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## Insuring Eggs in Baskets

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## **Abstract**

The vast majority of crop and revenue insurance policies sold in the United States are single-crop policies that insure against low yields or low revenues for each crop grown on a particular farm. This practice of insuring one crop at a time runs counter to the traditional risk management practice of diversifying across several enterprises to avoid putting all of ones eggs in a single basket. This paper examines the construction of whole-farm crop revenue insurance programs to include livestock. The whole-farm insurance product covers crop revenues from corn and soybeans and livestock revenues from hog production. The results show that at coverage levels of 95 percent or lower, the fair insurance premiums for this product on a well-diversified Iowa hog farm are far lower than the fair premiums for the corn crop alone on the same farm. The calculation of premium rates for the whole-farm insurance product is derived from a method for imposing correlations first proposed by Iman and Conover in 1982.

**Keywords:** correlations, diversification, livestock, volatilities, whole-farm revenue insurance.

# INSURING EGGS IN BASKETS

## Introduction

The vast majority of crop and revenue insurance policies sold in the United States are single-crop policies that insure against low yields or low revenues for each crop grown on a particular farm. This practice of insuring one crop at a time runs counter to the traditional risk management practice of diversifying across several enterprises to avoid putting all of one's eggs in a single basket. These single-crop policies are heavily subsidized and have grown in importance as farms have become increasingly specialized. While it is not obvious that single-crop policies have increased specialization, it is clear that the absence of policies that reward diversified production has created an environment that rewards those producers who specialize even at the expense of increasing risk. This trend toward specialization is greatest among farms that once combined both crop and livestock operations. Farms that specialize only in crops do not offer year-round employment potential, and those that have specialized only in livestock are controversial in some communities (see Paarlberg 2000; Park, Lee, and Seidl 1999; and Rhodes 1998).

Mahul and Wright (2000) examine optimal designs of crop revenue insurance. They find that when the indemnity is based on individual prices and yields, the optimal insurance contract depends only on individual gross revenue. When the indemnity is based on aggregate prices and/or yields, the optimal insurance contract can depend on gross revenue and the aggregate prices/yields. Hennessy, Babcock, and Hayes (1997) also find whole-farm (or portfolio) revenue insurance to be advantageous to agricultural producers in both risk coverage and cost. In addition, they argue that higher coverage levels may be possible with whole-farm insurance because of coverage diversification leading to lower risk and the limiting of potential moral hazard problems that occur with more specialized coverage.

One obvious way to reduce any bias in favor of increased specialization is to offer whole-farm policies that correctly adjust for diversification across crops and between crops

and livestock. This approach is technically challenging because well-diversified farms can potentially grow many individual crops and livestock species, each with a unique amount of production and price risk. To date, this problem has been addressed by Hennessy, Babcock, and Hayes (1997); Black (2003); and Hart, Babcock, and Hayes (2001).

The paper by Hennessy, Babcock, and Hayes describes the procedures by which whole-farm revenue-assurance rates are determined. The combined revenue from multiple commodities can be insured under Revenue Assurance if the individual commodities can be insured under Revenue Assurance. The insurance premium for the whole-farm Revenue Assurance policy is less than the sum of premiums for the individual commodity Revenue Assurance policies. Rates are determined by drawing yield and price deviates from appropriately specified distributions. This procedure begins with independent draws and imposes correlation by creating new draws that are weighted averages of the original draws using a method originally proposed by Johnson and Tenenbein (1981). The weights used in this procedure determine the correlation to be imposed. This method works extremely well when the number of marginal distributions is small, but it is almost impossible to implement accurately when the number of distributions expands, because little structure can be imposed on cross correlations.

The methodology developed by Black (2003) also is used in a whole-farm revenue insurance program (Adjusted Gross Revenue, AGR). This policy has been tested in several areas of the country. The AGR program insures revenue based on producers' income tax records. It was the first federally subsidized insurance program to allow coverage of livestock (up to 35 percent of the insured revenue can come from livestock production). The procedure used to calculate the impact of diversification is determined by a diversification formula: one divided by the number of commodities to be produced multiplied by 0.33 multiplied by the total expected income for the insurance year. This procedure produces intuitive rate-reduction properties, but it does not adjust this rate reduction for the unique properties of the particular operation. For example, farms with equal numbers of crops can have very different risk profiles if one operation is almost completely specialized in one crop while the other farm expects to earn equal revenues from several of the crops.

The procedure used by Hart, Babcock, and Hayes (2001) is based on the commercial software package @RISK and was used as the basis for a new livestock insurance policy called Livestock Gross Margin (LGM). LGM was made available in 2002 on a pilot-project basis in Iowa. The methods used to impose correlations within @RISK are proprietary and can only be imposed on the somewhat limited menu of distributions made available with the software. Of the three policies previously described, only AGR involves both crops and livestock.

This paper adapts and implements a method for imposing correlations first proposed by Iman and Conover in 1982. The procedure is open-ended, can be implemented using commercial spreadsheet software, and can be imposed on any combination of densities. The method is fully transparent since the only manipulation to the original data is a resorting of the data. Thus, the technique preserves the original distributional structure of each data series while changing the relationships among the series. The practical application chosen to apply the procedure has real-world importance and involves the expansion of whole-farm crop revenue insurance programs to include livestock. Crop yields and crop prices for both corn and soybean are used in conjunction with seven series of correlated temporal hog prices. The example results show that at coverage levels of 95 percent or lower, the fair insurance premiums for a well-diversified Iowa hog farm are far lower than the fair premiums for a corn crop alone on this same farm.

