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RATE-MAKING FOR FARM-LEVEL CROP INSURANCE

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ABSTRACT

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This research identifies two problems in the new Federal Crop Insurance that may cause adverse selection: 1) the relationship between rate-making and expected yields for individual farmers, and 2) the bias introduced in coverage protection when trends are not used to establish expected yields. A theoretical investigation using the normality assumption demonstrates the potential severity of these problems and empirical results from farm-level data lend further support.

Rate-Making for Farm Level Crop Insurance

One of the more significant changes made since the 1980 Federal Crop Insurance Act is a move toward developing coverage based upon individual expected yields (first the Individual Yield Coverage program and now the Actual Production History - APH - program). Under the APH program FCI uses either 10 years of certified farm data or a combination of limited farm data and an area indexing scheme to establish an individual yield level. Thus, FCI has taken a significant step toward eliminating adverse selection problems associated with using area average yields.

However, at least two features of the FCI program have the potential to cause adverse selection: 1) the manner in which FCI rates are developed for farms with different APH yields[1] and 2) the manner in which the APH yield is established. This research investigates these two features.

Conceptual Framework

Both farm level expected values and some measure of farm level variability are fundamental to an individual farmer's decision to purchase crop insurance. If the farmer has some knowledge of expected premiums over time and expected indemnity payments, his decision can then be based upon his willingness to accept risk. Under the APH program, a farmer can purchase protection equal to either 50, 65, or 75 percent of his APH yield. For example, if a corn farmer with a 120 bushel APH yield chooses the 75% level of protection, he will receive payments in any year that his yield falls below 90 bushels per acre (e.g., with an 80 bushel yield, indemnity payments will be made on 10 bushels). The payment will depend on the level of price protection purchased (i.e., three levels were available in 1984 - $2.90, 2.40, and 2.00).

It is possible to evaluate expected indemnity payments once expected yield and standard deviation are known by assuming a known parent distribution. Botts and Boles explored techniques for developing expected losses from a normal distribution, which is a common distribution associated with crop yields. Basically, a normal distribution must be integrated in the region below the coverage level:

$$(1) \quad EL = \int_{-\infty}^{Y_g} (Y_g - Y)\, f(Y)dy$$

where EL is expected losses or pure premium in bushels; Y_g is the yield guarantee (APH yield multiplied by the percentage level of protection); Y is the actual yield; and f(Y) is the probability density function for yields.

Using work by Botts and Boles and the polynomial function for integration of a normally distributed density function yields a more specific formulation for estimating expected losses from a truncated normal distribution:

$$(2) \quad Z = \frac{1}{\sqrt{2\pi}} e^{-.5\left(\frac{\bar{Y} - Y_g}{S}\right)^2}$$

$$(3) \quad T = \frac{1}{1 + b\left(\frac{\bar{Y} - Y_g}{S}\right)}$$

$$(4) \quad P = Z\,(a_1T + a_2T^2 + a_3T^3)$$

$$(5) \quad EL = P\,(Y_g - \bar{Y}) + ZS$$

where b=.33267, a_1=.4361836, a_2=-.1201676, and a_3=.937298 (these coefficients can be found in Abramowitz and Stegun). Other variables include: $\bar{Y}$ - expected yield; S - standard deviation; P - probability of collecting in any given year; and the variables defined above or through intermediate calculations (Z and T). Integrations using this polynomial deviate only 1 X 10^{-5} from the theoretical normal distribution.

Equations (2) - (5) provide an opportunity to investigate crop insurance under the assumption of normality. Such a theoretical investigation will be used to discuss the two issues central to this research. Next, the equations will be used to estimate expected losses for corn and soybean farms in Illinois. Finally, these results will be compared with results that disregard the normality assumption and use trend adjusted yield data to examine what losses would have been over the time series.

Theoretical Investigation

The first problem to be dealt with involves the relationship between rate setting and expected yields . For the most part FCI provides protection based on a percentage of APH yields (i.e. 50, 65, and 75%). In the transition from area average yields to more individualized yields, FCI set premium charges based on the rate for the area in which the individual farm was located. These premium charges were the same regardless of whether a farmer participated in the area coverage option or the individualized program, though the yield guarantee differed. An implicit assumption of this procedure is that relative yield risk (coefficient of variation) is constant across farms with different expected yields.

