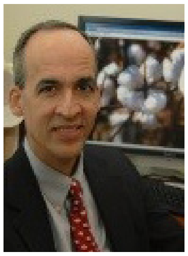
Farm Program Selection Using a Risk Programming Approach



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Abstract

U.S. crop producers have historically managed risk by participating in federal price and income support programs. While early farm programs focused on reducing agricultural output, programs in the last two decades have become structured more like insurance. Calculating payments from current programs has become more involved and deciding which programs will best fit a producer's needs is, unfortunately, not always straightforward. The choice of which Title I farm program to enroll in is modeled as a quadratic integer programming problem. This framework is used to determine optimum program selection for representative upland cotton production in Hale County, Texas.

INTRODUCTION

Agricultural production is inherently risky. It requires the investment of capital and labor months before the output is produced and before the value of the product is known. Although the value of agricultural products may, on average, cover the cost of inputs, there are years when they do not. In the case of upland cotton, unprofitable outcomes are unfortunately common (Liu, 2024). For agricultural firms to continue, they must be able to invest in production, year after year, until long-term averages make the enterprise successful.

Historically, U.S. crop producers have managed risk in the near term by participating in federal price and income programs (Mercier and Halbrook, 2020). While early farm programs focused on reducing agricultural output, programs in the last two decades have become structured more like insurance. Calculating payments from the various programs has become more involved, and the decision of which programs will best fit a producer's needs is, unfortunately, not always straightforward. This paper provides some guidance on risk management in general and farm program selection in particular. It examines the choice faced by cotton producers in Hale County, Texas, a county that was chosen for several reasons: Texas is the nation's largest cotton producer (USDA, 2025), and in 2018, the Texas High Plains produced 66% of Texas cotton and 30% of U.S. cotton. In that year, Hale County produced more cotton than any other county in the U.S. (Plains Cotton Growers, 2025).

The Title 1 farm programs available to U.S. cotton producers are the result of a series of events involving the U.S., Brazil, and the World Trade Organization (WTO), which are detailed by Schnepf (2018). Under threat of WTO-sanctioned retaliation by Brazil, the U.S. made upland cotton ineligible to participate in the Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) programs of the 2014 Farm Bill. Retaliation was avoided when both countries signed a memorandum of understanding that prevented the U.S. from subsidizing upland cotton except through 2014 farm bill programs such as the Stacked Income Protection Plan (STAX) and Marketing Assistance Loans.

In the years following the 2014 Farm Bill, the National Cotton Council lobbied for restored/increased federal support for U.S. cotton, owing to unfavorable market conditions. In addition to the hardships faced by the industry, brought about by unfavorable market conditions, the new system incentivized producers to grow commodities that still enjoyed government support. This industry lobbying contributed to an emergency supplemental bill H.R. 4667, which was passed in December 2017 and provided emergency assistance to producers of "seed cotton," a heretofore nonexistent commodity comprising both lint and seed products. This legislation paved the way for the re-inclusion of cotton subsidies in the farm bill, and in 2018, seed cotton was included as a titled commodity and made eligible for enrollment in ARC and PLC.

As a result, there are a number of different support programs now available to cotton producers that can be partitioned into two main groups. The first group uses farm-level data to calculate payments while the second group does not. The first group also includes programs that rely both directly and indirectly on farm-level data to calculate payments. An example of a program that relies directly is ARC – Individual (ARC-I). An example of one that relies indirectly is the Supplemental Coverage Option (SCO). Payments for this option are calculated using county-wide data, but SCO must be accompanied by an insurance policy that calculates premiums and indemnities based on farm-level data.

The second group includes a set of programs that rely strictly on county-level data and is limited to PLC, the county level of ARC (ARC-CO), and STAX. This study will limit the choice set to programs in the second main group that do not rely on farm-level data. The limitation in scope is justified for several reasons, including that while inclusion of all available options would be more complete, it would transform this work into a case study, reducing its generality. From a practical policy perspective, the three options compared in this paper account for most of the cotton acres enrolled in Title I farm programs.