First, we introduce the theory and techniques behind the Iman and Conover procedure. Then we discuss the design of the contract used in the example. Next, we show how the method can be applied to determine the fair premium for the example case. Finally, we present and discuss the results.

## **Methodology**

The Iman and Conover (1982) procedure has four attractive properties. First, the procedure works well with any distribution function. Most correlation techniques are aimed directly at standard distribution functions and cannot be used with other distribution functions. Second, the mathematics behind the procedure is not extremely complex. Cholesky factorization and inversion of matrices are the most exotic steps in the procedure. Third, the procedure can be used under any sampling scheme. Fourth, the

marginal distributions of interest are maintained throughout the procedure. The moments of the marginal distributions are not affected by the procedure.

The procedure is based on rank correlations. Iman and Conover point out that raw correlation numbers can be misleading when the underlying data is non-normal or contains outliers. The theoretical basis for the procedure is that given a random matrix  $A$  whose columns have a correlation matrix  $I$  (the identity matrix) and a desired correlation matrix  $B$ , there exists a transformation matrix  $C$  such that the columns of  $AC'$  (where  $C'$  is the transpose of  $C$ ) have a correlation matrix  $B$ . Since  $B$  is positive definite and symmetric, there exists a lower triangular matrix (the transformation matrix)  $C$  such that  $B = CC'$ .

Let  $X$  be a matrix of draws of marginal distributions of interest. Let  $R$  be a matrix of the same size that contains what Iman and Conover call “scores.” Iman and Conover suggest using ranks, random normal deviates, or van der Waerden scores ( $\Phi^{-1}(i / N+1)$  where  $\Phi^{-1}$  is the inverse of the standard normal distribution function,  $N$  is the number of draws, and  $i = 1, \dots, N$ ) as possible scores. Let  $T$  be the target rank correlation matrix for a transformation of the columns of  $X$ . Since  $T$  is positive definite and symmetric, there exists a lower triangular matrix  $P$  such that  $T = PP'$ .  $P$  can be found by Cholesky factorization. The transformed score matrix is  $R^* = RP'$ . The columns of  $R^*$  have a rank correlation matrix  $M$ , which is close to the target rank correlation matrix  $T$ . When the elements of  $X$  are arranged in the same ranking as in  $R^*$ , then the columns of the transformed  $X$  matrix will also have a rank correlation matrix equal to  $M$ , close to  $T$ .

The deviation of  $M$  from  $T$  is due partially to correlation with  $R$ . The transformation is exact for correlation (but not for rank correlation) matrices when the correlation matrix of the columns of  $R$  equals  $I$ . To minimize the deviations between  $M$  and  $T$ , Iman and Conover propose a variance reduction procedure. Let  $D$  represent the actual correlation matrix for the columns of  $R$  and let  $J$  represent the target correlation matrix. Then for  $J$ , a positive definite and symmetric matrix, there exists a matrix  $S$  such that  $J = SDS'$ . Since both  $J$  and  $D$  are positive definite and symmetric matrices, there exist lower triangular matrices  $U$  and  $V$  such that  $D = UU'$  and  $J = VV'$ . So  $VV' = J = SDS' = SUU'S'$ . This implies that  $S = VU^{-1}$  (where  $U^{-1}$  is the inverse of  $U$ ). The columns of the transformation  $RS'$  have a correlation matrix that is equal to  $J$ . The rank correlation matrix of the

columns of the transformation  $RS'$  (call it  $M^*$ ) provides a better estimate of the target rank correlation matrix  $T$  than does  $M$ . When the original draws from the marginal distributions (the columns of  $X$ ) are sorted to match ranks with the data in the columns of  $RS'$ , then the rank correlation matrix of the sorted draws is equal to  $M^*$ . Thus, the rank correlation matrix of the sorted draws approaches the target rank correlation matrix  $T$ .

For their analysis, Iman and Conover use van der Waerden scores in the score matrix. In our analysis, we follow this convention. For the application put forth here, target rank correlations are derived from historical data. The appendix illustrates the Iman and Conover technique by employing it to the first 20 draws of the Monte Carlo simulations that follow. All of the calculations for the appendix were conducted in Microsoft Excel. This highlights the fact that the Iman and Conover technique can be performed using commonly available software.

### **Contract Design**

We have chosen to form the insurance product as a gross revenue product. In the example that follows, gross revenues from corn, soybeans, and hogs are jointly insured. The contract would run from March to February, aligning the sign-up for this product with traditional crop insurance sign-up for corn and soybeans. At sign-up, producers would be required to provide information on their crop production and the number of animals that they intend to market in each calendar month. Prices for both the crops and livestock are based on the futures prices from relevant markets (Chicago Mercantile Exchange for livestock and Chicago Board of Trade for crops). Indemnities would not be known until the following spring (unless the marketing plan does not include any marketings during the latter half of the contract) because of the length of the insurance period.

The insurance policy is constructed to minimize the moral hazard problem. Under the policy framework, the crop component parallels the Revenue Assurance crop insurance product (without the harvest price option). For the livestock component, producers provide expected per-month marketing figures at sign-up. This number of animals is then insured under the assumption of set marketing weights, and insurance prices are set by the futures markets.



The hog insurance component assumes that the hogs are marketed at 260 pounds. The lean hog futures price is converted to a live weight basis by multiplying by a factor of 0.74. The calculated revenues from marketing one hog in month  $t$  is given by

$$260 \times 0.74 \times \text{LeanHog}_t \quad (1)$$

where  $\text{LeanHog}$  is the average price of the relevant lean hog futures contract.

