamble, as W_0 and $U(W_0)$ is greater than both CE_A, EU(A), and $U(CE_A)$. This method still requires a unique and individual utility function for each DM.

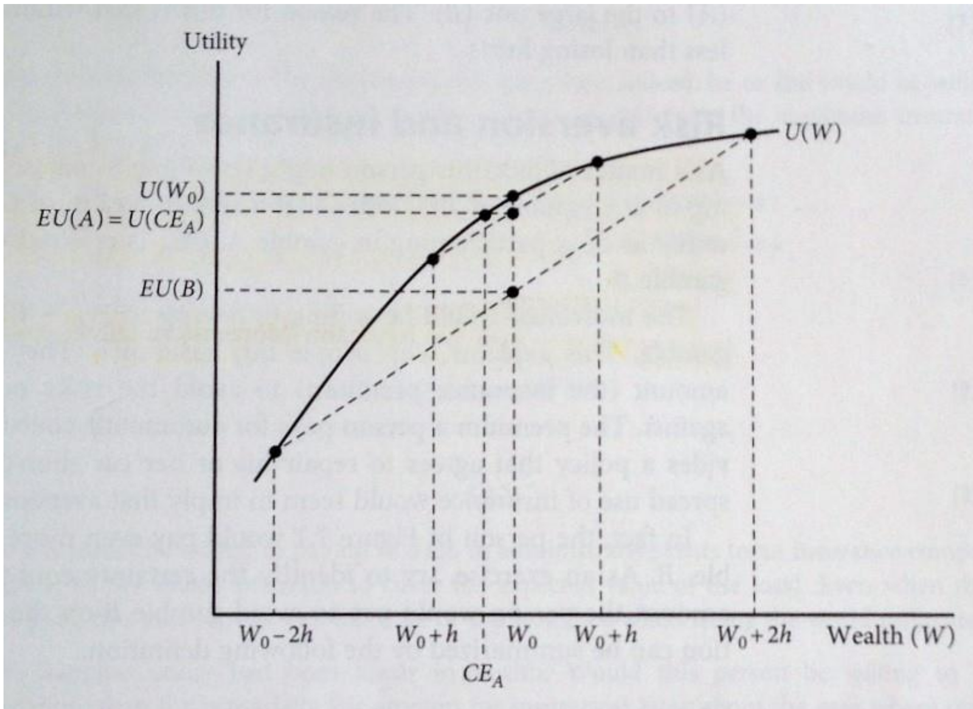

Figure 4.1. Utility of wealth, adapted from Nicholson and Snyder (2012)

4.5 Second Degree Stochastic Dominance

Instead, a decision guideline is needed, for a range of DMs whose degree of risk aversion will vary. A common efficiency criterion, given risk aversion, is second degree stochastic dominance (SSD) (Hardaker et al. 2004b). SSD again assumes the DM is risk averse for all values of wealth and prefers more wealth to less. If two risky options are graphed on one cumulative distribution function (CDF) chart, in Excel SSD calculates the sum of the difference between the distributions over the range graphed (Richardson 2008). SSD can calculate the preferred option over a general range of risk aversion, but SSD does not discriminate enough to yield useful results for an efficient set of preferred options.

4.6 Stochastic Dominance with Respect to a Function

An alternative to SSD is stochastic dominance with respect to a function (SDRF). Here the risk aversion bounds are reduced to $r_L \leq r \leq r_U$, or the risk aversion coefficient (RAC) is defined between an upper and lower bound (Meyer 1977). SDRF could then rank the defined risky scenarios for all DM, using the same method as SSD, at the respective lower and upper bound of the RAC. Still SDRF does not provide enough discrimination power between risky options within the bounds of the risk aversion coefficient.

4.7 Stochastic Efficiency with Respect to a Function

To remedy this issue, Hardaker et al. (2004b) developed the method of stochastic efficiency with respect to a function (SERF). SERF is a more straightforward way to rank risky options. It is more transparent, easier to implement, and has stronger discriminatory power than SDRF. SERF orders a set of risky alternatives in terms of CEs for a specified range of relative or absolute risk aversion coefficients (Hardaker et al. 2004b). SERF was created when Hardaker, Richardson, Lien and Schumann (2004b) merged the use of CEs and Meyer's range of risk aversion coefficients. SERF assumes a utility function with a risk aversion range, but instead of evaluating CEs at the two extreme RACs, the upper and lower bound, it evaluates CEs for many RACs between the lower RAC and the upper RAC (Richardson 2008). SERF shows the preference of the alternatives, over a range of RACs for multiple alternatives at a time. Due to this, SERF creates a smaller efficient set of risky choices compared to the efficient set that

SDRF produces, this allows for a more confident decision making process (Hardaker et al. 2004b) and produces the desired guideline for DMs within a range of RACs.

SERF can be used with many utility functional forms. In the present study, an annual analysis is required and the change in income is small relative to W_0, the original wealth, therefore a negative exponential function form with CARA assumption will be used for the utility analysis. SERF will be used to rank the efficient set of risky alternatives, assuming a risk averse individual.

5. METHODOLOGY

5.1 Simulation

Risky variables must be simulated to estimate probability distribution functions (PDF) and cumulative distribution functions (CDF) of possible outcomes for the variables in question. Simulation allows for the estimation of these distributions, and provides the DM with more accurate and relevant information about key economic variables. The PDF and CDF are visual representations of the possible outcomes and demonstrate how likely each outcome is. Monte Carlo simulation techniques allow risk to be included in the analysis to determine a preferred set of options around the decision. Monte Carlo simulation is used for this study, with Latin Hypercube sampling. Using Simetar ®, the model will incorporate the stochastic variables, be solved over 500 iterations, and provide a statistical representation of the possible outcomes and likelihood of the outcomes. The first step to develop a stochastic model is to determine the critical stochastic variables that influence the decision, and develop probability distributions for the variables that are stochastic in nature.

