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Equity and efficiency considerations in area versus individual yield insurance

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Abstract

Equity and efficiency considerations in area versus individual crop insurance are investigated for 609 Ontario cash crop farms. Results show that the relationship between individual and area premiums and risk reduction are explained by systematic and non-systematic yield risk relationships. On average, area insurance premiums are much lower than individual yield insurance premiums, and in terms of efficiency in risk-reduction individual plans are superior to area plans. As it turns out arguments of asymmetric information which has lead some researchers to investigate area vs. individual yield insurance is not totally resolved. Inequities in the benefits of area plans across farmers are not equitably distributed, favouring high-risk producers. Adverse selection causes instability in the pooled contracts which will ultimately cause area insurance plans to fail.

Difficulties in tailoring multiple peril yield-loss insurance to individual farms coupled with problems of moral hazard and adverse selection has been cited as major reasons for considering area-yield crop insurance (Miranda, 1991; Carriker et al., 1991; Williams et al., 1991) and in the United States has been implemented as the Group Risk Plan under the Federal Crop Insurance Program V (Baquet and Skees, 1994; Smith et al., 1994). Unlike individual-yield insurance, area-yield insurance pays equal indemnities and charges equal premiums to all farmers in a given region regardless of their own risk profiles. Because indemnities are paid on area averages, there are no incentives for individual farmers to alter their input use or take other actions of moral hazard to alter the probability of payouts, nor are there problems of adverse selection due to asymmetric information which may discourage some low-risk farmers from participating in all-risk crop insurance (Halcrow, 1949; Miranda, 1991; Carriker et al., 1991). Miranda's analyses of 102 Kentucky farms (Miranda, 1991), Carriker et al.'s analyses of 136 Kansas corn and wheat farms (Carriker et al., 1991), Carriker et al.'s study of 98 Kansas wheat farms (Carriker et al., 1990), Williams et al.'s study of 45 Kansas wheat and sorghum farms

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(Williams et al., 1991) and Smith et al.'s study of 123 Montana wheat producers (Smith et al., 1994), all show that while area-yield insurance does result in, sometimes substantial, risk reduction, farmers' preference would likely favour individual crop insurance plans, especially those who are risk-averse.

Economic problem. The notion of moral hazard and adverse selection affects both the supplier of insurance and that population of insureds which either honestly reveal their outcome probabilities or do not undertake dubious practices to undermine the fair integrity of the insurance policy. The implication is two-fold. In competitive equilibrium insurers can offer a multitude of contracts which can result in non-negative profits. Given two populations, one of unidentifiable high-risk types and the other low-risk types, insurers would be indifferent towards offering a choice of individual contracts or a single pooled contract comprised of average risks. But as Rothschild and Stiglitz (1976) point out, a pooled contract, such as area-yield insurance, cannot be sustained since high-risk types force an externality measured in the form of a subsidy, on low-risk types. Any equilibrium involving a pooled contract is unstable, and can be mitigated through the introduction of self-selecting contracts which would be adopted by the low-risk types. Consequently, the pool of high-risk types shrinks, so that the highest-risk individuals in the pool impose an even higher subsidy on those remaining. This gives rise to self-selecting contracts for the lower-risk population remaining in the pool. Through introduction of a sequence of self-selecting contracts the final pool will comprise of only one individual, and thus the final pool will in itself comprise a single self-selected contract. [1]

Low participation rates in Canadian and U.S. crop insurance programs may be due to asymmetric information in the form of adverse selection or moral hazard. The argument used for area-yield insurance is that the inability of insurers to collect reliable data is such that properly designed individual contracts cannot be offered, or on-farm activities which might affect state contingent outcomes cannot be monitored. From the insurer's perspective area-yield crop insurance will reduce loss-ratios since area yield histories are far more easy to garnish, and since moral hazard effects can have only a marginal, if not zero, effect on area outcomes, monitoring costs would decrease.

For reasons discussed earlier this view is myopic; area-yield crop insurance is not Pareto-optimal since alternative self-selecting policies exist which will be preferred by all participants. Hence area-yield crop insurance is inefficient. Furthermore, since pooled contracts by their very nature impose an externality on less-risky participants, area-yield insurance cannot be equitable.