The insurance product has the standard indemnity stream of the form

$$\max[0, \text{revenue guarantee} - \text{marketing revenue}] \quad (2)$$

where the revenue guarantee is based on prices at the time the insurance is purchased, and the marketing revenue represents the revenue calculated at the end of the insurance period. Both the revenue guarantee and the marketing revenue are based on futures prices. The revenue guarantee is calculated from the coverage level and projected prices formed from the average futures prices for the various livestock and crop futures over the first five trading days in March. For the livestock component, prices for non-contract months are set at the price of the nearby futures contract for that month. For example, the projected hog price for May is the projected hog price for June.

Marketing revenue is based on the actual average futures settlement prices in the closing month of the contracts. For contract months, the average price is taken from the settlement prices of the first five trading days of the month. For non-contract months, we follow the same formula as in setting the revenue guarantees by using the price for the nearby futures contract for that month. For example, the September hog price is the price established for October.

### **Premium Determination**

To determine the actuarially fair premium for the proposed revenue insurance policy, we perform Monte Carlo simulations based on closed-form probability density functions for the crop yields and crop and livestock prices. The crop yields follow Beta distributions, as assumed under the Revenue Assurance policy product. The crop and livestock prices follow lognormal distributions, where the standard deviations of prices are derived from the implied volatilities from options markets. Because the prices used in

the insurance product are average prices, we face the issue that the sum (or in our case, the average) of lognormal random variables is not lognormal and, in fact, has no closed-form probability density function. Two analytical approximations have been employed in recent literature, using either a lognormal or inverse gamma distribution to represent the required distribution. Turnbull and Wakeman (1991) and Levy (1992) have supported the use of a lognormal distribution as a good approximation. However, the lognormal approximation fares less well as volatilities increase (Levy 1997). For this analysis, we have employed the lognormal approximation for all of the price distributions.

For the Monte Carlo analysis, we have eleven random variables: the corn and soybean yields, the corn and soybean futures prices, and seven hog futures prices (one for each contract month during the insurance period). There have been many studies of the distribution of farm-level yields. Day (1965) showed that crop yields are skewed and found the beta distribution to be an appropriate functional form for parametric estimation purposes. Just and Weninger (1999) discuss the possible problems of the data used to measure yields. Babcock and Blackmer (1992), Borges and Thurman (1994), Babcock and Hennessy (1996), and Coble et al. (1996) have all used beta distributions in their applied work.

For this analysis, yields ( $y$ ) follow beta density functions

$$g(y) = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)} \frac{(y - y_{\min})^{p-1} (y_{\max} - y)^{q-1}}{y_{\max}^{p+q-1}} \quad \text{where } y_{\min} \leq y \leq y_{\max}, \quad (3)$$

where  $p$  and  $q$  are shape parameters and  $y_{\max}$  and  $y_{\min}$  are maximum and minimum possible yields. The beta distribution is advantageous because both negative and positive skewness can be incorporated into the distribution. Also, the beta distribution has finite minimum and maximum values and can take on a wide variety of shapes.

The values for the beta distribution parameters are chosen so as to be consistent with the Actual Production History (APH) rates for corn and soybeans at the 65 percent coverage level. For a given mean  $\mu$ , standard deviation  $\sigma$ , maximum  $y_{\max}$ , and minimum  $y_{\min}$ ,  $p$  and  $q$  can be obtained from the following equations (Johnson and Kotz 1970, p. 44):

$$p = \left( \frac{\mu - y_{\min}}{y_{\max} - y_{\min}} \right)^2 \left( 1 - \frac{\mu - y_{\min}}{y_{\max} - y_{\min}} \right) \left( \frac{\sigma^2}{(y_{\max} - y_{\min})^2} \right)^{-1} - \frac{\mu - y_{\min}}{y_{\max} - y_{\min}} \quad (4)$$

$$q = \frac{\mu - y_{\min}}{y_{\max} - y_{\min}} \left( 1 - \frac{\mu - y_{\min}}{y_{\max} - y_{\min}} \right) \Big/ \left( \frac{\sigma^2}{(y_{\max} - y_{\min})^2} \right) - 1 - p. \quad (5)$$

The minimum and maximum yields are defined as

$$y_{\min} = \max(1 - 4\sigma, 0) \quad (6)$$

and

$$y_{\max} = 1 + 1.5\sigma. \quad (7)$$

Given these four equations, a search for a standard deviation that generates the 65 percent APH rates is conducted and this procedure provides the parameter estimates for the yield distributions.

For the price distributions, given the lognormality assumption, we require only estimates of the mean and standard deviation to define the distributions. In all cases, the mean price is defined as the five-day average price for the first five trading days in March, and the standard deviation of price is defined as the product of the mean price and the five-day average of implied volatility from “at the money” options over the same days.

For our analysis, we have set up a corn-soybean-hog farm in Webster County, Iowa. The farm has 250 acres of corn and 250 acres of soybeans. To explore the effects of the diversification between crops and livestock, we allow the number of hogs to vary within the analysis. The prices and annualized implied volatilities used in the analysis are the actual values for the relevant markets over the first five trading days of March 2002. A summary of the distributional assumption underlying the analysis is given in Table 1.

In implementing the Monte Carlo procedure, it is very important that the methods incorporate the correlation among the random variables. To induce the desired correlation, we follow the procedure outlined by Iman and Conover and implement the variance reduction method in the procedure. The procedure takes independent draws from the various marginal distributions (in our case, the price and yield distributions) and resorts them to obtain the desired levels of rank correlation. The procedure preserves the marginal distributions because the original draws are not changed (just rearranged). The correlations required by the procedure are the rank correlations among the variables.