The critical stochastic variables are simulated and used as input to the model to simulate the impact of stochastic variables on the decision variables. To appropriately simulate a random variable, the shape of the distribution for the random variable must be defined and the parameters for the distribution must be estimated (Pouliquen 1970). The best way to simulate a random variable is to remove all structural variability possible. Once this is done, the residuals are used to calculate parameters for possible forms of the distribution. Several candidate distributions for the residuals can be simulated and the best candidate can be determined by summing the difference between the simulated and actual historical probability distributions, and the distribution with the least error is the preferred distribution shape for the random variable. Once the shape of the best distribution is determined, the random variable can be simulated in the model (Richardson 2008). Simetar ® provides a function for comparing candidate distributions to the historical data to pick the best distribution.

The current study will simulate and estimate probability distributions for the critical stochastic variables: yield, market price, and aflatoxin contamination level, specific to Bell County, Texas. Two distributions are simulated for aflatoxin contamination level, with respect to fields treated and not treated with an atoxigenic. The stochastic variables are used to calculate separate stochastic net revenues for each insurance option available, in the treatment and no treatment decision. The insurance options available are yield protection, revenue protection, and revenue protection with harvest price exclusion. Each of the three insurance options have coverage levels, in 5% increments, from 50%-85%. In total, accounting for each insurance option, and coverage level available under the treatment and no treatment scenario, and the option of no insurance under each scenario, there are 50 simulated choices.

5.2 Validation and Verification

Verification and validation will be practiced when simulating the stochastic variables. Verification requires the theoretical soundness of the output variables be checked, verifying the order of equations, typed calculations, and cell references are correct. Validation can be completed through hypothesis testing. The stochastic variables are univariate, so validation will be accomplished by comparing the historical mean to the simulated mean, as well as the historical variance to the simulated variance. Failing to reject the null hypotheses, which states the historical mean and variance statistically equal the simulated mean and variance, respectively, validates the soundness of the simulated values in comparison to the historical values (Richardson 2008).

5.3 Model Development

After developing the probability distributions for the stochastic variables, they must be linked to their deterministic counterparts to calculate stochastic revenues and insurance indemnities in the full model. For example, yield is a critical stochastic value that will impact the net revenue. The stochastic yield value will be multiplied by the number of acres in production to calculate total production of corn, which is used to calculate crop insurance indemnities, receipts and net income.

The appropriate mathematical and accounting equations are set up to correctly incorporate the critical variables, to solve for the stochastic key output variable net revenue. The stochastic net revenues will be simulated and used in a SERF ranking analysis to determine the efficient set of options, given the available crop insurance coverage types and levels and the option of treating or not treating corn with an atoxigenic.

5.4 Data

The estimated costs and returns of corn for 2013 in District 8 of Texas, were developed by Texas A&M Agrilife Extension (Johnson 2013). The cost of the atoxigenic treatment, $11/acre, and the aerial application, $5/acre, was included in the budget, for treated scenarios. The cost of the atoxigenic treatment was an average cost of the two methods currently available to corn producers in Texas (Pirtle, Double CT 2013), and the aerial application cost was based off of personal communication with Pirtle Crop Insurance (Pirtle 2013).

The aflatoxin test field data came from Georgia Pirtle, of Pirtle Crop Insurance, in Bell County, Texas, also located in District 8. The aflatoxin test results span 3 years, 2011, 2012, and 2013, and report the aflatoxin test results in ppb for 110, 92, and 114 fields, respectively, as well as if the field was treated with an atoxigenic or not (Pirtle 2013). The test results are from a disinterested third party testing facility used for insurance purposes. Stochastic aflatoxin contamination values were simulated from this data and will be used to calculate indemnity payments for crop insurance. Crop insurance farmer premium costs were calculated from USDA's Risk Management Agency's Quick Estimate tool (RMA 2014).

The indemnity payments will be added to actual producer revenue to calculate total gross revenue. Historical yield data for Bell County is from the National Agricultural Statistics Service (NASS) of USDA, using yields from 2000-2012 (NASS 2013b). The corn yields will be simulated to provide stochastic yield values for the model. Historical prices also came from USDA, using the US annual national price average from 2003-

2012 (NASS 2013b). The model assumes a $5.00/bu (Welch 2013) mean corn price to effectively capture the recent diminishing market price increases. The model assumes a 500 acre corn operation.

6. RESULTS

The results are presented in this section for Bell County, Texas. Stochastic simulation results will be presented for critical variables, market revenue, and indemnity payments. Market revenue, indemnity payments, and atoxigenic costs will be incorporated into the partial budget and net revenue simulation results will be compared for all the insurance options available.

6.1 Stochastic Variable Results

Three stochastic critical variables were included in the present study. The variables are yield in bushels/acre (bu/acre), market price in $/bushel ($/bu), and aflatoxin contamination level for treated (TAF) and non-treated scenarios (NTAF) in ppb. Treated denotes the use of atoxigenics during the corn production cycle. Simulation results for these stochastic variables follow.

Yield was simulated with a Weibull distribution, and reported a simulated average of 73.10 bu/acre and a coefficient of variation (CV) of 19.21%. Market price of corn was simulated with a mean of $5/bu, an Empirical distribution based on historical variability about the mean, and reported a simulated average of $5.09/bu and CV of 19.54%.

Four distributions were simulated for aflatoxin test results in corn; treated local (TL), non-treated local (NTL), treated insurance (TI), and non-treated insurance (NTI). Treated and non-treated define corn that was treated with the atoxigenic or not treated, respectively. Local describes corn tested for aflatoxin at the local elevator, and insurance defines corn tested by a disinterested third party aflatoxin testing facility for insurance purposes. The data available from Bell County reports aflatoxin test results from a disinterested third party insurance testing facility, and segregates the results by treated and non-treated fields. The data were used directly, to simulate distributions for TI and NTI test results. Using past literature on test variance between local facilities and a state testing laboratory (Park et al. 2007), each random draw for the stochastic test result variable was multiplied by 53.8% to simulate local test results. The two additional test result distributions, TL and NTL, were created using this method. Empirical distributions were used for all four test simulations and summary statistics are reported in table 6.1.

