Investigating the Implications of Multi-crop Revenue Insurance for Producer Risk Management

Corey Miller

Corresponding Authors
Keith H. Coble
Barry J. Barnett

Department of Agricultural Economics
Mississippi State University
P.O. Box 5187
Mississippi State, MS 39762

jcm5@ra.msstate.edu
Phone: (662) 325-7985
Fax: (662) 325-8777

Abstract

This study investigates the potential for alternative multi-crop revenue insurance designs in comparison to single crop yield and revenue insurance designs. A non-parametric multi-crop insurance model is developed which subsumes the single crop designs. The results compare alternative designs in terms of rate levels and risk reduction gains for representative Mississippi producers.

Keywords: crop insurance, revenue insurance, risk

Selected Paper
2000 Southern Agricultural Economics Association Annual Meeting
Lexington, Kentucky
January 29-February 2, 2000

Investigating the Implications of Multi-crop Revenue Insurance for Producer Risk Management

Corey Miller
Keith H. Coble
Barry J. Barnett[1]

Selected Paper

2000 Southern Agricultural Economics Association Annual Meeting
Lexington, Kentucky
January 29-February 2, 2000

Abstract

This study investigates the potential for alternative multi-crop revenue insurance designs in comparison to single crop yield and revenue insurance designs. A non-parametric multi-crop insurance model is developed which subsumes the single crop designs. The results compare alternative designs in terms of rate levels and risk reduction gains for representative Mississippi producers.

---

[1] The authors are graduate research assistant and assistant professors, respectively, in the Department of Agricultural Economics at Mississippi State University. The contact author is Corey Miller, P.O. Box 5187, Mississippi State, MS 39762, Telephone (662)325-7985, E-mail miller@agecon.msstate.edu.

Background

With the advent of the Federal Agricultural Improvement and Reform Act of 1996 (FAIR), interest in crop insurance instruments of all kinds has increased. While the focus on some of the more widely used instruments that insure against losses in yields has grown since this legislation became law, more fundamental has been the growth of revenue insurance, which provides protection against the combined risk of price and yield shortfalls.

In the last three years, the availability and number of different revenue insurance policies has grown on a national and regional basis. The foremost is Crop Revenue Coverage (CRC), introduced in 1996. CRC was available in 36 states in 1999, paying for losses below the yield guarantee at the higher of pre-season and harvest price. Other insurance products developed during this time include Income Protection (IP) and Revenue Assurance (RA). These instruments pay indemnities when the product of appraised yield and harvest price is less than the revenue guarantee. IP has been piloted on a few crops on a limited basis in several Southern states; RA pilot programs have generally been confined to the Midwest.

The development of revenue insurance policies resulted from the demand for greater insurance against price and yield shortfalls. In the same fashion, existing insurance policies have been augmented and others developed that provide protection against these shortfalls beyond a single enterprise. RA offers producers a multiple crop option that recognizes the diversification effect of insuring more than one crop. Adjusted Gross Revenue insurance (AGR), which provides gross revenue protection to producers without Multiple Peril Crop Insurance policies, emphasizes multiple crops and provides discounts for diversification. The success of these aforementioned insurance instruments suggests producers have an interest in insuring a portfolio of crops across the farm. The objective of this paper is to develop a model of revenue insurance that provides an insurance guarantee against shortfalls in aggregate gross revenue of multiple crops.

Rates are generated by this model for multiple crops and contrasted with comparable rates for single crop designs. These designs are compared in terms of rate levels and risk reduction gains for representative Mississippi producers. These rates are found to be lower than those of single crop designs because of the diversification effect, and risk-reducing efficiency is also higher because of more directly insuring total farm revenue (Coble, et al. 1999).

The Model

The multi-crop revenue insurance rating model is a non-parametric bootstrap simulation model which uses resampling to define the probability distribution function. The revenue distribution of each crop is assumed to be composed of the three random components of price, county yield, and farm yield deviations from the county yield. The farm yield deviations across multiple crops are important because those factors affecting one crop on a farm may also affect other crops on the same farm. The non-parametric approach was used because it does not require the parametric distributional assumptions regarding the underlying random components. The non-parametric approach is expected to be a more robust estimator capable of addressing a variety of empirical data.