That area-yield insurance is both inefficient and inequitable are propositions to be investigated in this study. To do this we compute area-yield and individual insurance policy outcomes and show invariably that the propositions hold true. However, we do our analyses under strict assumptions about perfect information with regards to the mean and variance of area yields and their relation to individual yields. We are unable, therefore, to test any propositions about the efficiency of area-yield insurance relative to individual contracts with asymmetric information. Thus, when we refer to individual crop insurance we are referring to full information self-selecting contracts. It is therefore notable that we do not (can not) examine the proposition that area-yield insurance leads to self-selecting contracts but only assert that this is a logical consequence.

To assess equity considerations we employ theory and techniques similar to Miranda's (1991) and compute ex post gross revenue standard deviations and skewness coefficients under the two policies. To assess efficiency criteria we compare individual- to area-yield crop insurance premiums and relate these to crop-yield single index model parameters. The analyses, in addition to broaden-

[1] Interestingly, as Baquet and Skees (1994) describe the new U.S. Group Risk Plan, insurers will be able to select either the area plan or an individual (actual production history) plan but not both.

ing the issues surrounding the area-yield versus individual-yield debate, uses a rich data set comprising 25 different pools of farmers covering five crops and eleven counties in Ontario.

1. Background and theory

1.1. Area-yield crop insurance in Canada

Canadian agricultural policy has had a long history of area-yield crop insurance, and it is thus useful to describe the application and pitfalls of area-yield type contracts with reference to this history. The first use of area-yield crop insurance in Canada fell under the 1939 Prairie Farm Assistance Act (PFAA), which provided crop loss protection for Manitoba, Saskatchewan, Alberta and parts of British Columbia. Although it shared some of the features of a crop insurance plan it was actually considered a permanent disaster relief plan. Payments under the PFAA did not fully protect against all crop losses nor did its indemnities cover operating costs and living expenses.

Indemnities in each area (usually a township or smaller) were based on average wheat yields. If average wheat yields in an area fell below a target then all crops in the area were eligible for payments regardless of individual yields. Restrictions applied on the amount of payments a single producer could receive with the greatest restriction being that only 50% of planted acreage could receive payments. The program was funded by a 1% levy on all grains sold by producers. The loss ratio (indemnities over premiums) over the 1939–1973 period of operation was ($399.1 million/$215.6 million) 1.85. [2]

The PFAA, although providing security to some producers was criticized since (a) the payments were too small and all producers in the same area received the same indemnity regardless of individual yields, and (b) producers in areas with high yields and low losses paid more in terms of the 1% levy and received less benefits than producers with low and more variable yields.

The 1959 Crop Insurance Act superseded the PFAA, and by 1974 crop insurance plans affecting the prairie provinces were revised so that although yield areas were regionally specific for premium setting purposes, crop insurance indemnities were based on individual farm performance and were commodity-specific.

Today only Quebec's 'collective' approach resembles a commodity-specific area yield crop insurance plan. The collective approach uses area yield averages but loss adjustments are based not on individual yields but the area. Producers in each area pay the same premiums (not a levy as in PFAA), receive the same amount of protection, and the same indemnities regardless of individual yield performance and experience. Area average yields and losses are determined through samples taken just before harvest.

The advantages of the 'collective' approach relate to stability of crop losses and administrative ease. Premiums tend to be lower since only systematic risk is considered in evaluation. Also the plan eliminates the disproportionate level of benefits that can accrue to below average producers under the individual yield approaches. The program's drawbacks are that the performance is not related to individual farm performance and area boundaries are often questioned.

In Canada, hay can be insured separately from other crops and has some area-yield features. Hay insurance relies on regional simulation models (Selirio and Brown, 1979; McBride and Brown, 1984) based on heat, sunshine, rainfall, and other factors. Within a given region, climatic data is collected throughout the growing season and entered into the simulation model. If simulated yields fall short of long-run average yields, an indemnity is paid out to all insured farmers in the region.

For crop insurance purposes, Ontario, Alberta, Saskatchewan and Manitoba use the model to expedite hay and pasture insurance claims, citing primarily that on-farm measurement of hay and pasture crops is virtually impossible and costly (Selirio and Brown, 1979). Problems cited with the approach are lack of sensitivity to yield-de-

[2] These are sums of nominal dollars. Due to the timing of payouts and receipts over the 1939–1973 period, this number will differ from an average of loss ratios over the same period.