Table 6.1. Summary Statistics of Simulated Aflatoxin Contamination Test Results

Variable	TI	NTI	TL	NTL
Mean ppb	4.87	73.60	2.62	39.65
StDev ppb	25.85	140.49	13.92	75.71
CV %	530.31	190.87	531.77	190.93
Min ppb	0.00	0.00	0.00	0.00
Max ppb	270.02	730.35	145.27	392.94

TI=treated, insurance
NTI=not treated, insurance
TL=treated, local
NTL=not treated, local

In the summary statistics both the simulated mean and maximum aflatoxin values, in ppb, are much higher for non-treated fields under both insurance and local test results. The cumulative distribution function (CDF) graph in figure 6.1 shows that NTI and NTL have a higher probability of testing at 20 ppb or greater.

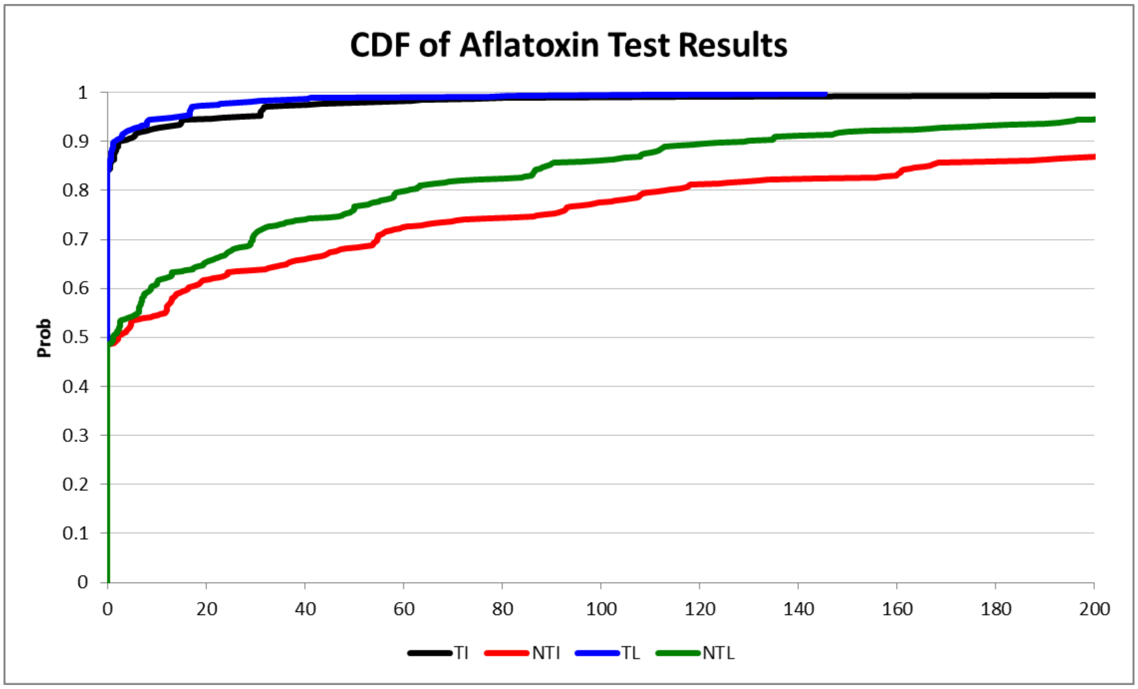

Figure 6.1. CDF of simulated aflatoxin test results
TI=treated, insurance
NTI=not treated, insurance
TL=treated, local
NTL=not treated, local

6.2 Market Revenue

The stochastic variables listed above were incorporated into corn production equations to solve for total production and gross market revenue. Stochastic yield multiplied by total acres in production, 500, results in total bushels of corn production. It was assumed that all corn production was transported to a local grain elevator by semi-trucks that carry 1000 bu of corn per load, and each semi load was tested for aflatoxin at the local elevator. Aflatoxin contamination was determined, per load, using a stochastic aflatoxin test value draw. Each semi load was allowed three stochastic aflatoxin draws. If the first draw was over 300 ppb, it was assumed the semi drove to the next closest elevator and had the corn retested. If the second draw was under 300 ppb the corn was sold to that elevator, but if the second draw was also over 300 ppb the semi would again go to the next closest elevator and have the corn retested. A cost of $0.17/bu, or $170, was applied to the load each time it tested over 300 ppb, or in other words there was a transportation cost when the semi had to drive to the next closest elevator. When a semi load had a stochastic aflatoxin draw of over 20 ppb, a corresponding discount was applied to the market price of that load of corn. Market revenue per load of corn was calculated by multiplying 1000 bu of corn by a stochastic market price pre-adjusted for any aflatoxin discounts. Then transportation costs were subtracted, if the semi had to drive to the next closest elevator. Total market revenue was the sum of revenue from all semi loads of corn. This process was completed for both treated and non-treated scenarios, using treated local and non-treated local stochastic aflatoxin values, respectively.

Table 6.2. Summary Statistics for Market Revenue (MR), for Treated Local (TL) and Non-treated Local (NTL)

	MR TL	MR NTL
Mean $/ac	376.68	350.73
StDev $/ac	105.90	98.99
CV	28.11	28.23
Min $/ac	134.90	121.41
Max $/ac	771.50	717.90

MR TL=market revenue, treated local
MR NTL=market revenue, no treatment local

The market revenue was simulated and the summary statistics are reported in table 6.2. The market revenue summary statistics for the TL and NTL scenarios show an obvious difference. The simulated mean revenue is $12,810 higher, or $25.62 per acre, for the treated scenario when compared to the non-treated scenario. The minimum and maximum revenues are both higher for the treated scenarios. This advantage strongly suggests there is a clear benefit to using atoxigenics in corn production in Central Texas.