The programs under consideration were designed as risk management tools. In theoretical terms, they can be viewed as lotteries with non-negative returns, that is, farm program choices have risky, albeit mostly non-negative financial outcomes. From this perspective, the problem of program selection becomes similar to the stock portfolio selection problem, which is a more familiar research scenario.

As in choosing a stock portfolio, there is a tradeoff between risk and expected return when enrolling in different farm programs. For instance, in this study, average PLC payments are significantly higher than average ARC payments. Unfortunately, the higher expected return of PLC is accompanied with a higher level of variance, making returns less certain. This study presents a framework for analyzing this tradeoff and shows how it relates to producer risk aversion.

LITERATURE REVIEW

The question of which stocks to include in an investment portfolio was addressed in a seminal paper by Markowitz (1952). His key insight was that investors do not choose a portfolio that maximizes the future value of discounted returns; instead, people are willing to forego some return in exchange for a reduction in risk. His model was able to account for the preference for diversification observed in actual portfolios.

Four years after Markowitz, Freund (1956) independently developed a multi-objective, quadratic programming model that incorporated the same insights as Markowitz. Freund's model is expressed as:

(1) $Max\ \bar{C}'X - \emptyset X^{\wedge\prime}\, SX$

(2) $S.T.\ \ A'X \quad \leq b$

(3) $X \quad \geq 0$

where X is a vector of choice variables corresponding to the levels of stocks purchased, $\bar{C}$ is a vector of expected returns on the stocks under consideration, A is a vector of stock prices, S is a variance-covariance matrix of the returns, B is the amount someone wants to invest in their portfolio, and $\emptyset$ is a parameter that captures risk aversion. We use this approach to model the subsidy selection problem and determine the optimal choice for a producer displaying the average level of risk aversion for cotton producers in Hale County, Texas.

There is a small amount of scholarly literature focusing on cotton policy selection, e.g., Graff et al. (2023) compared STAX and SCO to PLC and ARC-CO under different scenarios to demonstrate how different combinations of subsidy programs can be used to manage risk. Educational bulletins such as by the USDA Farm Services Agency (2018) are more typical of available publications.

There are various examples of stand-alone or online decision aids as well, and the simplest of these involve Microsoft Excel spreadsheets with formulas that allow producers to enter production data and calculate static payments. Other tools, such as the one developed by the University of Illinois (2024), give the probability of payment and the expected payment amounts for different programs. Texas A&M University developed a tool that uses Monte Carlo simulation to derive the efficient frontier for the tradeoff between risk and expected payment for alternative farm management decisions (AFPC, 2024). None of these approaches involve optimization using linear or quadratic programming, though.

The purpose of this paper is to describe the implementation of an optimization framework that uses expected returns and the variance of those returns for making these types of decisions.

METHODS

The creation of the new farm program commodity—seed cotton—immediately raised the question of how to calculate its price. For the purposes of this study, it is important to also be able to calculate historic prices.

The market year average (MYA) price of seed cotton is a weighted average of the price of upland cotton lint and the price of cottonseed. More specifically, it is a weighted average of the revenue generated by upland cotton lint production and the revenue produced by cottonseed. If we define the gross value of lint production as:

$$\textit{lint value} = \textit{U.S.upland cotton lint production} \ast \textit{U.S.upland cotton lint MYA price} \tag{4}$$

and

$$\textit{cottonseed value} = \textit{U.S.cottonseed production} \ast \textit{U.S.cottonseed MYA price} \tag{5}$$

then the MYA price seed cotton can be calculated as:

$$\textit{seed cotton MYA price} = \frac{(\textit{lint value} + \textit{cottonseed value})}{(\textit{U.S.upland lint production} + \textit{U.S cottonseed production})} \tag{6}$$

With a price in hand, it is now possible to calculate subsidy payments. The analysis begins with PLC. Payments for this program depend critically on two parameters, the reference price and the price floor—for seed cotton, the reference price is set at $0.367 per pound, and the price floor is set at $0.25 per pound.

