ECONOMIC IMPLICATIONS OF ALTERNATIVE CROP INSURANCE DESIGNS

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Staff Paper 95-66
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ABSTRACT

Participation and welfare implications of alternative crop insurance designs are examined. Results show that relaxing trigger yield restrictions can significantly improve risk management performance, particularly in an area-yield insurance program. The optimal design is found to be especially sensitive to premium rates and correlation between individual and area yield.

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Recent political debates have focused on changing and/or eliminating many farm programs, including deficiency payments and crop insurance. Deficiency payment programs reduce price risk and provide an implicit subsidy to farmers. Crop insurance helps farmers manage yield risk and reduces exposure to overall income risk. The crop insurance program established in 1980 by the Federal Crop Insurance Corporation (FCIC) has never been financially sound (U.S. General Accounting Office). Efficient delivery of crop insurance is hindered by moral hazard and adverse selection problems, and by catastrophic risk caused by indemnification payouts being correlated across geographic regions. New forms of crop insurance have been proposed in an attempt to improve the financial situation of FCIC. An area-yield crop insurance scheme, referred to as the Group Risk Plan is one alternative design currently being tested in the field (Baquet and Skees). Designing new crop insurance instruments and evaluating their economic implications is a high priority in today's political environment.

In this paper we investigate the performance of alternative crop insurance designs in a portfolio context where the portfolio of risk management instruments may include futures, options, and government deficiency payments in addition to the crop insurance instrument. The focus here is on crop insurance and the effects of alternative design features on participation rates and farmer welfare. Consequently we allow farmers to use the other instruments to manage risk, but only report participation results for crop insurance. The complexity of the portfolio problem makes analytical results extremely difficult to generate. Nevertheless, a portfolio approach is required because the existence of deficiency payments, futures, and options can have crucial implications for how farmers use and view crop insurance. As a result, we use stochastic simulation and numerical optimization results to investigate a portfolio of risk management decisions for a representative farm in Iowa.

The Model

Let $\boldsymbol{p}$ be a random price vector consisting of cash and futures prices for corn in the harvest period, and $\boldsymbol{y}$ be a random yield vector consisting of the individual farm's corn yield and a corn yield index (which may be the individual farm's yield) used to trigger crop insurance payouts. In the planting period, the farmer chooses a portfolio of risk management instruments, $\boldsymbol{x}$, to maximize the expected utility of per acre profits,

$$\max_{x} \int_0^{\infty} \int_0^{\infty} u[\pi(p,y;\, x)]g(p,y|\Omega)\,dp\,dy \tag{1}$$

where $u(\cdot)$ is an increasing and concave von Neumann-Morgenstern utility function, $\pi(\cdot)$ is a per acre profit function and $g(\cdot|\Omega)$ is a given joint density for prices and yields conditional on Ω, a set of information available when x is chosen. The utility function is specified to have constant relative risk aversion (CRRA) $u(\pi) = (1-\theta)^{-1}\pi^{(1-\theta)}$ where the risk aversion parameter is set at $\theta = 2$. Profit is defined on a per acre basis to simplify calibration of the model.

The profit function has four components,

$$\pi(p,y;\, x) = NP + FO + CI + GP \tag{2}$$

where $NP = py - c$;

$FO = h(f_0 - f) + z[\max(0, s - f) - k]$;

$CI = m\ [w \max(0, y_0 - y_i) - \lambda a(y_0, w)]$; and

$GP = b[y_b(1 - q - r)\max(0, p_0 - p) - q(NP + CI)]$.