Table 1
Crop insurance loss ratios Canada, Manitoba, Ontario and Quebec

Year ending March	Canada			Manitoba			Ontario			Quebec		
	Loss ratio (I/P)	Loss ratio ($(I+A)/P$)	Cost/acre 1987 = 100	Loss ratio (I/P)	Loss ratio ($(I+A)/P$)	Cost/acre 1987 = 100	Loss ratio (I/P)	Loss ratio ($(I+A)/P$)	Cost/acre 1987 = 100	Loss ratio (I/P)	Loss ratio ($(I+A)/P$)	Cost/acre 1987 = 100
1990	2.89	3.12	N.A.	4.00	4.16	N.A.	2.18	2.59	N.A.	1.51	2.39	29.23
1989	4.51	4.81	24.40	6.17	6.45	1.21	2.92	3.16	37.22	2.45	3.32	31.08
1988	1.55	1.82	11.88	1.65	1.89	17.52	0.82	1.05	25.65	1.46	2.38	23.34
1987	1.83	2.04	15.42	1.53	1.71	21.31	1.43	1.66	35.68	4.66	5.39	39.43
1986	3.66	3.89	25.23	1.74	1.93	22.51	0.62	0.79	31.58	0.63	1.54	17.32
1985	3.34	3.58	23.61	2.02	2.29	19.01	0.72	0.90	35.18	0.47	1.06	16.32
1984	2.00	2.22	15.29	1.67	1.95	16.75	1.47	1.64	47.72	4.94	6.09	32.70
1983	1.98	2.29	16.40	1.70	1.96	18.01	4.50	4.70	75.76	2.22	3.19	16.33
1982	1.38	1.56	12.37	1.56	1.82	16.47	1.18	1.34	40.90	1.23	2.20	9.47
1981	2.66	2.88	18.79	5.66	6.04	41.75	1.21	1.37	41.89	4.22	5.30	17.38
1980	2.72	2.97	18.08	1.34	1.61	14.39	6.07	6.31	72.84	1.49	3.09	8.93
1979	1.08	1.30	11.05	0.76	0.98	11.57	1.72	1.96	38.27	0.81	2.75	11.37
1978	1.52	1.73	13.60	0.59	0.80	10.14	3.41	3.65	54.25	1.27	3.38	21.99
1977	1.15	1.37	12.01	1.58	1.85	14.83	2.27	2.55	48.64	1.58	4.22	36.68
1976	1.36	1.57	12.77	1.95	2.25	17.33	1.59	1.85	46.57	0.57	2.81	26.46
1975	2.33	2.59	15.48	2.91	3.34	17.49	3.22	3.53	60.39	1.49	3.10	17.65
1974	1.43	1.77	8.73	1.04	1.45	7.45	1.97	2.45	33.36	2.15	4.06	18.87
Mean	2.20	2.44	15.95	2.23	2.50	19.23	2.19	2.44	45.37	1.95	3.31	22.05
σ	0.95	0.96	4.79	1.55	1.56	9.20	1.41	1.43	13.85	1.35	1.31	8.97

I/P is indemnities divided by farmers' premiums; $(I+A)/P$ is indemnities plus administration costs divided by farmers' premiums.

terminate climatic variables (e.g. extreme temperature and moisture conditions); lack of farm specificity due to use of regional rather than individual farm yields differences of which may be attributed to variable soil conditions or even sporadic but significant rainfall differences within a region; its limited applicability to perennial, legume based forage crops and; its complexity which makes the evaluation of specific yield-limiting cause and effect relationships difficult (McBride and Brown, 1984).

However, most crop insurance policies in Canada and the U.S. are of the individual type wherein a farmer can elect to cover a fixed percentage of long-run average yields at an elected price. For example, in Ontario premiums are based on provincial average losses but indemnities are based on individual farm performance. Premium adjustments are made over time in accordance with claim histories. A variation of the Ontario plan found in other Canadian provinces (e.g. Manitoba) establishes base rates defined by smaller regions of homogenous soil type and climatic conditions.