To our knowledge, obtaining long time series of yields can typically only be done at the aggregate level. NASS data from 1956-98 were used, both for county yield and the historical price series. Farm yield deviations from county yields, however, combine county yields with shorter crop insurance APH yield histories from 1989-97. This avoids decreasing the farm yield variability by aggregating less than perfectly correlated yields.

Regional Yield Trend and Varability

To estimate aggregate yield, yield trend must first be estimated to create a mean stationary sample of aggregate yield variation. Changes in technology, which may vary across different crops, are incorporated by the time trend. The trend is estimated separately for each crop although it is assumed that residuals may not be independent. Equation (1) uses a spline trend estimator where g(t) is estimated county-by-county as a linear spline function with the knots constrained from the endpoints (Skees, Black, and Barnett).

(1) $R_t^C = g(t) + e_t^R$

where R_t^C = predicted county yield (for now we will drop the crop-specific subscripts i and j)

g(t) = a function of time, which may vary be county

e_t^R = residual deviations from county yield trend in year *t*

Equation (1) differs from Atwood, Baquet, and Watts who estimated trend at a multi-county regional level and then made county-specific adjustments. A predicted county yield, R_t^C, is specified in Equation (1), where county yield is a function of time represented by g(t). The residual in Equation (1), e_t^R, is used to bootstrap county yield variability. The residual deviations are percentage deviations, which should avoid potential heteroskedasticity.

Multi-Crop Farm Yield Simulation

The yield simulation may now be extended to the farm level while accounting for multiple crops. The approach to yield variability is a generalization of Miranda's approach to the multi-crop case. The model of farm yield is written in Equations (2a) and (2b):

(2a) $y_{ti}^{f} = \bar{y}_{i}^{f} + B_{ii}(R_{ti}^{C} - \bar{R}_{i}^{C}) + B_{ij}(R_{tj}^{C} - \bar{R}_{j}^{C}) + e_{ti}^{f}$

(2b) $y_{tj}^{f} = \bar{y}_{j}^{f} + B_{ji}(R_{ti}^{C} - \bar{R}_{i}^{C}) + B_{jj}(R_{tj}^{C} - \bar{R}_{j}^{C}) + e_{tj}^{f}$

where *i* and *j* are different individual crops. These two equations describe the farm yield variability for a crop *i* or *j* in year *t* as a function of the mean yield of the farm for that crop, the deviation of the county yield from the expected county yield for that crop, and the deviation of the county yield from the expected county yield for the other crop. The B_{ij}/B_{ji} coefficient accounts for the interaction between the farm yield of *i* and the county trend-adjusted yield of *j*. This coefficient allows for interaction between the disaggregate yield of one crop and the aggregate yield of another crop. Empirically, however, this appears to be of no consequence for the location we are examining. Thus, in the analysis that follows B_{ii} is assumed to equal 1 and $B_{ij} = B_{ji} = 0$. The residuals, e_{ti}^{f} and e_{tj}^{f}, are jointly selected in the bootstrapping model by a random draw *t* so that each crop has its residuals drawn from the same period. This maintains the empirical covariance across crops. These residuals were also taken from APH records of farms that insured more than one crop.

Farm Yield Deviations

Given the assumptions made in the preceding paragraph, deviations in farm yield from the county yield are needed to complete the yield simulation. Because county yield is an aggregate measure that contains farm yields, a statistical relationship exists between the two. Equation (3) derives farm yield deviations:

(3) $d_{t}^{f} = y_{t}^{f} - R_{t}^{c}$

where d_{t}^{f} = the absolute difference in yield of farm *f* and county yield in year *t* and

y_t^f = yield of farm *f* in year *t*

The absolute difference d_t^f is calculated for the subset of data that includes APH records. These records have up to ten years of farm yield data. In selecting records for this analysis, a lower limit of six years of actual recorded yields was imposed. Equation (4) computes the mean farm yield deviation for each farm:

$$(4) \qquad \bar{d}^f = 1/T_f \sum_{t=1}^{T} (y_t^f - R_t^C) = \bar{y}^f - \bar{R}^C$$

where $\bar{d}^f$ = mean difference of yield of farm *f* from county yield (and R_t^C is constrained to include only those years with a corresponding value for y_t^f)