The first component, NP, is the normal profit from producing and selling corn. Thus, p is the cash price of corn at harvest, y is the individual farm yield, and c is production costs per acre. The second component, FO, is net return from futures and option trading. Hence, h is the quantity of futures contracts purchased (sold if negative) per acre, f_0 is the initial futures price when h is chosen, f is the futures price at harvest, and z is the number of put options purchased (written if negative) per acre with strike price s and premium k. The third component, CI, represents net returns from crop insurance. Thus, w is the (given) price used to value yield shortfalls in the crop insurance scheme, y_0 is the yield level which triggers crop insurance payouts (i.e. the coverage level chosen by the farmer), and $a(y_0, w)$ is the actuarially fair crop insurance premium per acre which depends on y_0 and w. The constant λ inflates or deflates the actuarially fair premium to reflect transaction costs and/or difficulties in assessing the distribution of y_i. Notice that the crop insurance scheme depends on realizations of a random yield index y_i which might be the individual farm yield (as in conventional multiple peril crop insurance) but which also might be county yield (as in an area-yield scheme). The proportion of planted acres covered by crop insurance is given by m. The fourth and final component of profits is net returns from participation in the government deficiency payment program. Here b is a binary variable which equals one if the farmer chooses to participate and zero if not; r is the proportion of total land which is "flexible" (not included in base acres); q is the proportion of land which must be set aside to be eligible for government payments; and p_0 is the target price. Deficiency payments are based on the difference between the target price and the market price (whenever this difference is positive) but payments are made only on base yield for the farm, y_b. The cost to the farmer of participating in the program is the value of the set aside, which depends on realized yield not base yield. The profit function (2) is a simplified representation of reality in a number of respects but it does incorporate a stylized version of the four main risk management instruments currently available in U.S. agriculture.

The choice vector, $\boldsymbol{x} = (h, z, y_0, m, b)$ consists of decisions about futures and options positions, the trigger yield and coverage levels for crop insurance, and whether or not to participate in government programs. It is assumed that these decisions are made simultaneously in a portfolio context taking the remaining parameters and probability distributions as given. Because the model is solved with numerical methods it must first be calibrated and validated.

Price and Yield Distributions

We calibrate a joint distribution over cash and futures prices at harvest, conditional on information available at planting, by estimating a bivariate ARCH model with a seasonal component for cash and futures prices. The data are weekly cash and futures prices for corn from the first week in May 1989 to the last week in April 1994 obtained from the Agricultural Extension Service in the Department of Economics at Iowa State University. The cash price is the average price for each Thursday in the southwestern Crop Reporting District of Iowa. Futures data are for the December contract on the Chicago Board of Trade and reflect settlement prices at the close of each Thursday.

The conditional distribution of harvest prices is the distribution of a multi-step forecast error which has no closed form in the ARCH model, even when the innovations are conditionally normal (Engle). Hence, a discrete estimate of the required joint distribution is generated through stochastic simulation (see Myers and Hanson). The frequency distribution of the simulated realizations of harvest prices is then used as an estimate of the joint distribution of cash and futures prices at harvest, conditional on information available at planting.

Recent work by Moss and Shonkwiler (1993) uses an inverse hyperbolic sine function to model yield distributions around a measure of central tendency. The yield process might be thought of as having stochastic shocks, which are due to factors such as weather, insects and disease, around a mean-yield level which changes over time as technology improves. The residuals around the time-varying mean are corrected for skewness and kurtosis by use of a transformation based on the inverse hyperbolic sine function. This model simultaneously shrinks large residuals toward zero and parameterizes the skewness and kurtosis of the distribution. Equally important, the model characterizes both the trend and stationary component of yields in a way that easily accommodates the use of time series data. The model used in this study is similar to Moss and Shonkwiler.

Because the time series data on yields are annual observations, we can predict the yield process for the upcoming year by specifying the current year's yield and iterating the model forward one period. There is no closed form distribution for the resulting conditional distribution, but it is straightforward to simulate it empirically. Again, the frequency distribution of the simulated realizations is used as the estimated discrete county yield distribution.

Individual farm yield distributions were derived from the county yield distribution by making location and scale adjustments. Data on individual farm yields were available for each farm in the county for a limited sample period. Thus, the same yield model was estimated for this limited data set on individual farms and results were used to determine reasonable adjustments to the location and scale of the county yield distribution which would be representative of the individual farm yield distributions in the county. In general, individual farm yields have higher variance than county yields.

Correlation between prices and yields is imposed using the normal transformation procedure described by Taylor. Taylor's method empirically transforms the marginal distributions of any pair of general distributions to the standard normal. Bivariate standard normal random draws are then taken with the desired level of correlation imposed on the bivariate normal generator. The realized draws are then transformed back to the (generally) non-normal distributions using the original marginal distributions. The end result is a joint distribution with marginal distributions similar to the original independent distributions, but with a desired degree of correlation imposed between prices and yields.