If farms with higher expected yields have less risk in percentage terms, those farmers will receive less protection but pay the same premium (i.e., multiplying a percent by a small number yields a smaller number than multiplying the percent by a large number). For example, a farmer who chooses 75 percent protection for an expected yield of 80 bushels would receive indemnity payments for yields below 60 bushels (<u>20 bushels</u> below his average). His neighbor, who has an expected yield of 120 bushels, would receive indemnity payments for yields below 90 bushels (<u>30 bushels</u> below his average). If the farmer with the 120 bushel average has a standard deviation for yield which is 50 percent higher than his neighbor, he would have the same coefficient of variation as the farmer with the 80 bushel expected yield. Both farmers would have the same relative risk and should be charged the same premium. However, if both farmers have similar yield dispersions (similar standard deviations) and different expected values, charging the same premium for a fixed level of protection (e.g., percentage of average yield) causes an adverse selection problem - farmers with relatively high expected yields will not participate in FCI. The empirical question involves the relationship between expected yields and measures of variation (e.g., standard deviation).

Equations (2) - (5) can be used to illustrate the potential differences in premiums and rates as expected yields vary. Expected yield losses under various insurance program designs can be converted to premiums and rates. A pure premium should simply equal the expected loss multiplied by the level of price protection. Since FCI offers different levels of price protection, rates are used by FCI to develop premiums. Theoretical rates (which are analogous to FCI rates) can also be developed from the expected loss information:

(6) $R = (EL / Y_g)\ 100$

where R is the rate, EL is the expected loss from equations (2) - (5) and Y_g is the yield guarantee level. FCI calculates premiums by:

(7) $PR = R\ Y_g\ P_g / 100$

where PR is premium and P_g is price protection. Again, until the 1985 crop year, the yield guarantee used to calculate premium was the area average value. Thus, premiums were the same regardless of the individual farm yield. In 1985, FCI will offer discounts for some crops as expected yields increases.

If standard deviation is fixed at 25, equations (2) -(5) demonstrate the effects of expected yield increases on pure premiums. Substantial differences exist between pure premiums when expected yields change. For the relatively low yield of 65 bushels of corn per acre, annual bushel loss is expected to be 3.88 bushels. Doubling corn yields reduces expected bushel loss by 3.4 times (i.e., at 130 bushels expected loss is 1.14 bushels). Therefore, given these assumptions, premium discounts based on expected yield can easily be justified. Some empirical questions remain: Are expected yields and standard deviations independent? Is the assumption of normality valid for crop yields? These questions are addressed in the next section.

The above analyses assumed that expected yields and APH yields were equivalent. In fact, when a significant trend is present, expected yields will exceed APH yields. Ideally, FCI strives to obtain 10 years of certified farm yields for the APH program. In the transition, they will accept limited data and use an indexing scheme with adjusted ASCS yield data for the area. Although these methods can be challenged, they must be accepted as a means of attracting new farmers into FCI.

The problem that this study addresses is that FCI does not make an attempt to adjust yield data for trends. Given 10 years of data, FCI drops the high and low yield and takes a simple average to obtain the APH yield. Since coverage levels are tied to APH yields, this means that farmers with positive yield trends will not be able to purchase as much protection as is implied because APH yield is a biased estimate of expected yield. For example, a farmer with an expected yield of 100 bushels per acre and a trend of two bushels per year would likely have an APH of only 90 bushels based on ten years of data (i.e., 100 - 2 X 5 years). Rather than having the option to protect yield shortfalls below 75 bushels (75 percent of expected yield), the maximum protection available is for yields below 67.5 bushels under the APH program. Due to the properties of a normal distribution, such a discrepancy results in an even larger difference in the expected losses. Again, assuming a standard deviation of 25, results from equations (2)-(5) illustrate the degree to which neglecting trend adjustments can influence expected losses. For example, a farmer with an expected yield of 100 bushels and an APH yield of 90 bushels would have an expected bushel loss of only 1.34 bushels versus 2.08 bushels. The differences are not trivial, which indicates another reason for participation problems. Empirical results below will provide further insights.

Empirical Results

A number of testable hypotheses evolve from the theoretical investigation: 1) Farm-level expected yields and standard deviations are independent, 2) Farm-level yield distributions are normally distributed, and 3) Trends in farm-level data are zero. Results of these hypothesis tests will directly relate to the two issues addressed in this paper.

Clearly, county level yield data are unacceptable for this research.

Further, experiment station data were considered unacceptable since a great degree of control is used at experiment station farms. A time-series of farm-level yields from farm analysis records was used for this study. The data on corn and soybean yields came from a specially developed sample of farms in Northern Illinois that had no substantial farm expansion over the observation period. Yield data are developed on a per planted acre basis. The sample included twelve years of data, 1972-1983, for 54 farms.