T_f = total number of years of yield records of farm *f*

Equation (4) allows farm-level residual variability to be decomposed as in Equation (5):

$$(5) \qquad e_t^f = d_t^f - \bar{d}^f = (y_t^f - \bar{y}^f) - (R_t^C - \bar{R}^C)$$

This equation can be rewritten as

$$(5a) \qquad y_t^f = \bar{y}^f + (R_t^C - \bar{R}^C) + e_t^f$$

Recall that $\bar{d}_f = \bar{y}^f - \bar{R}^C$ so (5a) can be rewritten as

$$(5b) \qquad y_s^f = R_s^C + \bar{d}^f + e_t^f$$

where the subscript *s* represents simulated.

It may be useful to represent (5b) in terms of vectors, as each bootstrap simulation is computed by the random selection of a value from each vector used in (5b):

(5c) $[y_s^f] = [R_s^C] + \overline{d}^f + [e_t^f]$

Price-Yield Relationships

To begin the price simulation, the price-yield relationships must first be established. ABW modeled a historical relationship between changes in futures prices from the pre-planting period to the harvest. This relationship is found in Equation (6a):

(6a) $$\frac{P_t^1}{P_t^0} = a_1^P + a_2^P \left(\frac{R_t^C}{\hat{R}_t^C} - \frac{1}{T_C}\sum_{t=1}^{T_C}\frac{R_t^C}{\hat{R}_t^C}\right) + e_t^P$$

where P_t^1 = futures price at harvest

P_t^0 = futures price at planting

a_1^P, a_2^P = coefficients for deviation of county yield from expected county yield for a given year

R_t^C = county yield in year *t*

$\hat{R}_t^C$ = predicted county yield in year *t*

T_C = total number of years of regional yield data for county *C*

ε_t^P = residual deviations of price in year *t*

The key to this equation is shown in parentheses as the difference between the ratio of the county yield to the predicted county yield and the mean of this ratio for the data set. Equation (6a) can be modified to produce a price simulation at harvest:

(6b) $$P_s^1 = P^0\left(1 + a_2^P\left(\frac{R_t^C}{\hat{R}_t^C} - 1\right) + \varepsilon_t^P\right)$$

where P_s^1 = simulated price at harvest and other variables as in (6a)

Here the mean county yield to predicted county yield ratio is assumed to be 1, and the equation is multiplied through by the futures price at planting to reach a simulated price at harvest. In addition to price-yield relationships, the multi-crop case must also include–as with yields–interactions between crops. Equation (6a) can be extended to capture this correlation for multiple crops:

$$\text{(7a)} \qquad \frac{P_{it}^{1}}{P_{it}^{0}} = a_{i1}^{P} + a_{ii}^{P}\left(\frac{R_{it}^{C}}{\hat{R}_{it}^{C}} - \frac{1}{T_C}\sum_{t=1}^{T_C}\frac{R_{it}^{C}}{\hat{R}_{it}^{C}}\right) + a_{ij}^{P}\left(\frac{R_{jt}^{C}}{\hat{R}_{jt}^{C}} - \frac{1}{T_C}\sum_{t=1}^{T_C}\frac{R_{j}^{C}}{\hat{R}_{jt}^{C}}\right) + \varepsilon_{it}^{P}$$

$$\text{(7b)} \qquad \frac{P_{jt}^{1}}{P_{jt}^{0}} = a_{j1}^{P} + a_{jj}^{P}\left(\frac{R_{jt}^{C}}{\hat{R}_{jt}^{C}} - \frac{1}{T_C}\sum_{t=1}^{T_C}\frac{R_{jt}^{C}}{\hat{R}_{jt}^{C}}\right) + a_{ji}^{P}\left(\frac{R_{it}^{C}}{\hat{R}_{it}^{C}} - \frac{1}{T_C}\sum_{t=1}^{T_C}\frac{R_{i}^{C}}{\hat{R}_{it}^{C}}\right) + \varepsilon_{jt}^{P}$$

where i and j = individual crops

Note that Equations (7a) and (7b) are similar to (6a) except they include another crop. All three equations take the difference of the ratio of the expected county yield for a crop in a given year and the mean of this ratio for the entire data set. The bootstrapping model will use the parameters and residuals from these equations to determine prices. The price residuals for each crop will be jointly selected by a random draw t so that each crop has its residuals drawn from the same period.