**TABLE 1. Yield and price distributions**

<b>Variable</b>	<b>Type</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Annualized Implied Volatility</b>
		(bu/acre)	(bu/acre)	
Corn yield	Beta	135.00	36.45	
Soybean yield	Beta	40.00	10.00	
		(\$/bu)	(\$/bu)	(%)
Corn price	Lognormal	2.30	0.45	23
Soybean price	Lognormal	4.65	0.79	21
		(\$/cwt)	(\$/cwt)	(%)
Apr. hog price	Lognormal	58.94	4.52	19
June hog price	Lognormal	66.75	7.18	19
July hog price	Lognormal	63.15	7.33	18
Aug. hog price	Lognormal	60.70	7.18	17
Oct. hog price	Lognormal	51.89	7.14	17
Dec. hog price	Lognormal	49.38	7.60	17
Feb. hog price	Lognormal	51.04	8.61	17

Table 2 contains the target rank correlation matrix (T) for the variables. The target rank correlation matrix is the historical rank correlation matrix for the deviations of the variables from their expected values. To estimate the historical relationships, we examined trend yields, actual yields, expected prices (the average prices for the relevant futures contracts over the first five trading days of March), and actual prices (the average prices for the relevant futures contracts over the first five trading days of the contract month) from 1980 to 2001.

The Monte Carlo analysis consists of 5,000 draws from the distributions outlined in Table 1. The draws for each variable are accomplished independently of each other. The Iman and Conover technique is applied to impose the target rank correlation matrix in Table 2. The score matrix (R) was constructed from 11 columns of 5,000 van der Waerden scores. The van der Waerden scores were randomly mixed within each column. (Because our analysis involved 5,000 draws and 11 variables, it was cumbersome to apply the Iman and Conover technique within a spreadsheet and we therefore used a C++ program that is available from the authors upon request.) Given the target rank correlation matrix (T) and the score matrix (R), the Iman and Conover technique solves



for the transformation matrix (S) where the product  $RS'$  has a correlation matrix equal to T (and a rank correlation matrix close to T). The elements within each column of  $RS'$  are then ranked from 1 to 5,000. The pattern of ranks within the columns is then replicated in the matrix of the distributional draws. This resorting of the draw matrix changes the rank correlation matrix of the draws to exactly match the rank correlation matrix of  $RS'$  and thus the rank correlation matrix comes close to the target rank correlation matrix T. As an example, suppose the first column of  $RS'$  started with the 300th, 4,230th, and 2,300th ranked elements in that column, and the first column of the draw matrix contained April hog prices. To match the rank correlations, the 300th, 4,230th, and 2,300th ranked April hog prices should be moved to the beginning of the April hog price column.

Table 3 contains the rank correlation matrix reached after applying the Iman and Conover technique. The largest difference between the values in the target and the actual rank correlation matrices is 0.02. Thus, the Iman and Conover technique provides a good approximation of the historical relationships.

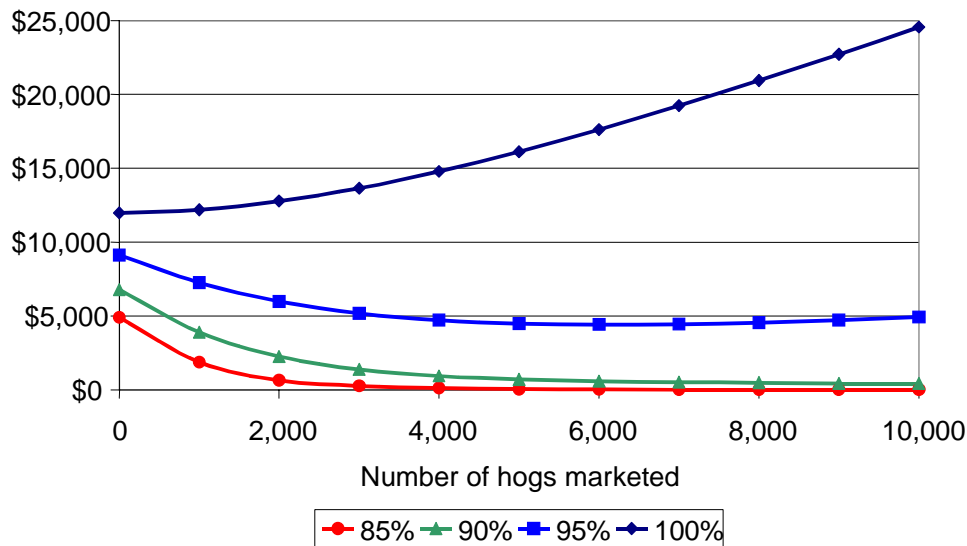
## **Results**

Figure 1 shows the premiums for the whole-farm policy at various coverage levels and the numbers of hogs marketed throughout the year (with an equal number of hogs marketed each month). As is apparent at the lower coverage levels, the diversification of adding hog revenues to crop revenues for a revenue insurance policy can reduce the overall premium needed to obtain the policy, creating a situation in which producers can insure more revenue for fewer premium dollars. At the 100 percent coverage level, the additional coverage of hog revenues does add to the premium bill. But as shown in Table 4, the sum of the premiums for individual commodity revenues still exceeds the premium for the combined coverage. To simplify the analysis for Table 4, the model assumes that 125 hogs are marketed per month (the typical output for an Iowa hog farm). The percentage reduction in premium for the whole farm policy depends on the coverage level. At 85 percent coverage, the whole farm premium is 84 percent less than the premium for separate insurance for each commodity. At 100 percent coverage, the reduction is 25 percent.