The first analysis involved testing the trend in the data sets. Given significant trends, adjustments are needed before other hypotheses can be tested. Since a limited number of years were available on an individual farm basis, data were pooled by region in order to test for a linear trend. In order to control for differences in mean yields for individual farms, a dummy variable was used for each farm (this allowed the intercept term to vary by farm). Chow tests were used to test the assumption that yield trends were the same across farms. These tests indicated that the hypothesis that yield trends were identical for all farms in each region could not be rejected at the 5 percent significance level. The trend values were judged to be significantly different than zero for the region, at the 5 percent level. Annual trend values (in bushels per acre) and corresponding standard errors (in parenthesis) were: 2.14 (.213) for corn and .622 (.066) for soybeans.

Since the Chow tests suggested that assuming a common yield trend for all farms was reasonable, each individual farm's data were adjusted to 1983 technology:

(8) $$Y'_{it} = Y_{it} + b(1983 - t)$$

where Y'_{it} is farm i's yield in year t adjusted for 1983 technology and b is the trend value (reported above). These transformed data sets were used for the remaining analyses.

In order to test the hypothesis that farm-level expected yields and standard deviations are independent, a simple regression was used:

(9) $$SD_i = c + a\ EY_i$$

Where EY_i is the expected yield (mean of the time series using adjusted data) for the ith farm and SD_i is the standard deviation. Results are as follows (standard errors in parentheses):

$$\text{(10)} \quad SD = 32.78 - \underset{(.067)}{.098}(EY) \quad \text{(corn)}$$

$$\text{(11)} \quad SD = 8.91 - \underset{(.055)}{.066}(EY) \quad \text{(soybeans)}$$

In all cases, the null hypothesis that standard deviation is independent of expected yield cannot be rejected at the 5 percent level of significance. Such a result provides legitimacy to the theoretical investigation of premiums and rates that assume a constant standard deviation across farms with different expected yields.

The next set of tests center on the assumption of normality. A Shapiro-Wilks test for normality (a common test for small sample sizes) was performed using individual farm yield data. Using a 20 percent significance level, the normality assumption was rejected for 31 percent of the corn sample and 19 percent of the soybean sample.[2]

Although normality cannot be rejected for the majority of farms, these results suggest that the normality assumption may not be appropriate for analyzing FCI. Examination of the third moment for each individual farm suggests that, if there is a significant skewness (small sample sizes prohibited strong statistical testing), it is negative. If the distributions are negatively skewed, this will increase the expected losses associated with FCI coverage. Initially, the normality assumption is used.

Given the individual farm data, it is possible to calculate expected losses for alternative designs in FCI. This also makes it possible to investigate the relationship between insurance rates and expected yields. In order to be consistent with the theoretical investigation, equations (2) - (5) were used for the 75 percent level of protection under the assumption that FCI coverage would be based on expected yield (i.e., 1983 mean values). Thus individual farm means and standard deviations were used to develop expected losses and farm rates. A simple regression model was used to test the relationship between farm level expected yields and rates. A curvilinear relationship was chosen since the theoretical investigation indicated that insurance rates should decline at a decreasing rate:

$$R_i = c + b(IY_i) \tag{12}$$

where R_i is the pure rate for the ith farm (calculated using equations (2) - (5)) and IY_i is the inverse of the expected yield for the ith farm. Results are as follows (standard errors are reported in parenthesis):

$$R_i = -3.10 + \underset{(157.96)}{492.25}(IY_i) \quad \text{(corn)} \tag{13}$$

$$R_i = -2.28 + \underset{(31.6)}{118.07}(IY_i) \quad \text{(soybeans)} \tag{14}$$

These results indicate that theoretical insurance rates decline as expected yields increase. All results are significant at the 5 percent level.

The corn equations are used to compare theoretical results that assume a constant standard deviation across farms. The mean standard deviation corn farms was 19.68. Therefore, a standard deviation of 20 was used to illustrate the results with a constant standard deviation across farms. The resulting equation was:

$$R = -3.338 + \underset{(20.78)}{496.45}(IY) \tag{15}$$

Equation (15) is very similiar to the empirical curve equation (13). Use of theoretical equations provide reasonable estimates for the pure insurance rates.

The above analysis used expected yields rather than the FCI method of APH yields. Therefore, further analysis is appropriate to indicate the differences between use of expected yields and APH yields in establishing theoretical rates. The farm level data were used to calculate APH yields in the same fashion as FCI (i.e. the last 10 years of unadjusted data are used after dropping the high and low). These data are used in the equations (2) - (5) to develop theoretical rates under APH yields. Once again the relationship between rates and expected yields were estimated with equation (12). Figure 1 contrast the use of APH yields versus expected yield (under the normality assumption). Results are consistent across regions and provide an indication of the degree to which using unadjusted (for trend) APH yields bias downward expected indemnity payments from FCI. If FCI develops rates that do not reflect these differences, participation will be thwarted.