To complete the price simulations, Equations (7a) and (7b) are modified as was Equation (6a) to get a harvest price simulation for each crop:

$$(8a)\qquad P_{is}^{1} = P_{is}^{0}\left(1 + a_{ii}^{P}\left(\frac{R_{it}^{C}}{\hat{R}_{it}^{C}} - 1\right) + a_{ij}^{P}\,\frac{R_{it}^{C}}{R_{it}^{C}} - 1\right) + \varepsilon_{it}^{P}\Big)$$

$$(8b)\qquad P_{js}^{1} = P_{js}^{0}\left(1 + a_{jj}^{P}\left(\frac{R_{jt}^{C}}{\hat{R}_{jt}^{C}} - 1\right) + a_{ji}^{P}\,\frac{R_{jt}^{C}}{R_{jt}^{C}} - 1\right) + \varepsilon_{jt}^{P}\Big)$$

Multi-crop Revenue Simulation

Using Equations (2) and (8), the complete revenue simulation model can now be generated. The bootstrapping procedure will generate a random price and yield that account for the earlier specified interactions. Equation (9) is the revenue simulation:

$$(9)\qquad M\,\mathrm{Re}v_{s}^{\,f} = \sum_{i} A_i P_{is}^{\,1} y_{is}^{\,f}$$

where $MRev_s^f$ = sum of revenues from multiple crops for a farm *f*

A_i = acres planted of crop *i*

P_{is}^{1} = simulated price of crop *i* at harvest

y_{is}^{f} = simulated yield of crop *i* for a farm *f*

Equation (10) demonstrates how indemnities would be calculated under this model:

$$(10)\qquad Indemnity = Max(0, L\sum_{i} A_i P_{it}^{\,0} \overline{y}_i^{\,f} - M\,\mathrm{Re}v_{s}^{\,f})$$

where L = coverage level (e.g., 75 percent)

Equation (10) calculates indemnities as the difference between the revenue expected at planting time and the revenue simulated at harvest time. Actuarially fair estimates of rates are found by bootstrapping 6,000 iterations that produce a different indemnity for each draw. Since each draw is equally random, the expected indemnity is the simple average of the indemnities for all iterations.

Results

Figure 1 charts the premium rates generated by the bootstrapping procedure using 6,000 iterations. These data are for a representative Sunflower County, Mississippi, multi-crop revenue product for a combined cotton/soybean/wheat policy, as well as traditional single crop policies for yield and revenue insurance and area yield and revenue insurance. The rates are for a 75 percent coverage level and are based on a farm size of 1,000 acres. These premium rates for each of these combinations are found on the Y-axis. Along the X-axis are various acreage combinations for the three crops–cotton, soybeans, and wheat, respectively. The first three combinations assume 100 percent of the acreage is planted to one of the three crops; i.e., 1,000 acres planted in cotton, followed by 1,000 acres in soybeans, and then all 1,000 acres in wheat. The remaining seven combinations assume different shares of the acreage for each crop, such 50-25-25 combinations, 50-50-0, etc. Thus, these first three combinations would essentially be the same as traditional single crop yield and revenue insurance products, and there are four bars for the policies for these three combinations. These bars represent the rates for the four insurance products mentioned above–in order, single crop revenue insurance, yield insurance, county yield insurance, and county revenue insurance. As would be expected, the rates from the area insurance products are lower than their farm-level counterparts. These first three sets reflect what rates would be for single crop policies. The bars for the other seven combinations are the rates for the multi-crop revenue policy. These are the rates for insuring the entire acreage according to different shares for each crop.