Table 1 presents loss ratios and the public cost/acre of crop insurance for Canada as a whole and the provinces of Manitoba, Ontario and Quebec. The ratio I/P is indemnities divided by farmer paid premiums and the ratio $(I+A)/P$ is indemnities plus administrative costs divided by farmer paid premiums. The average loss ratios with and without administrative expenses were; 2.23 and 2.50 for Manitoba; 2.19 and 2.44 for Ontario; and 1.95 and 3.31 for Quebec. Acreage enroled under the provincial programs in 1989 were 4 607 400, 2 543 340 and 2 098 000 for Manitoba, Ontario and Quebec, respectively. With per acre costs equal to \$41.22/acre, \$37.22/acre and \$31.08/acre, the public costs in 1989 (1987 = 100) were \$231 million, \$96.6 million and \$65.2 million for Manitoba, Ontario and Quebec, respectively. The average loss ratio for Canada was 2.20 without administrative costs and 2.44 with administrative costs: for every \$1 contribution by farmers the public contribution is \$2.44. The total cost/acre for Canada averaged \$15.95/acre in 1987 dollars. In 1989, 43 415 482 acres were covered under the Act for a total public cost of approximately \$1.05 billion (1987 = 100).

1.2. Area yield crop insurance

The appropriate valuation formula for crop insurance is given by:

$$V=\int_0^Z (Z-Y)\,f(Y)\,\mathrm{d}Y \tag{1}$$

where Z is the coverage level, Y represents yields, and $f(Y)$ is the underlying probability distribution. With individual crop insurance, Y reflects individual yields, and $f(Y)$ the individual yield distribution function. If Z is defined as a proportion of long-run yields then individual contracts across farms are distinguished by different distribution functions. For area-yield insurance the valuation formula is the same except that Y and $f(Y)$ are defined for area averages.

Miranda (1991) argues that individual yields are systematically correlated with area average and that it is this degree of correlation which determines the extent of risk reduction from area yield insurance. Like Miranda, we define a characteristic equation to measure the relationship between individual and area yields: [3]

$$Y_{it}=\alpha_i+\beta_i Y_{at}+\varepsilon_{it} \tag{2}$$

where Y_{it} represents individual yields, Y_a area averages or an index used as an instrument of the average, α_i and β_i are estimated parameters, and ε_{it} is an error term. The expected value of individual yields (after dropping the time subscript) is:

$$E[Y_i]=\alpha_i+\beta_i\ E[Y_a] \tag{3}$$

and the variance of yields is:

$$\sigma_y^2=\beta_i^2\sigma_a^2+\sigma_{\varepsilon i}^2 \tag{4}$$

The term $\beta_i^2\sigma_a^2$ is the yield-systematic risk. It is defined as that proportion of overall yield risk

[3] Miranda's equation is different. He defines $Y_{it}=E[Y_i]+\beta(Y_{at}-E[Y_a])+\varepsilon_{it}$. The estimated β coefficient, and systematic and non-systematic risk measures are identical to our Eq. (4). Carriker et al. (1991) also employ Miranda's model.

correlated with the area average. This risk is common to all farms in the area. Augmenting this systematic risk is the farm-specific risk which is uncorrelated with the area average. To establish hypotheses regarding the efficiency of individual- versus area-yield plans in terms of reducing downside risk, it is useful to describe the distribution of crop yields as a function of the area parameters. This is achieved by substituting Eq. (2) into (1) to get:

$$V_i(Z,g,h) = \int_0^\infty \left[\int_{-\infty}^{Z-(\alpha_i+\beta_i Y_a)} (Z-\alpha_i-\beta_i Y_a-\varepsilon_i)\ g(\varepsilon)\ \mathrm{d}\varepsilon \right] \times h(Y_a)\ \mathrm{d}Y_a \tag{5}$$

where $g(\varepsilon)$ is the error p.d.f. $(-\infty \leqslant \varepsilon \leqslant \infty)$, and $h(Y_a)$ is the p.d.f. for area yields $(0 \leqslant Y_a \leqslant \infty)$. Eq. (5) recognizes that the univariate distribution of individual yields can be defined in terms of its systematic and non-systematic components; for each observation of Y_a drawn from the outer integral over $h(Y_a)$, a predicted individual yield is determined. This predicted yield is independent of farm-specific risk. The bracketed term in Eq. (5) accounts for non-systematic risk. Given an area yield correlate, the probability that individual yields falls below Z is determined by $g(\varepsilon)$. The probability distribution is, therefore, comprised of two components with the first relating to systematic yield risk and the second to non-systematic yield risk. Eq. (5) implies that $f(Y_i)$ can be specified as a joint distribution, $f(Y_a, \varepsilon)$, with stochastically independent marginal distributions.