**TABLE 4. Insurance premiums (\$)**

Commodity Coverage	Coverage Level			
	85%	90%	95%	100%
Corn	4,563	5,717	7,080	8,650
Soybeans	2,453	3,101	3,866	4,765
Hog	2	39	606	3,206
Whole farm	1,114	2,964	6,565	12,446



**FIGURE 1. Premiums for whole-farm policy**

Figure 2 shows the premium rates for the whole-farm policy at given coverage levels and percentages of the liability that is derived from livestock. In all cases, the premium rate decreases with increases in the amount of liability from livestock. Also, as the 100 percent coverage line shows, even while the premium rate declines, the total premium (as shown in Figure 1) can still increase if the rate of change in liability is high enough.

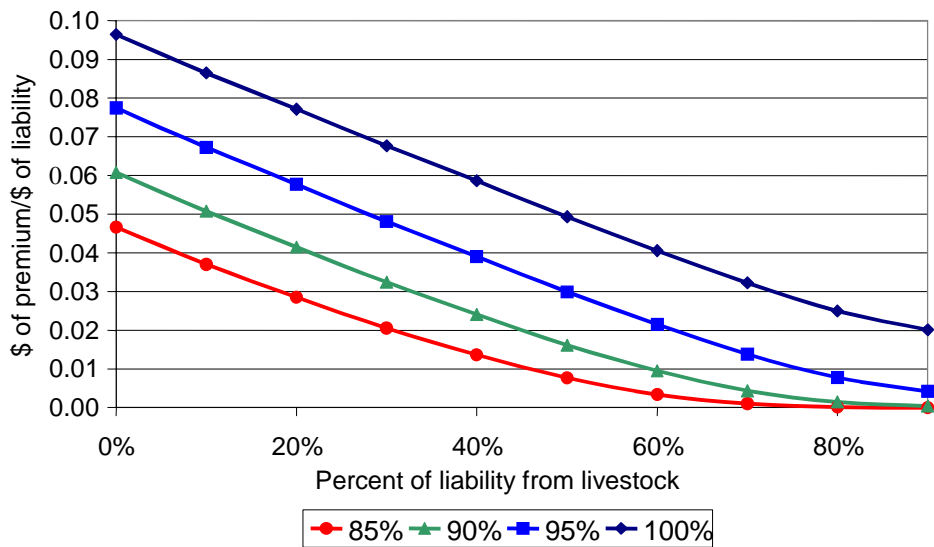
### Sensitivity Analysis

To investigate the effects of volatilities in the historical range on the proposed insurance product, we repeat the premium analysis with the distributional parameters set to reflect higher hog price volatilities. Table 5 summarizes the distributional assumptions.

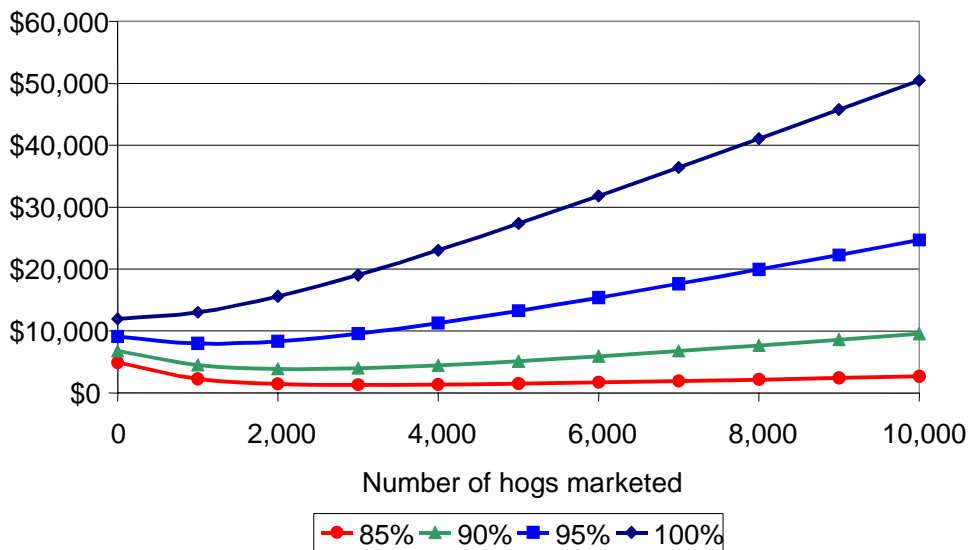


**TABLE 5. Distributions with increased hog price volatility**

Variable	Type	Mean	Standard Deviation	Annualized Implied Volatility
Corn yield	Beta	135.00	36.45	
Soybean yield	Beta	40.00	10.00	
		(bu/acre)	(bu/acre)	(%)
Corn price	Lognormal	2.30	0.45	23
Soybean price	Lognormal	4.65	0.79	21
		(\$/bu)	(\$/bu)	(%)
Apr. hog price	Lognormal	58.94	9.62	40
June hog price	Lognormal	66.75	15.42	40
July Hog price	Lognormal	63.15	16.31	40
Aug. hog price	Lognormal	60.70	17.17	40
Oct. hog price	Lognormal	51.89	16.95	40
Dec. hog price	Lognormal	49.38	18.03	40
Feb. hog price	Lognormal	51.04	20.42	40
		(\$/cwt)	(\$/cwt)	(%)

**FIGURE 2. Premium rates for whole-farm policy**

The rank correlation tables are the same for this analysis (see Tables 2 and 3). Figure 3 shows the premiums for the whole-farm policy at various coverage levels and the numbers of hogs marketed throughout the year (with an equal number of hogs marketed each month). The diversification of adding hog revenues to crop revenues for a revenue