Calculating PLC payments requires three steps. First, one must derive the seed cotton payment yield, which is calculated as:

$$\textit{seed cotton payment yield} = 2.4 \ast \textit{lint yield} \tag{7}$$

Next, one calculates the PLC payment rate in dollars per pound:

$$\textit{PLC payment rate} = \textit{reference price} - \textit{MAX}(\textit{MYA price, price floor}) \tag{8}$$

Finally, the PLC payment in dollars per base acre enrolled can be calculated as:

$$\textit{PLC payment} = \textit{PLC payment rate} * \textit{payment yield} * 0.85 \tag{9}$$

To calculate ARC-CO payments, it is first necessary to calculate the benchmark seed cotton price. It is an Olympic average of the previous five years' seed cotton price, meaning it is an average of the second, third, and fourth highest values from that period. Similarly, the benchmark seed cotton yield is the Olympic average of the seed cotton yield for the previous five years.

The benchmark revenue is:

$$\textit{benchmark revenue} = \textit{benchmark seed cotton MYA price} \ast\ast \textit{benchmark seed cotton yield} \tag{10}$$

The ARC-CO guarantee is set at:

$$\textit{ARC} - \textit{CO guarantee} = \textit{benchmark revenue} \ast 86\% \tag{11}$$

The actual revenue is:

$$\textit{actual revenue} = \textit{U.S.Seed Cotton MYA price} \ast \textit{seed cotton yield} \tag{12}$$

The maximum possible ARC-CO payment is limited to:

$$\textit{maximum ARC} - \textit{CO payment} = 10\% \ast \textit{benchmark revenue} \tag{13}$$

The revenue shortfall is defined as:

$$\textit{revenue shortfall} = \textit{ARC} - \textit{CO guarantee} - \textit{actual revenue} \tag{14}$$

Once all of these components have been calculated, they can be used to calculate the ARC-CO payments for each enrolled base acre using the following formula:

$$\text{ARC– CO payment} = \text{MIN}(\text{maximum ARC– CO payment}, \text{revenue shortfall}) * 85\% \tag{15}$$

The STAX program was first made available to cotton producers in the 2014 Farm Bill, and it remains available today. Unlike the ARC and PLC programs, STAX payments are based on cotton lint, rather than the newer commodity seed cotton.

Enrollment in STAX precludes producers from enrolling in ARC or PLC. It can be purchased in conjunction with other insurance or as a standalone policy. STAX covers up to 20% of the adjusted area revenue, but a producer enrolling in STAX must choose values for two parameters. The first is the protection factor (PF), which has a range between 80% and 120% in 1% increments; the second value is an area loss trigger (ALT), which has a range from 75% to 90% in 5% increments.

Once a producer chooses an ALT, their choice determines the coverage range (CR), which is equal to the ALT minus the higher of the coverage level of any companion policy in effect and 70%. For example, with an ALT of 90% and a companion policy with a coverage level of 65%, the STAX CR would be 20%. With a companion policy that covered 80% of revenue, the CR would be 10%.

Before calculating the STAX indemnity, one must first calculate the expected area revenue and the actual area revenue. The expected area yield area yield is a 30-year average for the county in which the farm is located. The expected price, also referred to as the projected price, is the average of the daily settlement prices during the price discovery period for the Intercontinental Exchange (ICE) December cotton futures contracts. The expected area revenue is the product of the expected area yield and the expected price. The harvest price is the average settlement price for the ICE December cotton futures contracts in the harvest period, and the actual area revenue is the product of the actual area yield and the harvest price.