The correlation between county yields and individual farm yields is also important when investigating crop insurance based on area (county) yield. Hence, Taylor's method was used again to impose a desired degree of correlation between individual and county yields.

Results

The model was solved initially for a base set of parameters chosen to be representative of those faced by farmers in southwest Iowa during the 1994-95 crop year. The futures price at planting was set at the Chicago Board of Trade price for the last week of April 1994. The strike price on put options was set at the closest strike price to the initial futures price. Both futures and options were restricted to be unbiased (expected gains from trading are zero). The target price was set at the 1994 level. There was no acreage reduction requirement in 1994; however, the normal flexible acreage requirement was set at 15% of base yield, $r=.15$. Base yield was set equal to expected yield. Area-yield crop insurance (AYCI) was assumed to be actuarially fair because moral hazard and adverse selection problems which plague individual yield crop insurance (IYCI) should not be a major problem. For IYCI premiums were initially set 35% above the actuarially fair level ($\lambda=1.35$), to reflect these moral hazard and adverse selection problems. The indemnification price was set equal to the expected cash price. The insurance coverage level was initially set at 100% of planted acreage, $m=1.0$, as in the current crop insurance program. The maximum trigger yield restriction, y_o, was initially set at 75% of expected yield for IYCI and 90% of expected yield for AYCI, reflecting current program characteristics.

The design parameters considered here include alternative restrictions on the maximum trigger yield level; alternative premium loadings for IYCI; alternative indemnification prices; and alternative crop insurance coverage levels. The se design features are used to compare IYCI and AYCI performance assuming two different price-yield correlations, zero and -.46. The correlation of -.46 was estimated using historical data on county yields and price while zero was used to determine sensitivity of results to this assumption. A number of alternative farm-county yield correlations were used in order to investigate how program performance varies with "yield basis risk."

Table 1 shows optimal trigger yield selection, y_o, and willingness-to-pay (WTP) for various risk management portfolios under alternative restrictions on the maximum trigger yield. The WTP measure is the amount of sure income that must be provided to the farmer in the case where no risk management instruments are available in order to generate the same level of expected utility achieved under optimal use of the specified risk management portfolio. Notice that crop insurance is quite valuable to the farmer in all cases (WTP between \$20 and \$34) but that futures and options provide little additional value once crop insurance is included. On the other hand, the deficiency payment program does provide considerable value as an addition to crop insurance.

Results for IYCI suggest the optimal trigger yield on this Iowa corn farm is close to 90% of expected yield (as opposed to the current 75% restriction). However, the welfare gains from eliminating the 75% IYCI trigger yield restriction are only \$1 to \$2 per acre. Furthermore, it may not be feasible to eliminate this restriction in the case of IYCI because of the moral hazard and adverse selection problems already mentioned.

Results for AYCI indicate the optimal trigger yield is of the maximum yield realization (as opposed to the current 90% of expected area yield restriction). The welfare gains from removing the 90% AYCI trigger yield restriction are much larger than those for IYCI, ranging from \$8.42 per acre to \$14.15 per acre. Eliminating trigger yield restrictions for AYCI would allow the farmer to use crop insurance more effectively to manage income risk. Furthermore, because moral hazard and adverse selection should be virtually eliminated under AYCI, the case for having such trigger yield restrictions on these grounds appears weak.

Comparison of IYCI and AYCI depends on the design of the trigger yield restriction. IYCI with a 75% trigger restriction is always preferred to AYCI with a 90% trigger yield restriction. However, when there are no trigger yield restrictions the AYCI, which is priced actuarially fair, is always preferred to IYCI (which has a 35% premium loading).

Table 2 shows the WTP for alternative IYCI premium levels when the trigger yield restriction is 75% of expected yield; and table 3 shows the optimal trigger yield and WTP when IYCI trigger yields are unrestricted. The optimal trigger yield is always above the current 75% of expected yield but varies widely depending on the premium. For actuarially fair premiums, the optimal trigger yield is near the maximum yield level. However, as the premium increases to 50% above the actuarially fair rate, the optimal trigger yield falls to around 80% of expected yield.