Atoxigenics cost approximately $11/acre with an additional $5/acre aerial application fee. With a total cost of $16/acre to employ atoxigenics in this model, and a total of 500 acres, the total cost of atoxigenics is $8000. The net benefit of using the atoxigenics is $4810 or $9.62 per acre in this simulation.

Under the treatment scenario the percentage of semi loads that were over 20 ppb (Trucks>20 ppb T) had a simulated mean of 2.88% while the non-treated scenario (Trucks>20 ppb NT) had a simulated mean of 33.08%. Table 6.3 reports the summary statistics for the percentage of trucks testing over 20 ppb for aflatoxin, in treated and non-treated scenarios. The non-treated scenario also had a simulated mean of 2.91% for trucks testing over 300 ppb.

Table 6.3. Summary Statistics for Simulated Semi-truck Aflatoxin Test Values

	Trucks>20 ppb T	Trucks>20 ppb NT
Mean	2.88%	33.08%
StDev	2.81%	7.95%
CV	97.28	24.04
Min	0.00%	4.17%
Max	13.64%	62.16%

6.3 Crop Insurance Results

The stochastic yield, market price, and aflatoxin values were also used to calculate stochastic indemnity payments for all crop insurance options available. The crop insurance options are yield protection (YP), revenue protection (RP), and revenue protection with harvest price exclusion (RPHPE). With each insurance option, an average yield coverage level ranging from 50-85% in 5% increments must be chosen. For example, TYP60%, means treated scenario, with yield protection insurance and 60% average yield coverage. With the addition of treatment with no insurance (TNONE) and no treatment with no insurance (NTNONE), there are 50 crop insurance options available to corn producers in Central Texas.

A value of production guarantee (VPG) was determined for each insurance option, based on the 500 acres with an average yield of 72 bu/acre, and the insurance option and coverage level chosen. Then a value of production to count (VPTC) was calculated using the stochastic market price, stochastic yield, and stochastic aflatoxin value. Based on these calculated values, an indemnity was paid when the VPG was greater than the VPTC, of a sum equal to VPG-VPTC. When an aflatoxin test is prepared for insurance purposes, one sample is taken for the entire insured field, instead of each load of corn being tested as happens at the local elevator for market discount purposes. Stochastic crop insurance indemnities were calculated for all combinations of insurance options and coverage levels, and a no insurance option, for both a treatment and non-treatment scenario.

The stochastic indemnities were simulated, and overall results consistently show treatment scenarios have a lower mean indemnity payment as well as lower probability of indemnity payment occurring (table 6.4). For example, summary statistics are compared between treated and non-treated scenarios under RP across coverage amounts in table 6.4. In table 6.5, the probability of indemnity payment occurring is consistently higher in non-treatment scenarios compared to treatment scenarios. The lower probability of payment in treated scenarios can be explained by the atoxigenic decreasing the risk of aflatoxin contamination and therefore decreasing the risk of revenues below the VPG.

Table 6.4. Summary Statistics, Dollar Amounts per Acre of Simulated Mean Indemnity Payments

	TRP 85%	TRP 80%	TRP 75%	TRP 70%	TRP 65%	TRP 60%	TRP 55%	TRP 50%
Mean $/ac	49.54	35.64	24.49	16.07	9.96	5.85	3.31	1.69
StDev $/ac	51.92	45.72	38.74	31.53	24.71	18.65	13.47	9.30
CV	104.81	128.26	158.18	196.15	248.12	318.88	406.62	550.26
Min $/ac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max $/ac	270.28	249.18	228.08	206.99	185.89	164.80	143.70	122.60

	NTRP 85%	NTRP 80%	NTRP 75%	NTRP 70%	NTRP 65%	NTRP 60%	NTRP 55%	NTRP 50%
Mean $/ac	91.57	75.03	60.67	48.43	38.46	30.43	24.10	19.38
StDev $/ac	95.68	91.65	86.56	80.82	74.64	68.38	62.24	56.28
CV	104.48	122.15	142.67	166.90	194.05	224.71	258.22	290.44
Min $/ac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max $/ac	358.63	337.54	316.44	295.34	274.25	253.15	232.06	210.96

T=treated, NT=not treated
RP=revenue protection
Mean=simulated mean indemnity

Table 6.5. Summary Statistics, Simulated Probability of Indemnity Payment

	TRP 85%	TRP 80%	TRP 75%	TRP 70%	TRP 65%	TRP 60%	TRP 55%	TRP 50%
Mean	71.6%	59.0%	46.0%	34.4%	23.6%	16.2%	10.0%	5.4%
StDev	45.1%	49.2%	49.9%	47.6%	42.5%	36.9%	30.0%	22.6%
CV	63.04	83.45	108.46	138.23	180.10	227.67	300.30	418.97

	NTRP 85%	NTRP 80%	NTRP 75%	NTRP 70%	NTRP 65%	NTRP 60%	NTRP 55%	NTRP 50%
Mean	81.0%	71.4%	61.0%	50.6%	41.4%	33.6%	26.4%	18.8%
StDev	39.3%	45.2%	48.8%	50.0%	49.3%	47.3%	44.1%	39.1%
CV	48.48	63.35	80.04	98.91	119.09	140.72	167.14	208.03

T=treated, NT=not treated
RP=revenue protection

Next the premiums from RMA are compared to the simulated mean indemnities. The RMA premiums listed in table 6.7 are from the USDA's Quick Estimator tool, for non-irrigated corn in Bell County, Texas. The premiums are based on 500 acres, with an average yield of 72 bu/ac, a projected price of $5.86/bu, 100% price coverage, and a price volatility factor of 0.2 for both RP and RPHPE. The additional administrative and operating expenses tied to these insurance options have been subsidized by RMA, as well as a certain percentage of the total premium cost. The producer pays a subsidized premium for each insurance option. It can also be assumed that the premium amounts were calculated based on risk associated with corn not treated with atoxigenics.