Of interest are the parameter specifications in (5). Eq. (5) suggests that $\partial V_i/\partial \beta_i < 0$ so that with all other things being equal, the higher the correlation between individual and area-average yields, the lower the individual premium, and $\partial V_i/\partial \alpha_i < 0$ so that the higher the intercept, the lower the premium. The latter condition represents individual mean yields relative to the average. For example if two farms have identical risk but the intercept of one is higher than the other, the former will have a higher expected yield. Therefore, as individual mean yields increase relative to risk and area yields, the probability and amount of indemnity decreases. These are treated as hypotheses in this study and tested empirically.

As Miranda argues, the effectiveness of area-yield insurance in reducing individual farm downside risk depends upon the degree of correlation between area-yield indemnities and individual yield distributions. Unless individual yields are perfectly correlated with area yields, ex post yield distributions with area-yield insurance are not truncated as is found in individual plans. In fact, area-yield insurance may be risk augmenting (Miranda, 1991). The relationship between individual and area-yield distributions is therefore a complex one which is explored more fully in the next section.

1.3. Area-yield versus individual yield insurance

This section expands on some of the concepts introduced by Miranda. The objective is to establish conditions under which individual-yield insurance will be unambiguously preferred to area-yield insurance under a mean variance rule. The following equations set up the expected returns from individual and area insurance, respectively:

$$Y_i^{\mathrm{F}} = Y_i + I - \Pi_{\mathrm{F}} \tag{6}$$

and

$$Y_i^{\mathrm{A}} = Y_i + N - \Pi_{\mathrm{A}} \tag{7}$$

where Y_i are stochastic yields, I and N are stochastic indemnities, and Π_i and Π_{A} are insurance premiums. Under either policy $E[Y_i^{\mathrm{F}}] = E[Y_i^{\mathrm{A}}]$ if premiums are actuarially sound, since $\Pi_{\mathrm{F}} = E[I]$ and $\Pi_{\mathrm{A}} = E[N]$. Thus preference for one over the other is related only to a decrease in downside risk.

The variances of individual and area insurance are, respectively:

$$\sigma_{i\mathrm{F}}^2 = \sigma_i^2 + \sigma_I^2 + 2\,\mathrm{cov}(Y_i, I) \tag{8}$$

and

$$\sigma_{i\mathrm{A}}^2 = \sigma_i^2 + \sigma_N^2 + 2\,\mathrm{cov}(Y_i, N) \tag{9}$$

where σ_I^2 and σ_N^2 are variances of individual and area insurance indemnities, respectively. Rearranging (8) and (9) as:

$$\sigma_i^2 - \sigma_{i\mathrm{F}}^2 = -\sigma_I^2 - 2\,\mathrm{cov}(Y_i, I) \tag{10}$$

and

$$\sigma_i^2 - \sigma_{iA}^2 = -\sigma_N^2 - 2\operatorname{cov}(Y_i, N) \tag{11}$$

gives the changes in variance due to insurance. Covariances between yields and indemnities are assumed to be non-positive, therefore individual yield insurance will be risk-reducing if and only if:

$$\frac{\operatorname{cov}(\tilde{Y}_i, \tilde{I})}{\sigma_I^2} > \tfrac{1}{2} \tag{12}$$

and area insurance will be risk-reducing if and only if

$$\frac{\operatorname{cov}(\tilde{Y}_i, \tilde{N})}{\sigma_N^2} > \tfrac{1}{2} \tag{13}$$

Individual insurance will be strictly preferred to area insurance if the following condition is satisfied:

$$\frac{\operatorname{cov}(Y_i, I)}{\sigma_I^2} > \frac{\operatorname{cov}(Y_i, N)}{\sigma_N^2} \tag{14}$$

or

$$\frac{\operatorname{cov}(Y_i, I)}{\operatorname{cov}(Y_i, N)} > \frac{\sigma_I^2}{\sigma_N^2} \tag{15}$$

Eq. (15) states that as long as the ratio of covariances between individual yields and indemnities exceeds the ratio of the indemnity variances, individual yield insurance will be preferred to area yield insurance. It is however, useful to interpret this condition using parameters and risk measures from the single index model.