All of the analyses above have assumed normality for the parent distribution on crop yields. If the distributions are not normal, this has profound repercussions for expected losses. Therefore, a final set of analyses were developed that imposed no formal distribution on crop yields. Thus the trend adjusted yield observations formed the yield distribution for each farm. Step integration was used to determine expected indemnity payments from these yields with both the predicted 1983 value (expected value) and the APH yield with step integration. That is, the sum of the difference between the yield guarantee and the yields that fall below that level were divided by the sample size for each farm:

$$EL = \sum_{i=1}^{i=n} (Y_g - Y_i)/n \quad \text{when } Y_i < Y_g \tag{15}$$

where EL is expected loss, Y_g is the yield guarantee (either developed based on expected yield or APH yield), Y_i is the trend adjusted yield in year i, and n is the sample size for the farm. Work by King illustrates that these procedures provide unbiased linear estimates.

Once again, procedures described above were used to fit equation (12) to the rates developed from equation (15). Figure 1 illustrate the differences obtained when using step integration rather than normal integration. These results shed doubt on the normality assumption. However, it is impossible to reach strong conclusions since sample size is small.

Finally, the similar shapes between the normal versus the non-normal curves show the consistency of the findings: 1) rates decline as expected yields increase and 2) using unadjusted APH yields to develop levels of protection is suspect. Therefore, the conclusions of this study are not sensitive to the normality assumption.

Conclusions and Implications

It appears that Congress is attempting to reduce the role of commodity programs in favor of farmer-financed alternatives. In 1980, Congress lifted the ban on trading of agricultural future options (a form of price insurance). The 1981 Farm Bill mandated an investigation into revenue insurance as an alternative to commodity programs. Disaster programs have been eliminated in favor of Federal Crop Insurance. Federal Crop Insurance has been significantly restructured. If these programs are to provide a safety net for American agriculture, they must be attractive to farmers.

This research has identified two problems with the Federal Crop Insurance program that discourage participation and probably lead to adverse selection: 1) farmers with relatively high expected yields can only expect very small losses when guarantees are tied to yield and 2) unadjusted (for trend) APH yields reduce the expected losses when a yield trend is present. FCI has taken steps to provide yield discounts so that farmers with higher expected yields will pay lower premiums. This research supports such action. Further, this research introduces a procedure for developing these yield discounts. However, the fact remains that farmers with high expected yields have little incentive to participate in FCI. Congressional action would be required to change the fashion in which yield guarantees are developed.

Conceptually, levels of protection should be tied to some measure of variability (e.g. standard deviation). This would provide farmers with different expected yields similar levels of protection (assuming that standard deviation is not a function of expected values - an assumption supported by this research). Clearly such a program would be difficult to administer. However, this approach or something similar is needed if crop insurance is going to be relied upon to provide stability to the agricultural community. There is no reason to assume that farmers with higher expected yields need less protection.

Footnotes

[1]FCI uses a two step process to determine insurance premiums from rates. The first step is to calculate an area acreage insurance rate. These rates facilitate the integration of different price protection levels in premium calculations. Equations (6) and (7) provide a more complete formulation for these calculations.

[2]The 20 percent significance level was selected because lower levels of significance would substantially increase the probability of a type II error.

References

Abramowitz, Milton and Irene Stegun. Handbook of Mathematical Functions. Washington, U.S. Government printing office, 1968.

Ahsan, Syed., A.G. Ali, and N. John Kurian. "Toward a Theory of Agricultural Insurance." American Journal of Agricultural Economics. 64(1982):520-529.

Botts, Ralph R. and James N. Boles. "Use of Normal-Curve Theory in Crop Insurance Ratemaking." Journal of Farm Economics. (1957):733-740.

King, Robert, Presentation to Federal Crop Insurance four state research team, San Francisco, Calif, June 1984.

Ray, P.K. "A Manual on Crop Insurance for Developing Countries." Rome: FAO, 1974.

Stephens, M.A. "Use of the Kolomogorov-Smirnov, Cramer-Von Mises and Related Statistics Without Extensive Tables." Journal of American Statistical Association. 69(1974):730.

------. "An Inside Look at Federal Crop Insurance." Crop Insurance Update, USDA, Federal Crop Insurance Corporation, 1984.

------. "Farm Income Protection Insurance: A Report to the United States Congress." Washington, D.C., 1983.