The significance of the multi-crop insurance product becomes evident in comparing the rates from single crops to the multi-crop combinations. The rates for the different acreage combinations are less than the rates from the individual crops (i.e., the "100 percent" acreage combinations) For example, the single crop rate for wheat, a riskier crop in this data set, has a rate considerably higher than soybeans or cotton. However, its introduction into the crop mix does not result in substantially higher rates, as might be expected. In fact, premium rates for those acreage combinations in which wheat has the largest share are less than or approximately the same as those in which cotton has the largest share. The reason rates are reduced when crops are combined is primarily the correlation between the crops. Because wheat is a crop planted and harvested at a significantly different time than cotton and soybeans, it is likely that its yield would be much less correlated with these two crops than cotton and soybeans are with each other. This situation is reflected in Table 1, which contains a matrix of correlation coefficients for the three crops in this data set. This matrix was calculated from county yield deviations. The correlation between cotton and soybeans is .50. The correlations between wheat and the other crops are even less, as only a .15 correlation exists between wheat and soybeans. Notice that these correlations have a rate-reducing impact even though they are positive. The correlations are reflected in the rates, as a 25–50–25 combination has a lower rate than a 50–50–0 combination despite the fact that wheat is a considerably riskier crop as evidenced by its own higher rate relative to cotton and soybeans. The lower correlations between wheat and the other crops allow a 50–50 combination of wheat and soybeans or wheat and cotton to have a rate comparable to that of a 50–50 combination of cotton and soybeans. Thus, the multi-crop product captures the benefits of diversification in these three crops. This diversification effect in different acreage combinations is tempered, however, by the fact that wheat rates are very high.

Also notable is that the lower rates are generally found with greater diversification. The 33–33–33 combination and the 50–25–25, 25–50–25, and 25–25–50 combinations have lower rates than most of the less diversified crop mixes. Diversifying the crop mix under this design generally allows a producer to achieve a lower premium rate.

An interesting comparison is also made between the multi-crop rates and the rates of the area insurance products. The rates for county yield insurance are considerably lower than those of its farm-level counterpart, as would be expected. An even greater difference exists between the rates of county revenue insurance and those of single crop revenue insurance. Protection can be offered at lower rates for area insurance because it indemnifies against shortfalls in expected county yields. Thus, these policies should be less risky because they insure against a systemic or more widespread loss. For most of the more diversified acreage combinations, the multi-crop revenue rate is comparable to the county revenue rates for each crop. As can be seen in Figure 1, generally the more diversified the crop mix the more comparable the multi-crop rates are to the area insurance products.

The risk reduction gains for Mississippi producers are also addressed in this analysis. The examples computed assume a beginning wealth of $500,000 and a relative risk aversion coefficient of 2. Ending wealth is found by subtracting costs (according to enterprise budgets for the Mississippi Delta) and premiums, and adding indemnities to market revenue. Ending wealth is used to find expected utility using the constant relative risk aversion utility function:

(11a) $$E(U)_r = \sum_{S=1}^{S} w_S \frac{W_S^{1-r}}{1-r}, r \neq 1$$

or

(11b) $$E(U)_r = \sum_{S=1}^{S} w_s \ln(W_s), r = 1$$

where r = risk aversion coefficient

W_s = ending wealth.

Certainty equivalents likewise are calculated using the expected utility found in (11) by the following formula:

(12a) $$CE_{sr} = (1-r)E(U_{sr})^{\frac{1}{1-r}}, r \neq 1$$

or

(12b) $$CE_{sr} = e^{E(U_{sr})}, r = 1$$

The use of multi-crop revenue insurance, single crop revenue insurance, and yield insurance was found to increase certainty equivalents for selected acreage combinations as compared to production with no insurance. Table 2 illustrates the average percentage increase in certainty equivalents for these three instruments for seven selected acreage combinations. The results indicate that the average increase in certainty equivalents is greatest for multi-crop and single crop insurance, as would be expected. However, in many instances the increases are only marginal at best. One can also see from Table 2 that the increases for multi-crop and single crop revenue insurance are approximately the same, as single crop revenue is slightly higher for most combinations. This is due to the fact that single crop revenue insurance pays indemnities in some instances where multi-crop revenue insurance does not, resulting in the higher rate. One can also notice in Table 2 that the increases are smallest where cotton makes up the largest acreage combination. This dominance of cotton in the crop mix may indicate a starting point for further investigation.