STAX only pays if the actual area revenue is less than the area loss trigger percentage, chosen by the producer, of the expected area revenue. When a STAX indemnity is paid, it can be calculated in the following manner:

$$\text{STAX indemnity} = (\text{expected area revenue} * \text{loss trigger} * \text{coverage range}) *$$

$$(MIN\left(\frac{MAX\left(\left(loss\ trigger - \frac{actual\ revenue}{expected\ revenue}\right),0\right)}{coverage\ range},1\right)) \tag{16}$$

For example, suppose the producer chooses a protection factor of 120%, an area loss trigger of 90%, and a companion policy with a coverage range of 70%. Also, suppose the expected area yield is 800 pounds per acre, the actual area yield is 750 pounds per acre, the expected price is 90 cents, and the harvest price is 85 cents. In that case, the expected revenue is 800*0.90 = $720.00, and the actual revenue is 750*0.85 = $637.50. The indemnity is:

$$STAX\ indemnity = (720 * 1.2 * 0.2) * \left(MIN\left(\frac{MAX\left(\left(0.9 - \frac{637.50}{720}\right),0\right)}{0.2},1\right)\right) = \$12.60 \tag{17}$$

Optimal program selection was determined by solving a multi-objective, non-linear mathematical program using the following notation:

- X1: percent of available base acres enrolled in PLC
- X2: percent of available base acres enrolled in ARC-CO
- X3: percent of available base acres enrolled in STAX
- C1: average net return on PLC in dollars per acre
- C2: average net return on ARC-CO in dollars per acre
- C3: average gross return on STAX in dollars per acre
- ∅: risk aversion parameter
- V_{ij}: the covariance between the returns on *i* and *j*. When *i* = *j*, V_{ij} represents the variance of the returns on *i*.

The problem of program selection becomes:

$$Max\ C_1 X_1 + C_2 X_2 + C_3 X_3 - \emptyset \begin{bmatrix} X_1X_1V_{1,1} & +X_1X_2V_{1,2} & +X_1X_3V_{1,3} \\ +X_2X_1V_{2,1} & +X_2X_2V_{2,2} & +X_2X_3V_{2,3} \\ +X_3X_1V_{3,1} & +X_3X_2V_{3,2} & +X_3X_3V_{3,3} \end{bmatrix} \tag{18}$$

$$S.T.\ X_1 + X_2 + X_3 \leq 1 \tag{19}$$

$$X_1, X_2, X_3 \in \{0,1\} \tag{20}$$

Before solving the model, the parameters must first be estimated. Hale County, Texas, was chosen as the geographic area, and a time series of each of the three programs was constructed, including every year from 1987 to 2021. Although these programs have only been available since 2014, the underlying data used to calculate the payment amounts is available for this entire period. To account for inflation, market year average prices from 1987 to 2014 were adjusted to 2014 values using the Consumer Price Index.

∅ is estimated using a method similar to (Brink and McCarl, 1979). This method calibrates the model by choosing a reference year and choosing a value of ∅ that minimizes the difference between the model solution and the values chosen by producers in that year. The method described in this paper varies slightly by using the average from several years to determine the reference values. The average participation rates for PLC by cotton producers in Hale County from 2014 to 2022 was 90%. The participation rate for ARC-CO was 10% and participation in STAX was negligible.

The following model was used to estimate ∅:

$$(21)\quad Max\ C_1X_1+C_2X_2+C_3X_3-\emptyset \begin{bmatrix} X_1X_1V_{1,1} & +X_1X_2V_{1,2} & +X_1X_3V_{1,3} \\ +X_2X_1V_{2,1} & +X_2X_2V_{2,2} & +X_2X_3V_{2,3} \\ +X_3X_1V_{3,1} & +X_3X_2V_{3,2} & +X_3X_3V_{3,3} \end{bmatrix}$$

$$(22)\quad \text{S.T. } X_1+X_2+X_3 \leq 1$$

$$(23)\quad X_1, X_2, X_3 \geq 0$$

Unlike in the first model presented, the choice variables are continuous, so in other words, constraint (20) is different than (23). This model was solved for different values of ∅, using an iterative algorithm until the levels chosen by the model matched observed proportions. The original model was then solved by using the estimated value of ∅ to determine the optimal subsidy selection for cotton producers in Hale County with an average aversion to risk. In addition, the integer model was solved using an iterative algorithm and different values of ∅ to determine the level of risk aversion necessary for a producer to switch from one subsidy to another.