Comparing the results in tables 1 and 2 shows that the relative performance of IYCI and AYCI depends critically on the premium rate. Under the current level of trigger yield restriction (75% for IYCI and 90% for AYCI), IYCI is generally preferred to AYCI for IYCI premium rates up to 50% above the actuarially fair rate (and AYCI at actuarially fair premiums). However, when there are no restrictions on the trigger yield, AYCI is always preferred to IYCI when the IYCI premium is 35% above the actuarially fair rate, and is still preferred in many cases with the IYCI premium rate only 20% above the actuarially fair rate. One implication of tables 1 and 2 is that if the AYCI trigger yield restriction is removed, AYCI will be the preferred design unless the IYCI premium rate is below 120% of the actuarially fair premium.

Four alternative choices for indemnification prices were evaluated: expected cash price, expected futures price, realized cash price, and realized futures price. The preferred pricing mechanism varied depending on the portfolio and degree of price-yield correlation for both IYCI and AYCI. However, the difference in WTP was generally less than $1 across the different pricing alternatives, much below the potential gains from redesigning the AYCI trigger yield restrictions.

Table 4 shows optimal acreage coverage and WTP levels under different trigger yield restrictions. Coverage levels increase as the trigger level restriction is lowered. When trigger yield restrictions are set at low levels, the optimal coverage levels range from 114% to 140% of the actual planted acreage. In the absence of trigger yield restrictions, the coverage levels drop to around 90% of planted acreage for IYCI and 105% of planted acreage for AYCI.

Under current trigger yield restrictions, the preferred coverage design is significantly above the current 100% of planted acres requirement. However, if the trigger yields restrictions are removed the optimal coverage levels are generally close to the current 100% restriction. Comparison of tables 1 and 4 shows the welfare gains from optimally designing the coverage level are generally less than $1 per acre, smaller than potential gains from altering AYCI trigger yield design.

Table 5 shows optimal trigger yield and WTP values at different levels of yield basis risk, as measured by the correlation between farm and county yield. In most cases the optimal trigger yield is at the maximum area yield realization. However, as the yield basis risk increases (a decrease in the farm-county yield correlation), the WTP values drop significantly, as much as $30 per acre.

The level of yield basis risk has significant implications for the relative performance of IYCI and AYCI. Comparison of tables 1 and 5 shows that for low levels of basis risk (farm-county yield correlation of 0.94) AYCI is preferred to IYCI, even with a 90% trigger yield restriction. However, comparison of tables 1 through 5 shows that for high levels of basis risk farm-county yield correlation of 0.64 the IYCI is preferred for all alternative designs considered. The preferred yield index is highly sensitive to the level of yield basis risk.

Summary

Alternative crop insurance designs related to trigger yield restrictions, premium level, indemnification price, yield index, and coverage level were examined for a representative corn farm in Iowa. The results suggest redesigning restrictions on AYCI trigger yield levels (increasing the maximum trigger yield) has the most potential to improve farmers' ability to manage income risk. The optimal index design was found to be particularly sensitive to the trigger yield design, IYCI premium level, and yield basis risk. Fewer restrictions on yield trigger and coverage levels, higher IYCI premium loadings and lower yield basis risk all contribute to a preference for AYCI over IYCI.

Table 1. Trigger Yield Selection and Willingness-to-pay Under Alternative Maximum Trigger Yield Restrictions