Figure 2 illustrates the revenues (market revenue plus insurance indemnities) per acre found for the three insurance designs discussed in the preceding paragraph. The three designs are compared to the distribution of revenue with no insurance. As expected, each insurance product decreases the probability of the lowest revenues per acre, effectively truncating the lower end of the revenue distribution with no insurance. In the upper tail of the revenue distributions, the revenue distributions of the insurance designs lie slightly to the left of the revenue distribution with no insurance due the cost of a premium while receiving no indemnity. The revenue insurance products do the best job of eliminating the lower end of the revenue distribution. Multi-crop revenue insurance provides a smooth cutoff at 75 percent of expected revenue. The multi-crop revenue insurance distribution has the lowest probability of low revenues. The single crop revenue insurance pays out in some cases when the multi-crop does not because the trigger can be reached on an individual crop while not occurring over multiple crops.

Conclusion

This objective of this analysis was to develop a model of revenue insurance that would provide an insurance guarantee against shortfalls in the aggregate gross revenue of multiple crops. A non-parametric approach was used to combine the random variables for both price and yield for multiple crops. It is the authors' belief that this approach is fundamentally sound to maintain a rigorous relationship between random variables such that valid estimates of the joint revenue across commodities for a single farm can be made, and at the same time allowing the expansion to multiple crops to be feasible. A limitation to this methodology, however, is the lack of needed data for different commodities for a single farm. This limitation applies particularly to the Mid-South and other regions where participation is much less dense.

In addition to the previously mentioned need for further investigation, the underwriting issues associated with the design of the multi-crop product must also be addressed. A producer who insured under the product before planting wheat would have knowledge of what wheat revenue would be prior to even planting other crops, such as cotton and soybeans. Thus, including wheat in the combination policy could potentially induce moral hazard on a second set of crops. Low wheat revenue could lead to a disincentive to effectively manage crops planted in the spring. In addition, knowledge of the acres of each crop being planted are required for this rating approach. Producers in Mississippi and other states could for legitimate reasons alter their acreage allocations between their crops, such as a staggered planting scenario. This situation, however, would have an effect on the appropriate premium rate. Insuring staggered seasoned crops under the multi-crop design could become problematic.