DATA DEVELOPMENT

PLC and ARC have only been available to cotton producers since 2018. The underlying data needed to calculate what the payments would have been, however, is available going back much further. The limiting factor in this study was the need to take a 30-year average when calculating the STAX indemnities. Data was available from 1956 to the present, which allowed calculation of hypothetical STAX payments from 1987 to 2021. Data was available to calculate PLC and ARC-CO payments during this time as well, so this study spans a 34-year period.

The yearly prices and U.S. production levels of both lint and cottonseed were secured from USDA National Agricultural Statistics Service (2024). This data was then used to calculate the nominal MYA price. Significant price inflation has occurred during this period, so using nominal values would have resulted in unrealistically high payments in years early in this series—to address this issue, real prices were used for years prior to 2014. This was accomplished by using the consumer price index to adjust prices to 2014 levels.

The PLC payments were calculated in the manner previously described (Figure 1). Things to note are the high expected payment of $44.12 per acre, as well as the high degree of variation.

The ARC-CO payments were also calculated for the period in question (Figure 2), with the expected payment being $31.67 per acre; ARC-CO always pays something, and the lowest payment is $16.36 per acre. STAX projected and harvest prices were calculated using historical ICE December cotton price settlements compiled at Texas A&M University (Gleaton, 2023).

Enrollment in the STAX program requires choosing both a price loss trigger and revenue protection level, and there are many different combinations of these two factors that a producer could choose. For this paper, the combination that resulted in the highest average STAX payments was chosen, and extensive trial and error showed a loss trigger of 90% and a protection level of 70% resulted in the highest revenue. It was also assumed that any companion policy held by the producer had a coverage level of not more than 70%. Although calculating net indemnities, i.e., indemnities minus premiums, would have been more realistic, the formulas used to calculate premium levels could not be obtained. Fortunately, this was not necessary. Even if a producer received STAX free of charge, it would still underperform PLC and ARC-CO for this specific group of producers in this time interval. Figure 3 shows STAX indemnities.

Comparative statistics for all three programs are given in Table 1. PLC has the highest average payment at $44.12 per acre, and it also has the highest payment in a single year at $162.00. Despite these advantages, there are many years in which PLC pays nothing, but it is also the most volatile option, with a variance far larger than ARC-CO or STAX.

ARC-CO has the second highest expected value at $31.67 but the smallest variance of the group. In addition, it pays more than zero every single year, with the lowest payment being $16.36.

Even though given every possible advantage and offered with a premium of $0.00, STAX still has a much lower expected value than ARC-CO. In addition, it has over twice the variance of ARC-CO. It is clearly an inferior choice, and participation in this program should be within a rounding error of zero (details below).

PROGRAMMING ANALYSIS

The variance-covariance matrix for the three options is given in Table 2. Given the variances, covariances, and expected values, ∅ is estimated by repeatedly solving the following:

$$\text{(24)}\quad \text{Max } 44.12X_1+31.67X_2+10.01X_3 — \emptyset\begin{bmatrix}2885.01X_1X_1 & +157.59X_1X_2 & +409.41X_1X_3\\ +157.59X_2X_1 & +367.98X_2X_2 & +303.58X_2X_3\\ +409.41X_3X_1 & +303.58X_3X_2 & +800.59X_3X_3\end{bmatrix}$$

$$\text{(25)}\quad \text{S.T. } X_1+X_2+X_3 \leq 1$$

$$\text{(26)}\quad X_1,X_2,X_3 \geq 0$$

(27) This procedure yields $\emptyset=0.002558$

The risk parameter, ∅, is of interest in itself as it represents the willingness of producers to give up expected returns in exchange for less risk. In this case, the model is solving for the average risk aversion for a group of agricultural producers. Producers within this group, however, may be very different from each other and exhibit a wide range of values, meaning they are likely to behave differently in different situations. For instance, a producer with minimal debt and significant cash reserves can afford to be less concerned about short-term variations in income than one with high debt payments and lower cash reserves.