	Trigger Yield				Willingness-to-pay			
Max. Trigger Yield	CI	Futures, Options and CI	Govt. Prog, and CI	Futures, Options, Govt Prog and CI	CI	Futures, Options and CI	Govt. Prog. and CI	Futures, Options Govt Prog and CI
Individual Yield Crop Insurance								
Negative price-yield correlation								
Max	0.868	0.895	0.906	0.898	$26.37	$27.47	$52.89	$52.96
0.90	0.868	0.895	0.900	0.898	26.37	27.47	52.89	52.96
0.85	0.850	0.850	0.850	0.850	26.35	27.36	52.70	52.81
0.75	0.750	0.750	0.750	0.750	25.66	26.38	51.45	51.76
Zero price-yield correlation								
Max	0.920	0.929	0.909	0.914	$31.51	$34.36	$54.75	$55.22
0.90	0.900	0.900	0.900	0.900	31.48	34.31	54.76	55.21
0.85	0.850	0.850	0.850	0.850	31.22	34.01	54.53	54.98
0.75	0.750	0.750	0.750	0.750	29.93	32.66	53.36	53.75
Area Yield Crop Insurance								
Negative price-yield correlation								
Max	1.216	Max	Max	Max	$26.74	$28.89	$56.89	$56.91
1.20	1.200	1.200	1.200	1.200	26.72	28.55	56.46	56.46
1.00	1.000	1.000	1.000	1.000	24.92	25.43	52.67	53.04
0.90	0.900	0.900	0.900	0.900	22.38	22.52	49.23	50.13
0.75	0.750	0.750	0.750	0.750	18.32	18.47	44.58	46.34
Zero price-yield correlation								
Max	Max	Max	Max	Max	$34.61	$38.60	$60.13	$60.72
1.20	1.200	1.200	1.200	1.200	33.93	37.95	59.52	60.10
1.00	1.000	1.000	1.000	1.000	29.17	34.14	55.68	56.25
0.90	0.900	0.900	0.900	0.900	25.02	30.90	52.53	53.09
0.75	0.750	0.750	0.750	0.750	20.46	25.70	47.88	48.12

Note: The selected trigger yields are reported as a proportion of expected yield. Max designates the selected trigger yield is at the maximum yield. CI denotes crop insurance.

Table 2. Willingness-to-pay for Alternative Premium Levels When the Trigger Yield Restriction Is 75% of Expected Yield

	Portfolios			
Premium Rate	IYCI	Futures, Options, and IYCI	Govt., and IYCI	Futures, Options Govt., and IYCI
Negative price-yield correlation				
1.00	$29.51	$30.23	$55.90	$56.20
1.20	27.29	28.01	53.35	53.65
1.35	25.66	26.38	51.45	51.76
1.40	25.13	25.84	50.82	51.13
1.50	24.06	24.77	49.57	49.87
Zero price-yield correlation				
1.00	$33.58	$36.63	$57.78	$58.18
1.20	31.59	34.34	55.24	55.64
1.35	29.93	32.66	53.36	53.75
1.40	29.38	32.10	52.73	53.12
1.50	28.29	30.99	51.48	51.87

Note: IYCI designates a crop insurance instrument with a yield index corresponding to the farmer's individual yield.

Table 3. Trigger Yield Selection and Willingness-to-pay for Alternative IYCI Premiums with No Trigger Yield Restriction

	Trigger Yield				Willingness-to-pay			
Premium Rate	IYCI	Futures, Options and IYCI	Govt. Prog. and IYCI	Futures, Options, Govt and IYCI	IYCI	Futures, Options and IYCI	Govt. Prog. and IYCI	Futures, Options Govt and IYCI
Negative price-yield correlation								
1.00	Max	1.320	1.333	1.354	$34.78	$38.46	$65.61	$65.91
1.20	0.954	0.999	1.005	1.005	29.24	30.73	56.77	56.78
1.35	0.868	0.895	0.906	0.898	26.37	27.47	52.89	52.95
1.40	0.846	0.872	0.879	0.872	25.58	26.60	51.85	51.93
1.50	0.798	0.827	0.823	0.821	24.18	25.07	50.00	50.15
Zero price-yield correlation								
1.00	1.418	1.363	1.368	1.369	$43.62	$46.97	$68.29	$68.95
1.20	1.016	1.032	1.020	1.027	35.13	38.12	58.75	59.29
1.35	0.920	0.929	0.909	0.914	31.51	34.36	54.75	55.22
1.40	0.897	0.901	0.882	0.885	30.55	33.36	53.70	54.15
1.50	0.848	0.852	0.830	0.834	28.85	31.61	51.85	52.28

Note: The selected trigger yields are reported as a proportion of expected yield. IYCI designates a crop insurance instrument with a yield index corresponding to the farmer's individual yield.