Figure 1

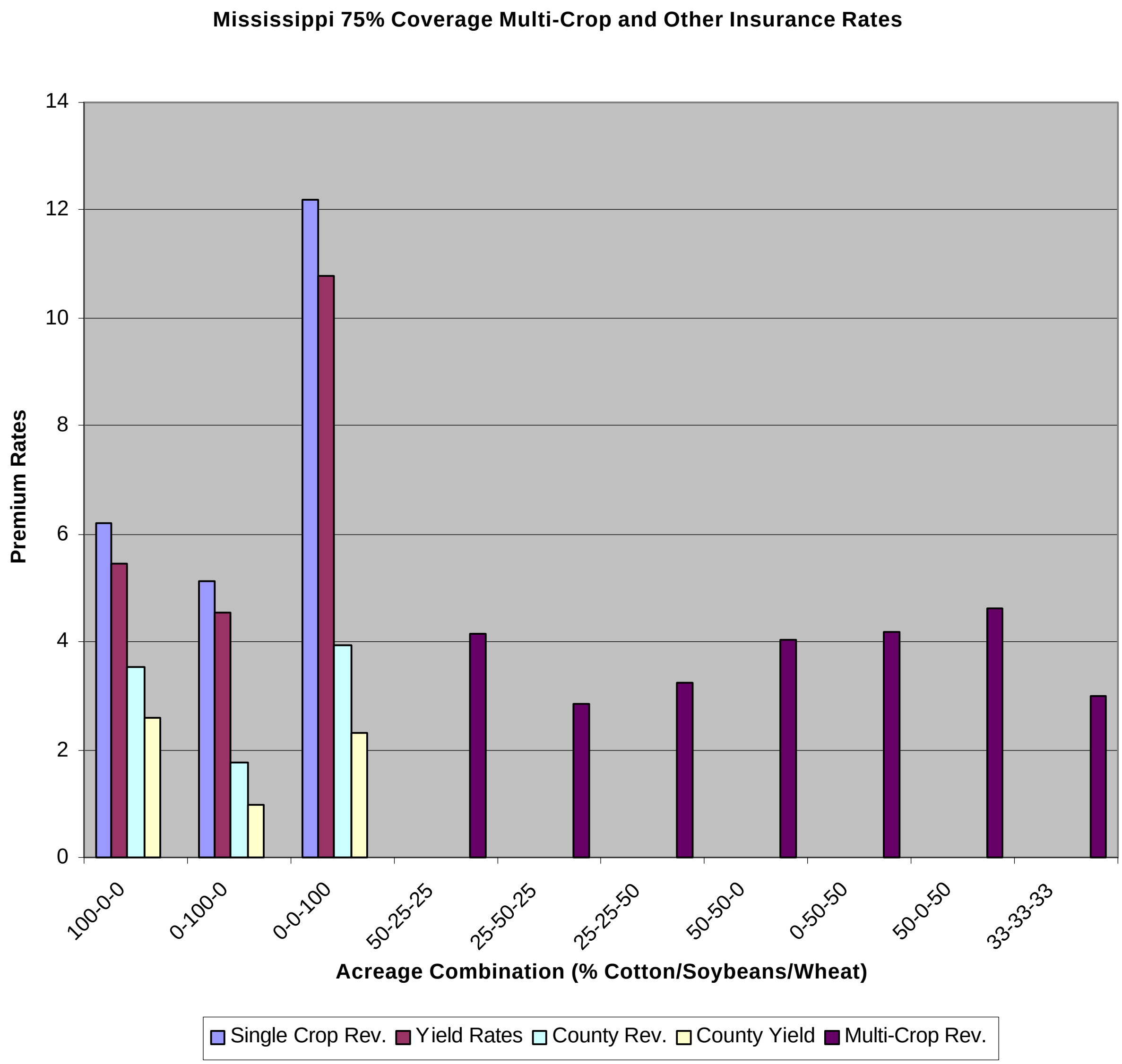
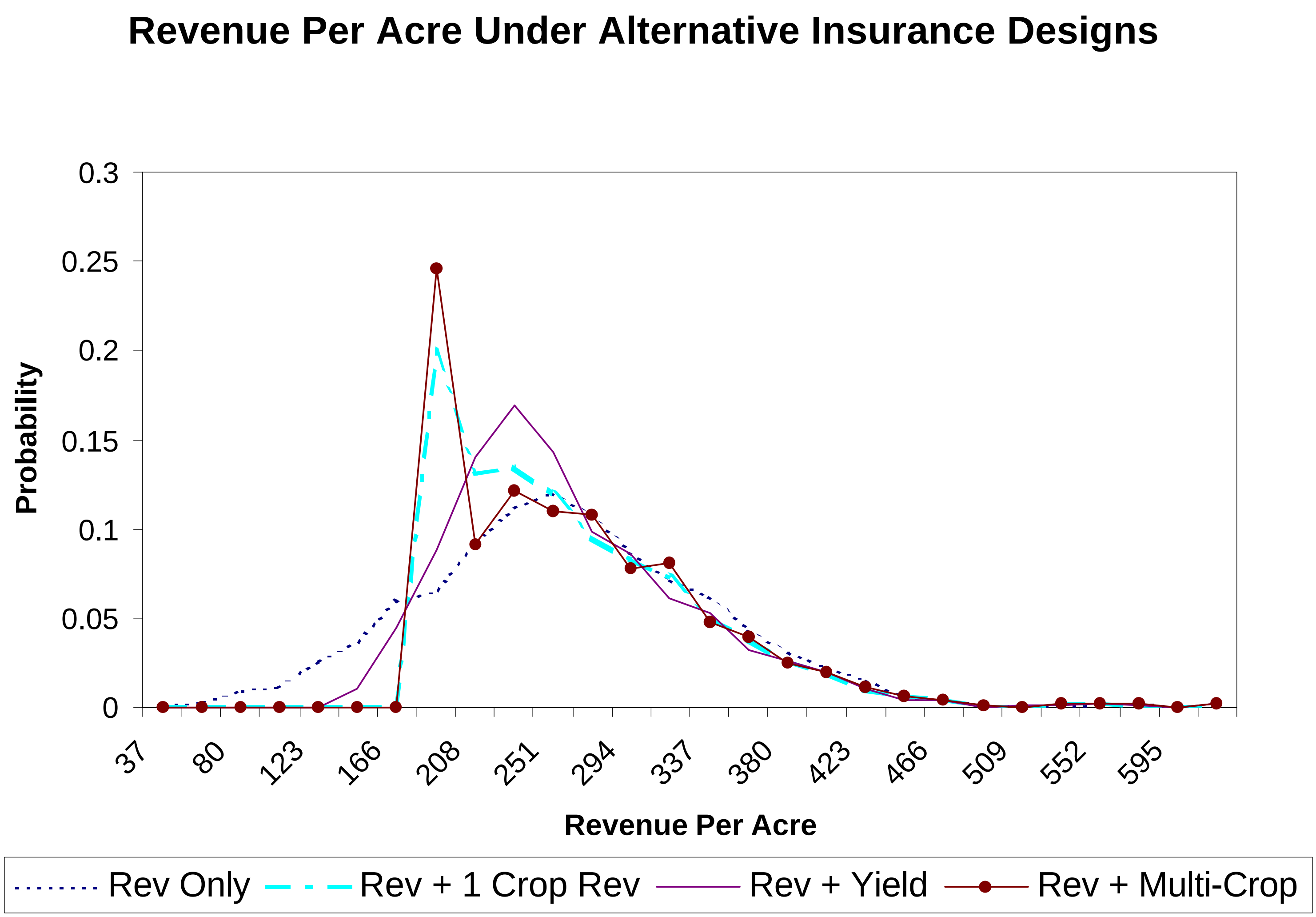