**FIGURE 3. Premiums for whole-farm policy under increased hog price volatilities**

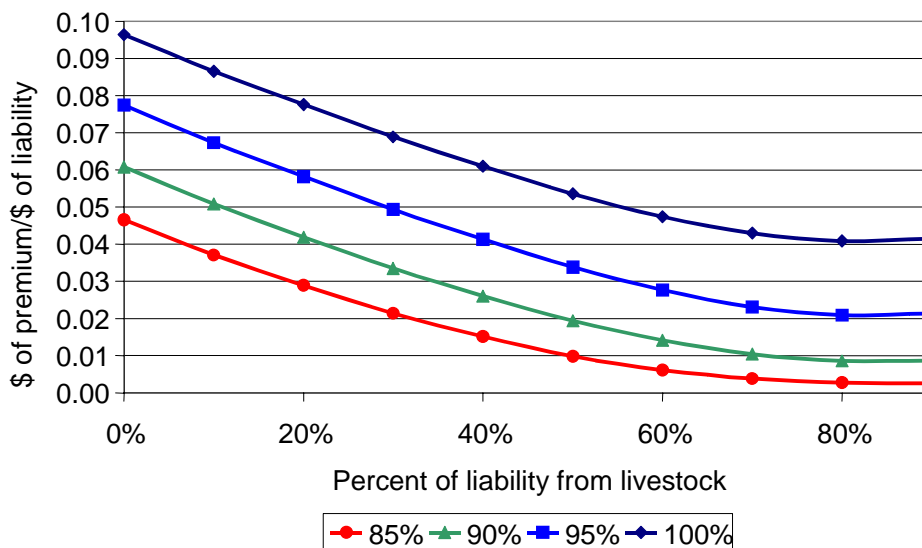
**TABLE 6. Insurance premiums given the higher volatilities (in \$)**

Commodity Coverage	Coverage Level			
	85%	90%	95%	100%
Corn	4,563	5,717	7,080	8,650
Soybeans	2,453	3,101	3,866	4,765
Hog	519	1,626	3,832	7,376
Whole farm	1,751	4,048	8,051	14,145

insurance policy again reduces the overall premium needed to obtain the policy. At the 85 percent coverage level, a producer with 250 acres of corn and 250 acres of soybeans obtains the lowest premium level when he or she insures 3,000 hogs during the year. The number of hogs needed to reach the minimum premium decreases with the coverage level.

The premium levels given in Table 6 assume that 125 hogs are marketed per month. Again, the premium for the whole farm policy is substantially less (between 32 percent and 77 percent depending on the coverage level) than the sum of the premiums for the individual commodity revenue policies.

Figure 4 shows the premium rates for the whole-farm policy at given coverage levels and percentages of the liability that is derived from livestock. In almost all cases, the



**FIGURE 4. Premium rates for whole-farm policy under increased hog price volatilities**

premium rate decreases with increases in the amount of liability from livestock. Only as the percentage of the liability that is derived from livestock exceeds 80 percent does the premium rate begin to increase.

### Concluding Remarks

Crop revenue insurance products have grown tremendously over the past decade. The federal government has shown interest in extending similar protection to livestock producers. Two pilot products for livestock were introduced in the summer of 2002. One idea that combines these programs is to create multi-commodity or whole-farm insurance programs. Examples of this type of program are the Revenue Assurance crop insurance program, which currently offers a whole-farm revenue insurance option, and the Adjusted Gross Revenue program, which insures revenue based on producers' historical income tax records.

This paper investigates the construction of whole-farm (covering both crop and livestock) revenue insurance programs. Recent innovations in both crop and livestock revenue insurance are combined into one program. The technique employed in the premium determination preserves the original distributional structure of the prices and yields, while imposing the desired correlation structure. The technique is transparent in

that the manipulation of the original data draws from the price and yield distributions and is limited to a resorting of the draws.

The estimated premiums for the proposed whole-farm insurance product are well below the combined total of estimated premiums for insurance products covering each of the commodities individually. We also examine the sensitivity of the premium to price volatility and the mix of commodities.

## Appendix

### Application of Iman and Conover Technique

This example shows how to apply the Iman and Conover technique using commonly available software. We performed all of the calculations for this appendix in Microsoft Excel. Table A.1 contains X, a matrix of draws of marginal distributions of interest. In this case, X contains the first 20 draws from the Monte Carlo simulation. Table A.2 contains R, a matrix of van der Waerden scores. Table 2 gives the target rank correlation matrix, T. Table A.3 gives U, the Cholesky factorization of T. In order for Excel to perform Cholesky factorization, the formulas for each element of the matrix must be entered. There is no Cholesky factorization command in Excel; however, some add-on products to Excel have Cholesky factorization commands. Table A.4 gives D, the correlation matrix of R. Table A.5 gives V, the Cholesky factorization of D. Table A.6 gives the transformation matrix  $S = VU^{-1}$ . The columns of the transformation  $RS'$  (Table A.7) have a correlation matrix that is equal to T. The rank correlation matrix of the columns of the transformation  $RS'$  ( $M^*$ , Table A.9) provides a good estimate of the target rank correlation matrix T. When the original draws from the marginal distributions (the columns of X) are sorted to match ranks with the data in the columns of  $RS'$ , the rank correlation matrix of the sorted draws is equal to  $M^*$ . Thus, the rank correlation matrix of the sorted draws approaches the target rank correlation matrix T.