The simulated mean indemnity is considered a fair premium for each insurance option, before profit or administrative fees are accounted for. In the treated scenario the mean indemnity is consistently less than the RMA premium across all insurance options. The opposite occurs in the non-treated scenario, the mean indemnity is consistently higher than the RMA premium across all insurance options. The results of the RMA premium compared to the mean indemnity, in the non-treated scenario, is consistent with the subsidized RMA premium producers currently pay. However it is obvious that under the treated scenario, the subsidized RMA premiums are too high. Table 6.7 shows the difference between the RMA premiums and simulated mean indemnities, on a per acre basis, for RP insurance coverage. The results presented suggest the current premium pricing strategy employed by RMA is not effective or accurate if the producer decides to treat their corn with an atoxigenic.

Table 6.6. Summary of RMA Premium and Mean Indemnity Pricing Results per Acre

	TRP 85%	TRP 80%	TRP 75%	TRP 70%	TRP 65%	TRP 60%	TRP 55%	TRP 50%
Mean $/ac	49.54	35.64	24.49	16.07	9.96	5.85	3.31	1.69
RMA Prem $/ac	52.29	36.10	26.62	19.74	16.00	11.98	10.20	8.01
Difference $/ac	(2.75)	(0.46)	(2.13)	(3.66)	(6.04)	(6.13)	(6.89)	(6.32)

	NTRP 85%	NTRP 80%	NTRP 75%	NTRP 70%	NTRP 65%	NTRP 60%	NTRP 55%	NTRP 50%
Mean $/ac	91.57	75.03	60.67	48.43	38.46	30.43	24.10	19.38
RMA Prem $/ac	61.77	43.02	31.81	23.81	19.53	14.61	12.38	9.64
Difference $/ac	29.81	32.02	28.86	24.62	18.94	15.82	11.72	9.74

TRP=treatment revenue protection
NTRP=no treatment revenue protection

As seen in table 6.6, it pays producers to not treat with an atoxigenic, and harvest corn contaminated with aflatoxin. From simulation results, this is a valid conclusion even with the additional risk of each semi load tested at the elevator for aflatoxin, compared to one test to represent the field aflatoxin level for insurance purposes. The cause of this can be seen in the probability distribution, in figure 6.2, of aflatoxin insurance test results in non-treated and treated fields. In corn not treated with an atoxigenic (NTI), there is an overall higher probability of testing at 20 ppb or greater for aflatoxin in corn, opposed to corn treated with an atoxigenic (TI) which has a higher probability of testing under 20 ppb. Literature suggests local elevator tests are consistently about 45% lower than insurance testing facilities and this partially compensates for the additional risk in multiple tests at the local elevator compared to one test for insurance.

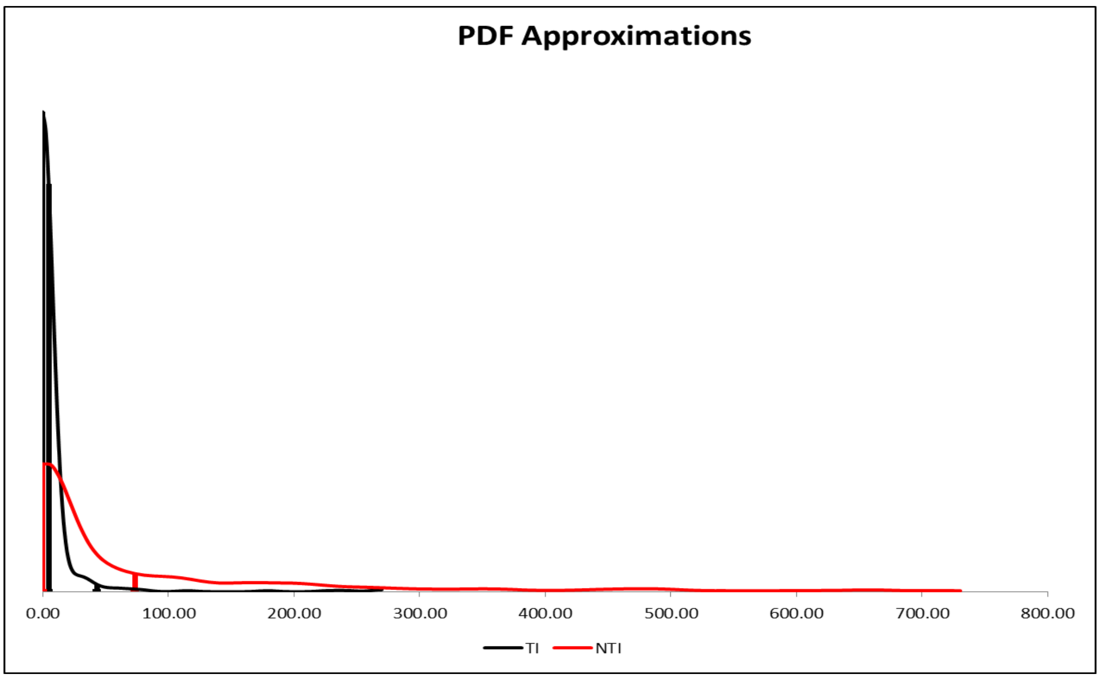

Figure 6.2. PDF of aflatoxin contamination in corn, treatment and no treatment scenarios
TI=Treated insurance
NTI=Not treated insurance

When corn is treated with an atoxigenic, the risk of aflatoxin is decreased and therefore the probability of payment and the amount of the indemnity is also decreased. Due to these factors, the crop insurance premium cost should also be reduced for corn treated with atoxigenics.