Table 4. Coverage Level and Willingness-to-pay for Different Trigger Yields

	Insured acreage				Willingness-to-pay			
Trigger Yield	CI	Futures, Options and CI	Govt. and CI	Futures, Options, Govt and CI	CI	Futures, Options and CI	Govt. and CI	Futures, Options Govt and CI
Individual Yield Crop Insurance								
Negative correlation price-yield								
0.75	1.184	1.318	1.349	1.318	$25.88	$26.93	$52.25	$52.33
0.85	0.999	1.112	1.133	1.114	26.35	27.45	52.86	52.91
0.90	0.918	1.022	1.042	1.024	26.37	27.47	52.91	52.95
1.00	0.778	0.868	0.886	0.868	25.95	27.05	52.48	52.51
Zero correlation price-yield								
0.75	1.302	1.317	1.293	1.305	$30.51	$33.27	$53.90	$54.33
0.85	1.103	1.115	1.091	1.099	31.32	34.13	54.61	55.07
0.90	1.019	1.029	1.006	1.014	31.49	34.32	54.75	55.21
1.00	0.876	0.884	0.861	0.869	31.36	34.24	54.53	55.02
Area Yield Crop Insurance								
Negative price-yield correlation								
0.90	1.157	1.181	1.354	1.298	$22.54	$22.72	$50.04	$50.64
1.00	1.090	1.161	1.282	1.244	24.98	25.63	53.34	53.49
1.20	0.890	1.034	1.084	1.098	26.90	28.56	56.56	56.58
Max	0.853	1.006	1.046	1.069	27.04	28.89	56.92	56.97
Zero correlation price-yield								
0.90	1.139	1.355	1.364	1.400	$25.17	$31.68	$53.33	$54.05
1.00	1.162	1.249	1.268	1.282	29.36	34.66	56.26	56.90
1.20	1.069	1.068	1.082	1.091	34.00	38.02	59.61	60.22
Max	1.044	1.045	1.055	1.063	34.64	38.63	60.17	60.78

Note: Coverage levels are reported as a proportion of planted acres. CI denotes crop insurance.

Table 5. Trigger Yield Selection and Willingness-to-pay for Different Levels of Yield Basis Risk

	Trigger Yield				Willingness-to-pay			
Farm-County Yield Corr.	AYCI	Futures, Options and AYCI	Govt. and AYCI	Futures, Options, Govt Prog and AYCI	AYCI	Futures, Options and AYCI	Govt. and AYCI	Futures, Options Govt and AYCI
90% Trigger Yield Restriction								
Negative price-yield correlation								
1.00	0.900	0.900	0.900	0.900	$32.16	$32.59	$53.23	$53.51
0.94	0.900	0.900	0.900	0.900	28.46	28.96	54.40	54.80
0.83	0.900	0.900	0.900	0.900	22.38	22.52	49.23	50.13
0.63	0.710	0.900	0.900	0.900	5.70	11.25	40.74	41.56
Zero price-yield correlation								
1.00	0.900	0.900	0.900	0.900	$35.33	$38.09	$59.48	$59.86
0.94	0.900	0.900	0.900	0.900	32.71	35.51	57.14	57.48
0.83	0.900	0.900	0.900	0.900	25.02	30.90	52.53	53.09
0.63	0.720	0.787	0.900	0.900	5.02	10.48	40.23	41.18
No Trigger Yield Restriction								
Negative price-yield correlation								
1.00	1.190	Max	Max	Max	$35.92	$38.07	$60.01	$60.11
0.94	1.210	Max	Max	Max	32.06	34.50	61.44	61.53
0.83	0.216	Max	Max	Max	26.74	28.89	56.89	56.91
0.63	Max	Max	Max	Max	13.16	15.16	44.33	44.84
Zero price-yield correlation								
1.00	Max	Max	Max	Max	$42.64	$45.72	$67.17	$67.70
0.94	Max	Max	Max	Max	40.24	43.26	64.85	65.35
0.83	Max	Max	Max	Max	34.61	38.60	60.13	60.72
0.63	Max	Max	Max	Max	19.57	19.80	44.91	45.45

Note: Selected trigger yields are reported as a proportion of expected yield. Max designates the selected trigger yield is at the maximum yield. AYCI designates a crop insurance instrument with a yield index corresponding to the county yields.

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