Miranda (1991) shows that:

$$\operatorname{Cov}(Y_i, N) = \beta_i \operatorname{Cov}(Y_A, N)$$

and from the definition of yield variance, $\operatorname{Cov}(\tilde{Y}_i, \tilde{I})$ can be redefined as:

$$\operatorname{Cov}(Y_i, I) = \rho_{iI}\left(\beta_i^2\sigma_A^2 + \sigma_\varepsilon^2\right)^{1/2}\sigma_I$$

where ρ_{iI} is the correlation between yield and individual indemnities. Thus (15) can be restated as:

$$W = \frac{\rho_{iI}\left(\beta_i^2\sigma_A^2 + \sigma_\varepsilon^2\right)^{1/2}\sigma_I}{\beta_i\rho_{iA}\sigma_A\sigma_N} > \frac{\sigma_I^2}{\sigma_N^2} \tag{16}$$

or

$$W = \frac{\rho_{iI}\left(\beta_i^2\sigma_A^2 + \sigma_\varepsilon^2\right)^{1/2}\sigma_N}{\beta_i\rho_{iA}\sigma_A\sigma_I} > 1 \tag{17}$$

Eq. (17) is a necessary condition for individual yield insurance to be unambiguously preferred to area yield insurance. It is useful then to establish how variables affect W. Hence:

$$\partial W/\partial(\sigma_N/\sigma_I) = \frac{\rho_{iI}\left(\beta_i^2\sigma_A^2 + \sigma_E^2\right)^{1/2}}{\rho_{iA}\beta_i\sigma_A} > 0$$

$$\text{for } \beta_i > 0 \tag{18}$$

$$\partial W/\partial\sigma_\varepsilon^2 = \frac{\rho_{iI}\left(\beta_i^2\sigma_A^2 + \sigma_\varepsilon^2\right)^{-1/2}\sigma_N}{2\rho_{iA}\beta_i\sigma_A\sigma_I} > 0$$

$$\text{for } \beta_i > 0 \tag{19}$$

and

$$\partial W/\partial\beta_i = \frac{-\sigma_E^2\rho_{iN}\sigma_N}{\beta_i^3\sigma_A^2\sigma_I} \leqslant 0$$

$$\text{for } \beta_i > 0 \tag{20}$$

All other things being equal, condition (18) states that a higher variance of area indemnities to individual indemnities increases preferences for individual yield insurance; condition (19) states that the greater the non-systematic risk the better off producers will be with individual insurance; and condition (20) stipulates that the higher the beta the less attractive individual yield insurance is over area yield insurance.

2. Methods

In this section we assess factors (risk and policy parameters) which affect individual indemnities directly, as well as those which relate individual indemnities to area indemnities. This section describes three tasks: first, the computation of single index model parameters and area and individual crop insurance premiums (expected losses); second, a determination of factors influencing expected indemnities; and third, a direct measurement of gross revenue variance under each of the two plans.

Area average yields for each year, t, are obtained by averaging across all N farms in a county for a single crop, i.e.

$$Y_{At} = \frac{1}{N} \sum_{i=1}^{n} Y_{it} \tag{21}$$

These averages are then used as the independent variable in OLS regressions of the form:

$$Y_{it} = \alpha_i + \beta_i Y_{At} + \varepsilon_t \tag{22}$$

OLS regressions of this form are, in general, biased from an econometric perspective since Y_{At}