6.4 Fair Premiums

In attempt to effectively compare treated and non-treated scenarios, under all crop insurance levels available, the RMA premiums were replaced with fair premiums for all insurance options in treated and non-treated scenarios. The fair premiums are simulated average indemnity payment, and do not include any profit margins or administrative fees. Previously, table 6.6 showed these fair premiums and compared them to current RMA premiums.

6.5 Partial Budget Simulation

The insurance premiums were adjusted to the fair premium amount in the partial budget. Stochastic market revenue and insurance indemnities were calculated using the stochastic yield, market price, and aflatoxin contamination variables. An atoxigenic and aerial cost was added to all treatment scenarios. Gross revenue consisted of market revenue and insurance indemnities, and costs included a fixed partial budget, the atoxigenic and aerial cost for the treatment scenarios, and varying insurance costs for the different insurance options and coverage levels. Stochastic net revenue was calculated and simulated for each insurance option under the treatment and non-treatment scenarios.

6.6 Net Revenue Simulation Results

Net revenue was simulated for a total of 50 options, 25 insurance coverage choices under the treatment scenario and 25 insurance coverage choices under the no treatment scenario. Summary statistics for the no insurance option under the treatment (TNONE) and no treatment scenarios (NTNONE) are reported in table 6.7. The StopLight analysis, figure 6.3, shows the respective probabilities of unfavorable, cautionary, and favorable net revenue results, between the range of $0 to $70,000 for the TNONE and NTNONE options. The analysis indicates with the TNONE option, the DM has a 37% chance of netting over $70,000 and a 14% chance of a negative net revenue. With the NTNONE option, there is a 30% chance of a net revenue over $70,000 and a 15% chance of a negative net revenue.

Table 6.7. Summary Statistics for Net Revenue under TNONE and NTNONE Scenarios

	TNONE	NTNONE
Mean $/ac	107.22	97.19
StDev $/ac	105.00	97.35
CV	97.93	100.16
Min $/ac	-149.21	-135.39
Max $/ac	522.17	470.53

TNONE=treatment, no insurance
NTNONE=no treatment, no insurance

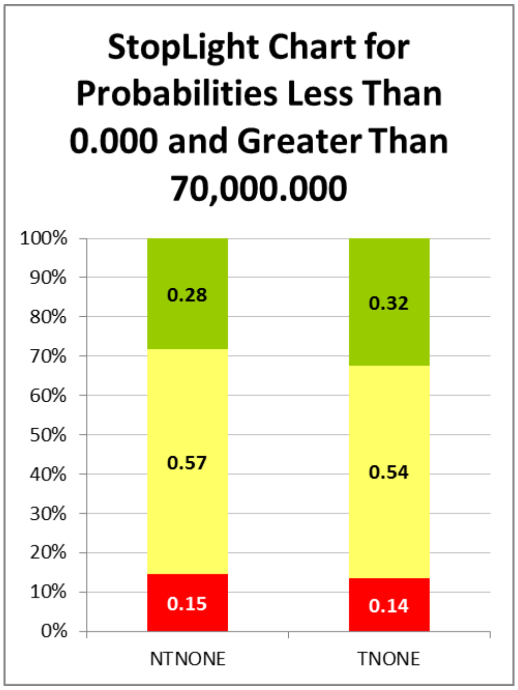

Figure 6.3. StopLight analysis of TNONE and NTNONE, based on simulate net revenues for each scenario

TNONE=treatment, no insurance
NTNONE=no treatment, no insurance

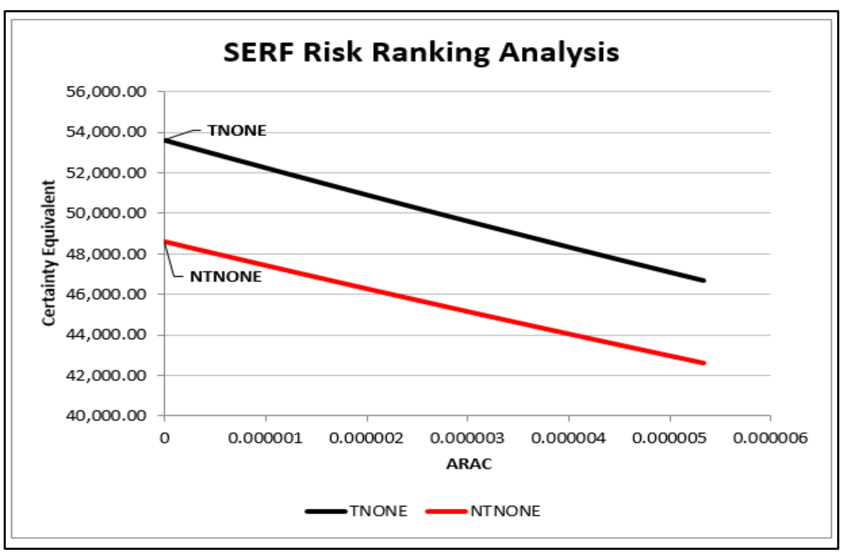

Figure 6.4. SERF risk ranking analysis comparing TNONE and NTNONE, based on simulated net revenue for each scenario

Additionally, the SERF ranking chart in figure 6.4 above shows the additional benefit in terms of a certainty equivalent (CE) dollar amount that the TNONE provides over the NTNONE. From risk neutral to risk averse, the TNONE provides an added benefit of about $5000 to $4000, respectively.

The net revenue results that included opting for insurance, were compared within their respective coverage groups first. All treatment yield protection (TYP) coverage levels were compared to each other, all treatment revenue protection (TRP) levels were compared to each other, and all treatment revenue protection with harvest price exclusion (TRPHPE) levels were compared to each other. The same was done for the no-treatment insurance options. Within each comparison, the top ranked option from the CE ranking chart in the SERF analysis was noted. This yields a group consisting of the top 8 risky options to compare; TYP85%, TRP85%, TRPHPE85%, NTYP50%, NTRP50%, NTRPHPE50%, TNONE, and NTNONE.