TABLE A.1. Original draws (X)

Corn Yield (bu/acre)	Soybean Yield (bu/acre)	Corn Price (\$/bu)	Soybean Price (\$/bu)	April Hog Price (\$/cwt)	June Hog Price (\$/cwt)	July Hog Price (\$/cwt)	August Hog Price (\$/cwt)	October		December	
								Hog Price (\$/cwt)	Hog Price (\$/cwt)	Hog Price (\$/cwt)	Hog Price (\$/cwt)
160.5	14.1	2.09	4.71	66.47	82.23	60.88	53.80	61.04	53.11	68.25	68.25
124.3	45.8	2.41	5.18	51.44	73.15	72.39	55.51	46.49	54.52	47.02	47.02
95.0	51.2	2.14	4.06	56.22	70.90	62.02	50.96	45.58	56.11	52.68	52.68
183.9	50.5	2.59	4.35	55.58	68.89	63.19	62.67	51.36	42.38	56.35	56.35
123.5	45.2	2.15	4.10	66.26	64.46	62.26	55.36	51.99	53.24	70.98	70.98
134.5	42.2	2.81	4.86	59.93	71.94	62.88	63.12	69.97	47.46	43.12	43.12
181.5	44.6	2.49	3.44	57.32	65.05	82.92	71.71	64.72	50.74	41.69	41.69
155.0	38.7	2.42	3.77	64.84	67.96	53.55	55.15	60.06	47.26	36.98	36.98
108.0	37.4	2.15	4.90	53.60	71.28	64.98	64.67	48.46	64.49	50.09	50.09
151.5	45.2	2.42	6.28	63.69	61.59	68.76	71.94	53.13	48.23	47.69	47.69
115.3	14.6	2.97	3.57	58.47	65.19	66.17	62.34	48.07	55.49	41.80	41.80
165.3	52.3	2.07	4.86	59.25	59.37	68.86	72.64	49.12	40.78	49.00	49.00
92.5	39.3	2.27	4.93	64.38	63.59	60.91	54.44	55.06	42.66	56.20	56.20
158.1	40.6	1.95	5.68	55.33	64.49	53.08	56.96	41.61	39.62	49.38	49.38
166.7	43.6	1.53	5.92	54.49	74.19	60.70	53.10	46.47	41.12	59.12	59.12
119.0	49.5	2.11	4.31	58.92	48.26	52.99	62.40	47.97	36.38	41.13	41.13
74.8	45.6	1.94	4.12	62.26	68.04	63.94	54.09	42.23	61.66	54.37	54.37
72.6	29.6	3.16	4.62	59.63	65.97	70.31	65.71	48.66	48.20	58.07	58.07
176.0	29.5	1.50	5.53	57.90	67.24	52.17	54.48	56.85	55.46	48.71	48.71
129.7	47.8	2.79	3.75	52.66	60.60	59.68	72.63	48.71	48.05	47.65	47.65

TABLE A.2. van der Waerden scores (R)

0.4307	-0.5659	-1.3092	0.3030	1.3092	-0.5659	-1.6684	-0.5659	0.8761	1.0676	0.4307
0.3030	0.0597	0.8761	-0.1800	0.1800	0.0597	1.3092	0.8761	-1.3092	-0.3030	1.3092
1.0676	-0.0597	-0.1800	1.3092	0.3030	-1.6684	1.0676	-1.6684	0.5659	-1.0676	-0.8761
-0.3030	0.3030	0.1800	0.0597	0.7124	-0.7124	0.1800	0.3030	-0.7124	1.3092	0.3030
0.1800	-0.7124	0.5659	1.6684	-0.3030	-0.0597	-0.5659	0.5659	-0.5659	-0.8761	1.6684
-0.8761	0.8761	-0.0597	-0.3030	0.0597	1.0676	-0.1800	1.0676	1.3092	-0.0597	-0.0597
1.6684	0.5659	-1.0676	0.5659	-0.1800	1.3092	-0.7124	0.0597	1.0676	0.8761	1.0676
-1.6684	-0.4307	0.7124	0.4307	-0.4307	0.7124	-0.0597	1.6684	-1.6684	-0.4307	0.8761
0.0597	0.1800	1.6684	0.7124	0.8761	0.4307	-0.3030	0.1800	0.4307	0.5659	-1.3092
0.5659	1.0676	0.3030	-0.5659	-1.6684	-0.8761	0.7124	-0.0597	-0.4307	1.6684	-0.4307
-0.4307	1.3092	0.4307	-1.3092	-0.8761	-0.1800	-0.4307	-0.4307	0.7124	0.3030	0.0597
1.3092	-1.6684	0.0597	-0.4307	0.4307	1.6684	1.6684	-0.3030	1.6684	0.4307	0.1800
-0.1800	0.4307	-0.8761	-0.8761	0.5659	0.1800	-1.0676	-0.7124	0.1800	-1.3092	-0.3030
-0.0597	-0.1800	1.3092	-1.6684	1.0676	-1.3092	-1.3092	0.7124	-0.0597	0.7124	0.5659
0.8761	1.6684	1.0676	0.8761	-0.0597	-0.4307	0.3030	-0.1800	-0.8761	-1.6684	-1.0676
-1.3092	-0.3030	-0.7124	1.0676	-0.5659	0.5659	0.0597	0.4307	0.0597	-0.5659	-0.1800
-1.0676	-1.0676	-0.5659	-0.7124	-1.3092	-1.3092	-0.8761	-1.3092	0.3030	-0.7124	-0.5659
-0.5659	-1.3092	-0.4307	-1.0676	-1.0676	0.8761	0.8761	-0.8761	-1.0676	0.0597	-0.7124
-0.7124	-0.8761	-0.3030	0.1800	1.6684	-0.3030	0.5659	1.3092	-0.3030	-0.1800	-1.6684
0.7124	0.7124	-1.6684	-0.0597	-0.7124	-1.0676	0.4307	-1.0676	-0.1800	0.1800	0.7124