Solving

$$\text{(28)}\quad \text{Max } 44.12X_1 1 + 31.67X_2 + 10.01X_3 — 0.002558\begin{bmatrix}2885.01X_1X_1 & +157.59X_1X_2 & +409.41X_1X_3\\ +157.59X_2X_1 & +367.98X_2X_2 & +303.58X_2X_3\\ +409.41X_3X_1 & +303.58X_3X_2 & +800.59X_3X_3\end{bmatrix}$$

$$\text{(29)}\quad \text{S.T. } X_1+X_2+X_3 \leq 1$$

$$\text{(30)}\quad X_1,X_2,X_3 \in \{0,1\}$$

gives levels of $X_1 = 1, X_2 = 0, X_3 = 0$, indicating PLC is the preferred choice.

This model was solved repeatedly for different values of ∅ to find the point at which the levels switched to $X_1 = 0, X_2 = 1, X_3 = 0$, and this occurred when $\emptyset=0.00495$ indicating ARC-CO only becomes the preferred alternative for producers who place a weight on variability that is at least 1.935 times as high as the average producer. Enrollment numbers indicate this describes approximately 10% of producers.

CONCLUSIONS

The data from this study comes from a specific commodity and county in Texas. The general principles used here, however, can be applied to a wide range of agricultural production situations. Intuitively, there is often a tradeoff between expected returns and the risk associated with those returns. While the exact methods used in this study could be replicated in other locations, the results highlight important aspects of decision-making under uncertainty and are instructive for producers who don't want to take such a quantitative approach. The individual nature of risk aversion also implies that producers from the same region may end up choosing different options.

Risk is a complex subject, and like all models, this study is a simplification of reality that may omit important details. One of the details not taken into account is the capital reserves possessed by individual producers. For those who can farm profitably without any subsidy, or at least have enough money set aside to farm for several years in a row without receiving a subsidy, PLC is a very attractive choice. The average payout is significantly higher than that of the other available options.

On the other hand, producers with limited resources may find ARC-CO better suits their needs. It pays almost 72% as much as PLC, but it is a much more reliable source of income as it always pays something and usually pays well. For those making loan payments, this is an especially attractive feature.

While STAX may be well suited to other commodities, it is clearly the worst alternative for cotton producers in the area covered by this study.

While this study uses nothing but past data, yearly decisions are often influenced by yield and price expectations for the coming year. Forecasts for both yield and price are readily available, so looking at an expected range of prices and calculating the payoffs for each value in that range may offer an advantage over the methods presented in this paper. The relative merits of these programs also change over time. Several years of drought, as observed from 2022 to 2024 in West Texas, have substantially lowered the five-year Olympic average yield for cotton producers in that region. This has, in turn, has lowered ARC-CO payments, making it a less desirable option. At the same time, trade disputes and higher yields nationally have depressed cotton prices, increasing the likelihood that a PLC payment will be triggered. The results of this study should be viewed with the expectation that actual decisions will be heavily influenced by current market conditions.