Mississippi 75% Coverage Multi-Crop and Other Insurance Rates
Premium Rates
0
2
4
6
8
10
12
14
100-0-0
0-100-0
0-0-100
50-25-25
25-50-25
25-25-50
50-50-0
0-50-50
50-0-50
33-33-33
Acreage Combination (% Cotton/Soybeans/Wheat)
Single Crop Rev.
Yield Rates
County Rev.
County Yield
Multi-Crop Rev.

Figure 2



Revenue Per Acre Under Alternative Insurance Designs
0.3
0.25
0.2
0.15
0.1
0.05
0
Probability
37
80
123
166
208
251
294
337
380
423
466
509
552
595
Revenue Per Acre
Rev Only
Rev + 1 Crop Rev
Rev + Yield
Rev + Multi-Crop

Table 1

Correlation of Sunflower County, Mississippi crop yields			
	Cotton	Soybeans	Wheat
Cotton	1		
Soybeans	0.50	1	
Wheat	0.26	0.15	1

Table 2

Average Percentage Increase in Certainty Equivalents for Selected Acreage Combinations			
Acreage Combination	Multi-Crop Rev. Ins.	1-Crop Revenue Ins.	Yield Insurance
75-12.5-12.5	3.05%	3.98%	3.63%
12.5-75-12.5	21.15%	21.60%	20.40%
12.5-12.5-75	14.97%	14.78%	13.64%
50-25-25	10.23%	10.91%	10.09%
25-50-25	17.45%	17.66%	16.71%
25-25-50	14.31%	14.84%	14.00%
33-33-33	14.30%	14.96%	13.96%

References

Atwood, Joseph A., Alan E. Baquet, and Myles J. Watts. "Income Protection." Department of Agricultural Economics and Economics Staff Paper 97-9. Montana State University: Bozeman, Montana, August 1997.

Coble, Keith H., James C. Miller, Barry J. Barnett, Thomas O. Knight. "A Proposed Method to Rate a Multi-Crop Revenue Insurance Product," A Report to the USDA/Risk Management Agency, 29 Nov. 1999.

"Delta 1999 Planning Budgets." Agricultural Economics Report No. 100, Mississippi State University, December 1998.

Miranda, Mario J. "Area-Yield Insurance Reconsidered." American Journal of Agricultural Economics, 73 (1991):233–242.

Skees, Jerry R., J. Roy Black, and Barry J. Barnett. "Designing and Rating an Area Yield Insurance Contract." American Journal of Agricultural Economics, 79 (1997):430–438.