**TABLE A.7. Transformed van der Waerden scores (RS')**

0.4307	-0.0311	-1.3803	-0.7616	1.7144	1.1621	0.0836	-0.2511	-0.4060	0.1557	0.3845
0.3030	0.2469	0.5656	0.1882	-0.2135	-0.1551	0.8190	1.0444	0.6356	0.2375	1.0447
1.0676	0.7115	-0.6738	0.3917	0.2781	-0.5771	0.3524	-0.0599	0.3192	0.0315	0.1018
-0.3030	-0.0340	0.3585	0.3402	0.6437	0.1646	0.6995	0.6259	0.2119	1.1268	1.2959
0.1800	-0.2924	0.2037	1.3254	-0.3213	-0.4152	-1.1684	-0.4238	-0.1840	-0.6082	0.3569
-0.8761	-0.0983	0.5740	0.3244	0.1254	0.9279	0.8015	0.9373	1.2663	0.6627	0.9352
1.6684	1.4989	-1.5315	-0.7786	-0.0874	1.2863	0.2228	0.4623	0.2652	0.1129	0.0377
-1.6684	-1.4195	1.2787	1.3770	-0.2995	-0.1828	-0.4717	0.2288	-0.1258	-0.3613	0.3924
0.0597	0.1474	1.3424	1.4096	0.2701	0.5540	0.4831	0.4127	0.8973	1.8382	0.9343
0.5659	1.0226	0.2084	-0.3150	-1.9384	-1.9671	-1.1440	-0.6947	-0.5316	0.4230	-1.2023
-0.4307	0.4675	0.8471	-0.3010	-1.1386	-0.9318	-0.6917	-0.8756	-0.4733	0.0197	-0.0930
1.3092	-0.0641	-0.9622	-1.2419	0.2798	0.9641	1.1863	0.7822	1.6274	1.3149	1.3396
-0.1800	0.1270	-0.5146	-0.9438	0.7720	0.8949	0.3769	-0.2403	-0.8130	-1.4704	-0.9557
-0.0597	-0.1474	1.0325	-0.5956	0.4422	-0.7230	-0.6493	-0.6254	-0.2257	0.3293	-0.0854
0.8761	1.5922	0.8035	1.1503	-0.6723	-0.2303	0.4187	0.5382	0.1030	-0.4952	-1.0467
-1.3092	-1.0934	-0.0028	0.9833	0.0566	0.2649	-0.1806	0.1233	0.1451	-0.3489	0.1933
-1.0676	-1.3733	-0.1753	-0.5560	-0.8183	-1.0513	-2.0343	-2.3357	-1.8783	-1.6428	-1.6936
-0.5659	-1.1644	-0.3647	-1.0363	-0.7301	-0.6409	-0.6570	-1.0464	-1.3537	-0.9206	-1.2858
-0.7124	-1.0126	-0.0943	0.1299	1.9151	1.1893	1.6557	1.6751	1.3677	0.5836	-0.1088
0.7124	0.9165	-1.5149	-1.0901	-0.2779	-0.5335	-0.1024	-0.2773	-0.8473	-0.9883	-0.5449

TABLE A.8. Resorted draws

Corn Yield (bu/acre)	Soybean Yield (bu/acre)	Corn Price (\$/bu)	Soybean Price (\$/bu)	April Hog Price (\$/cwt)	June Hog Price (\$/cwt)	July Hog Price (\$/cwt)	August Hog Price (\$/cwt)	October		December	
								Hog Price (\$/cwt)	Hog Price (\$/cwt)	Hog Price (\$/cwt)	Hog Price (\$/cwt)
119.0	43.6	2.81	4.93	52.66	60.60	62.88	62.67	53.13	48.05	47.65	
123.5	39.3	2.11	4.35	59.25	65.97	53.08	53.10	46.49	47.46	41.69	
92.5	37.4	2.59	4.10	56.22	70.90	62.02	62.34	47.97	48.23	49.00	
155.0	44.6	2.14	4.12	54.49	65.19	59.68	54.44	48.46	40.78	41.13	
124.3	45.8	2.15	3.75	62.26	68.04	72.39	64.67	51.36	55.46	47.69	
166.7	45.2	2.09	4.31	57.90	63.59	53.55	53.80	45.58	41.12	41.80	
72.6	14.6	3.16	5.18	58.92	48.26	62.26	55.15	48.07	48.20	49.38	
183.9	52.3	1.53	3.57	59.93	67.24	64.98	55.51	49.12	53.24	47.02	
129.7	40.6	1.50	3.44	57.32	64.49	60.70	55.36	46.47	36.38	43.12	
115.3	29.5	2.15	4.86	66.47	82.23	70.31	71.71	56.85	42.66	59.12	
158.1	38.7	1.95	4.71	66.26	73.15	68.86	71.94	55.06	50.74	52.68	
74.8	45.2	2.79	6.28	55.58	61.59	52.99	54.09	41.61	39.62	36.98	
151.5	42.2	2.49	5.53	53.60	64.46	60.91	62.40	60.06	61.66	56.35	
134.5	45.6	1.94	4.90	55.33	71.94	66.17	65.71	51.99	47.26	50.09	
95.0	14.1	2.07	3.77	63.69	67.96	60.88	54.48	48.71	54.52	58.07	
181.5	49.5	2.27	4.06	58.47	65.05	63.94	56.96	48.66	53.11	48.71	
176.0	51.2	2.42	4.86	64.84	74.19	82.92	72.64	69.97	64.49	70.98	
160.5	50.5	2.42	5.68	64.38	71.28	68.76	72.63	64.72	55.49	68.25	
165.3	47.8	2.41	4.62	51.44	59.37	52.17	50.96	42.23	42.38	54.37	
108.0	29.6	2.97	5.92	59.63	68.89	63.19	63.12	61.04	56.11	56.20	



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