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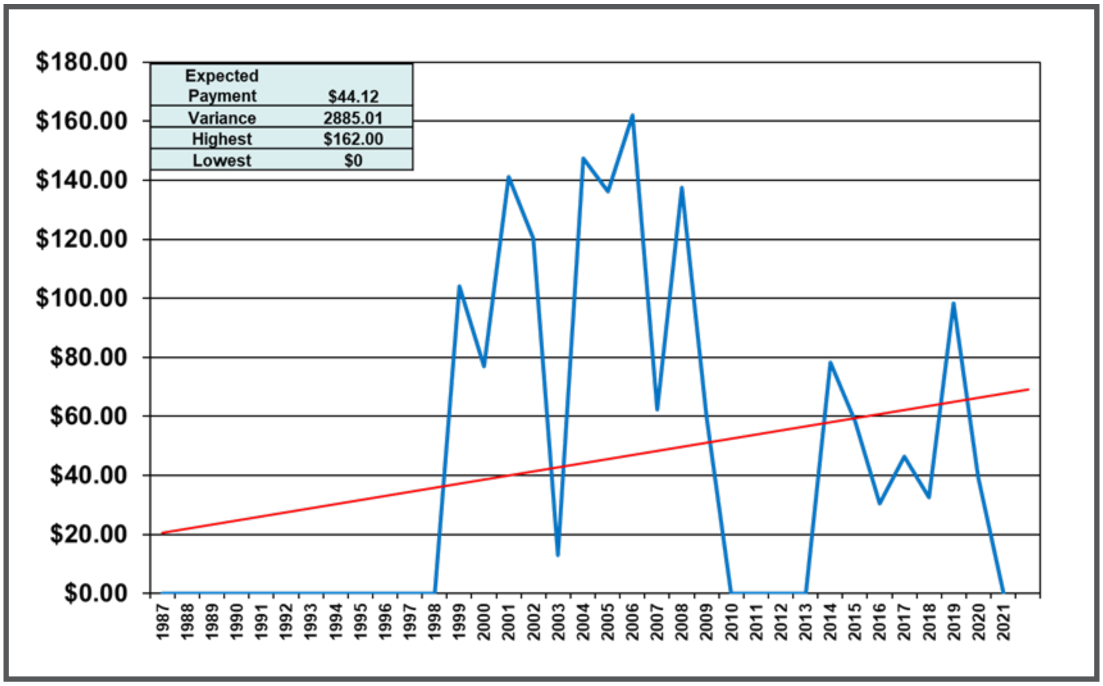