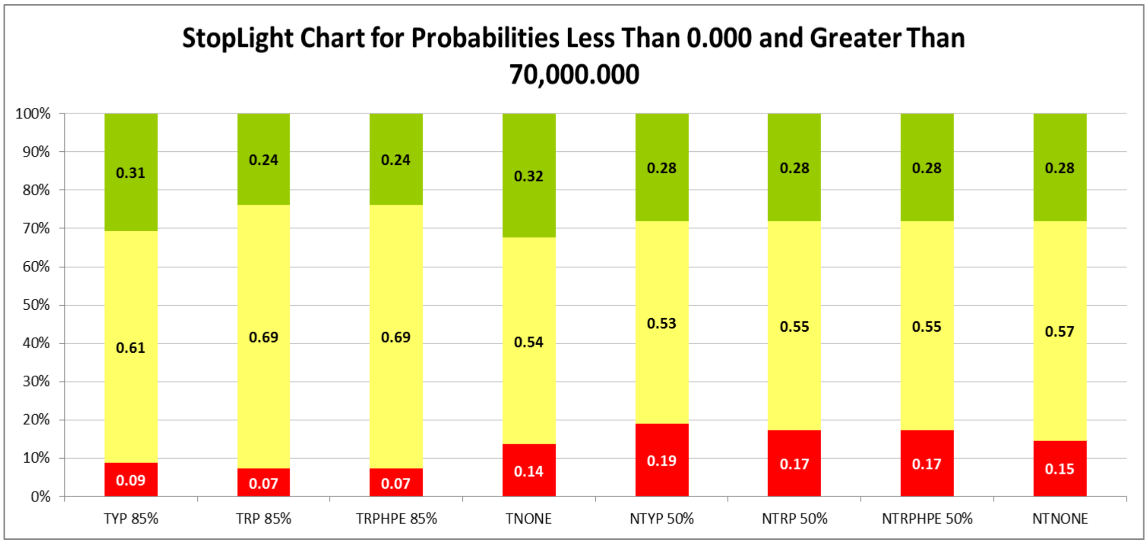

Figure 6.5. StopLight analysis of the top 8 choices, based on net revenue simulation results

TYP85%=treatment, yield protection, 85% average yield coverage
TRP85%=treatment, revenue protection, 85% average yield coverage
TRPHPE85%=treatment, revenue protection with harvest price exclusion, 85% average yield coverage
NTYP50%=no treatment, yield protection, 50% average yield coverage
NTRP50%=no treatment, revenue protection, 50% average yield coverage
NTRPHPE50%=no treatment, revenue protection with harvest price exclusion, 50% average yield coverage
TNONE=treatment, no insurance
NTNONE=no treatment, no insurance

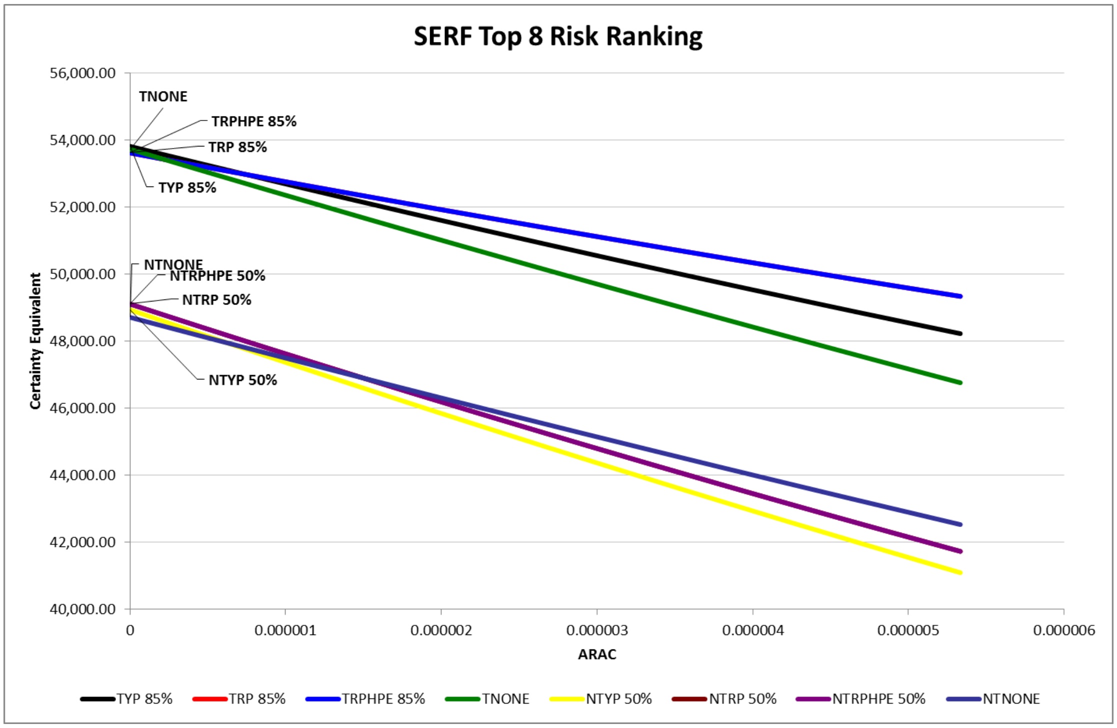

Figure 6.6. SERF risk ranking analysis of the top 8 choices, based on net revenue simulation results

TYP85%=treatment, yield protection, 85% average yield coverage
TRP85%=treatment, revenue protection, 85% average yield coverage
TRPHPE85%=treatment, revenue protection with harvest price exclusion, 85% average yield coverage
NTYP50%=no treatment, yield protection, 50% average yield coverage
NTRP50%=no treatment, revenue protection, 50% average yield coverage
NTRPHPE50%=no treatment, revenue protection with harvest price exclusion, 50% average yield coverage
TNONE=treatment, no insurance
NTNONE=no treatment, no insurance

The StopLight graph in figure 6.5 shows the treatment options in the top 8 set are less risky in terms of producing a lower probability of generating a negative net revenue. Conversely, figure 6.5 also demonstrates the no treatment options with RP and RPHPE result in a 4% greater probability of yielding a net revenue over $70,000 when compared to the treatment scenario of those two options.