Figure 1. Price loss coverage payments per acre

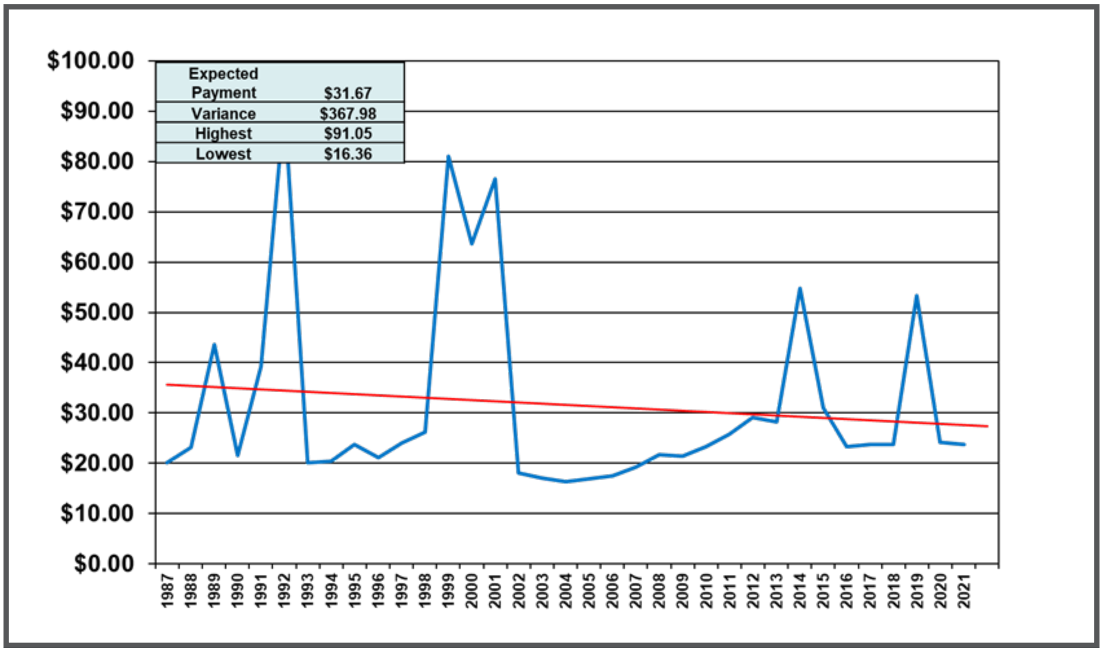

Figure 2. Agricultural risk coverage payments per acre

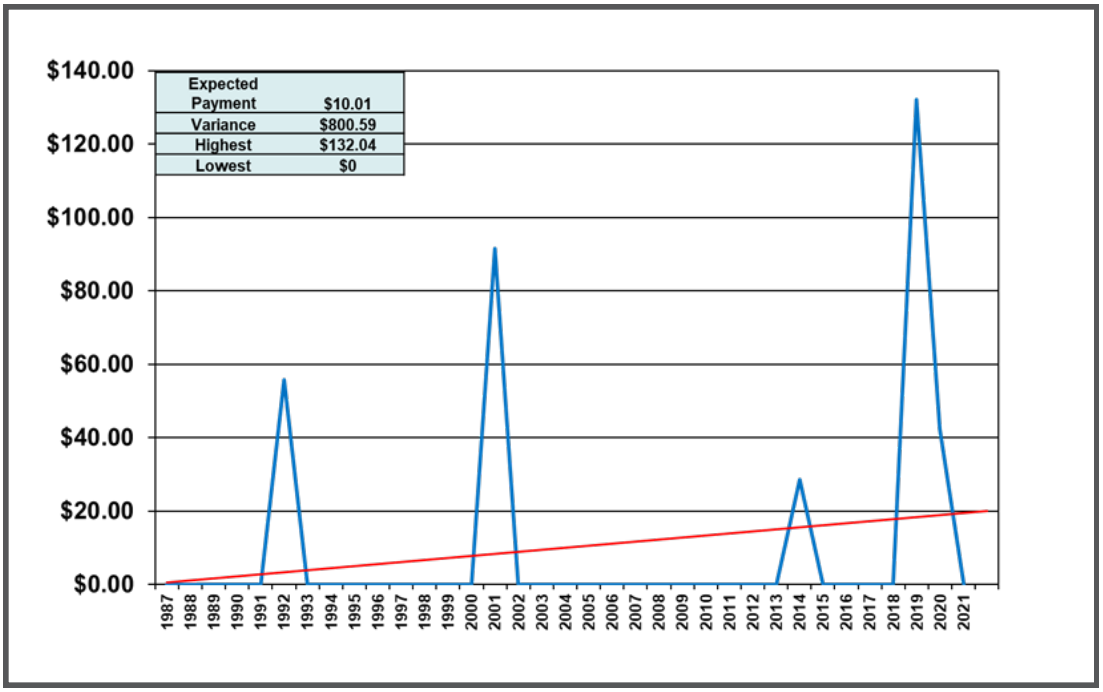

Figure 3. Stax program indemnities per acre

Table 1. Summary Statistics for Farm Program Outcomes

	PLC	ARC-CO	STAX
Average Payment	$44.12	$31.67	$10.01
Variance	$2885.01	$367.98	$800.59
Highest Payment	$162.00	$91.05	$132.04
Lowest Payment	$0.00	$16.36	**<$0.00**

Table 2. Variance-Covariance Matrix

	PLC	ARC-CO	STAX
PLC	2885.01	157.59	409.41
ARC-CO	157.59	367.98	303.58
STAX	409.41	303.58	800.59