The risk ranking analysis in figure 6.6 shows a definite preference of the treated options over the no treatment options, for all ARACs from risk neutral to fairly risk averse. Note, the treatment RP and RPHPE and no treatment RP and RPHPE have the exact same outcome, because the 2013 projected price was greater than the harvest price.

To conclude the results, prior to the introduction of crop insurance there is a definite simulated monetary benefit of applying atoxigenics to a corn crop in Central Texas. The monetary benefit ranges from $4000-$5000, for risk averse to risk neutral DMs, respectively. For the 500 acre operation that was simulated in this model, the atoxigenic monetary benefit equates to an approximate $8-$10 per acre increase in net revenue to the producer. When crop insurance is added to the model, given existing RMA premium costs, simulation and risk analysis results show the most efficient option is NTRP85% or a no treatment decision with revenue protection crop insurance with an 85% average yield coverage level. The discrepancy between the monetary benefit atoxigenics provide compared to the most efficient option produced by simulation and risk analysis can be explained by the premium pricing strategy. Current premiums are priced based on risk involved with corn not treated with atoxigenics. When an atoxigenic is used, the risk of aflatoxin contamination is reduced therefore reducing some components contributing to the risk of revenue or yield loss the crop insurance will cover. By using fair premiums equal to the simulated average indemnity payment for all insurance options, a more consistent risk ranking can be conducted. A risk ranking analysis of the simulated net revenue outcomes, using a fair premium pricing schedule, show the most efficient options are those using an atoxigenic.

7. SUMMARY AND CONCLUSIONS

Atoxigenics and crop insurance are available to producers to assist in preventing economic loss from aflatoxin contamination in corn. The problem surrounding these tools is a lack of economic analysis to assist farmers in making the most informed and economically reasonable decisions concerning their individual production practices. Atoxigenics are a newer technology available to farmers, and although professional opinion of this biotechnology encourages its use, an economic analysis has not been performed to determine if the atoxigenics are overall economically beneficial to the industry when combined with other tools such as crop insurance.

The current study uses Simetar ®, an Excel add on, to estimate a risk based partial budget simulation model combined with an aflatoxin contamination simulation model. With simulated net revenue results for 2013, a risk analysis is conducted on the decision to use atoxigenic mitigation methods. SERF was used to estimate a risk ranking for risk neutral to fairly risk averse DMs, based on simulated net revenues for all insurance options available under an atoxigenic treatment and no treatment scenario. Field level data on aflatoxin contamination levels are from Bell County, Texas. The current study should assist the decision maker by considering the risk of aflatoxin contamination, contamination level, aflatoxin test discrepancies, cost of the atoxigenic, cost of the insurance, indemnity payments, and stochastic market prices and local yields.

The objective of this paper was to perform an economic analysis on the decision to use available atoxigenic treatments on a corn crop, and evaluate the economic outcome at different crop insurance levels for corn producers in Central Texas.

Results show atoxigenics do provide a monetary benefit to producers, prior to accounting for crop insurance premiums or indemnities. Considering only two scenarios, either treat with the atoxigenic and do not purchase crop insurance or do not treat with the atoxigenic and do not purchase crop insurance, the atoxigenic provided a simulated average net benefit of $8-$10 per acre for fairly risk averse to risk neutral DMs, respectively.

Crop insurance premiums for 2013, set by RMA, and simulated indemnity payments were incorporated into the model for all crop insurance options available to corn producers in Bell County, Texas under a treatment and no treatment scenario. Preliminary simulated average indemnity payment results indicated that compared to the premiums set by RMA, premiums for no treatment insurance options were too low and premiums for treatment insurance options were too high. When net revenues were simulated with the RMA premiums, results concluded that DMs obtained the most benefit from not treating, and purchasing a revenue protection or revenue protection with harvest price exclusion insurance option, with 85% average yield coverage.

To correct for over and underpriced premiums, in attempt to more specifically deduce possible economic benefits of atoxigenics when combined with insurance options, RMA premiums were replaced by the simulated average indemnity payment for each insurance option, or in other words a fair premium. After incorporating the fair premiums into the net revenue model, a risk ranking of the simulated net revenues indicated the treatment scenario, for YP, RP, RPHPE, and no insurance was more efficient than the no treatment scenario. Across all 25 insurance options, including no insurance, when the treatment scenario was compared to the no treatment scenario, treatment provided the DM with additional total monetary benefit of $4000-$8000, or $8-$16 per acre, for fairly risk averse to risk neutral DMs when net revenue was simulated with fair premiums.

There is a discrepancy between this model and industry opinion, areas where risk may be understated or overstated in this model need to be determined to more accurately represent the scenarios. Many avenues of further study are available for this topic. The current study was completed on a specific region, and expansion of the areas incorporated in the study would be beneficial. Incorporating the one sample strategy, briefly discussed in Section 2, has potential to cut down test variation between insurance and local test results. Adjusting the model to reflect the one sample method could quantify a dollar amount of money saved by removing additional test variance. There is a discrepancy between this model and industry opinion, areas where risk may be understated or overstated need to be determined to more accurately represent the scenarios. Further investigation into the premium pricing issue, for treated compared to not treated, could be beneficial to facilitating premium discounts to producers that use the atoxigenics, which would incentivize new technology incorporation into production practices and benefit all parties involved.

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