Table 2
Area versus individual yield insurance premiums

County/crop	OBS [b]	Expected average area yield (bu/ac)	Area standard deviation	Coverage					
				Area yield insurance			Individual yield insurance		
				75%	80%	85%	75%	80%	85%
				(Premiums: $/acre) [a]					
Perth									
Winter wheat	16	64.25	7.55	0.17	0.52	1.37	1.10	1.84	3.33
Spring grain	25	65.40	11.69	0.79	1.43	2.43	3.56	4.72	6.20
Corn	32	99.39	16.14	1.14	2.25	4.13	4.74	6.87	9.74
Soybeans	31	36.23	3.44	0.03	0.13	0.51	1.48	2.35	3.75
White beans	28	23.88	5.85	4.24	6.20	8.79	10.03	12.68	15.87
Essex									
Corn	8	102.01	21.54	3.19	5.08	7.75	6.47	8.99	12.24
Soybeans	36	35.42	7.48	2.68	4.26	6.51	6.26	8.42	11.19
Kent									
Corn	19	115.71	13.40	0.19	0.58	1.58	3.14	4.77	7.15
Soybeans	29	38.28	7.55	2.27	3.79	6.02	5.05	7.09	9.80
Wellington									
Spring grain	30	63.67	12.40	1.08	1.82	2.91	3.38	4.52	5.98
Corn	25	82.01	12.48	0.69	1.46	2.84	4.48	6.36	8.86
Middlesex									
Winter wheat	12	60.04	7.84	0.26	0.66	1.52	1.61	2.60	4.09
Corn	21	103.20	12.94	0.28	0.78	1.87	3.46	5.32	7.76
Soybeans	19	34.80	2.37	0.0004	0.006	0.07	1.52	2.52	4.08
Prescott									
Spring grain	23	53.85	23.39	8.35	9.99	11.85	11.51	13.27	15.22
Corn	43	76.59	20.68	5.66	7.90	10.77	14.28	17.34	20.91
Lambton									
Winter wheat	5	65.96	7.98	0.17	0.50	1.28	0.69	1.42	2.70
Corn	16	106.50	17.47	1.24	2.41	4.38	4.53	6.60	9.47
Soybeans	21	33.71	5.27	0.75	1.54	2.93	3.44	5.03	7.21
Dundas									
Corn	34	82.76	16.19	2.22	3.72	5.95	6.16	8.28	11.06
Ottawa-Carleton									
Spring grain	24	52.60	16.88	4.24	5.53	7.09	8.58	10.18	12.01
Corn	44	84.78	12.81	0.75	1.59	3.11	7.34	9.63	12.56
Russel									
Spring grain	21	43.28	18.04	6.13	7.42	8.90	11.34	12.84	14.49
Corn	33	79.35	21.08	5.65	7.93	10.86	12.84	15.85	19.39
Norfolk									
Winter wheat	14	38.76	9.12	2.10	3.13	4.52	4.69	6.04	7.72

[a] Premiums are computed based on normal curve theory (see Skees and Reed, 1986).
[b] Observations refer to the number of farms growing the slated crops in each county.

has as one of its components Y_{it} but this bias diminishes with large N. Nonetheless, the parameter estimates are correct in theory since they provide an exact measure of covariance between individual and area yields. Given Eq. (22), systematic risk measures equal to $\beta_i^2\sigma_A^2$ and non-systematic risk measures equal to $\sigma_i^2 - \beta_i^2\sigma_A^2$ were computed for each crop. Individual and area-yield insurance premiums were computed using the polynomial approximation to the normal density function as described in Botts and Boles (1958), Skees and Reed (1986) and elsewhere.

Differences between individual and area yield premiums were explained by the regression:

$$V_i = \gamma_0 + \gamma_1(\mathrm{RR}_i) + \gamma_2\alpha_i + \sum_{j=2}^{5} \gamma_j\ \mathrm{DC}_{ji} + \varepsilon_i \quad (23)$$

where $V_i = \Pi_i - \Pi_A$; $\mathrm{RR} \equiv \sigma_\varepsilon/\beta_i\sigma_A$ is the ratio of non-systematic to systematic risk; α_i is the intercept of the characteristic line equation, and DC_{ji} are crop specific dummy variables. Since $\partial\mathrm{RR}/\partial\sigma_\varepsilon > 0$, $\partial\mathrm{RR}/\partial\beta_i\sigma_A < 0$, and $\partial\mathrm{RR}/\partial\beta_i < 0$, it is hypothesized that H_0: $\gamma_1 > 0$; that is, the spread between the individual and area premium increases with non-systematic risk and decreases with systematic risk. Similarly, it is hypothesized that H_0: $\gamma_2 < 0$; that is, the greater the value of α_i, the smaller the spread between individual and area premiums. Finally, crop-specific dummy variables are evaluated against the null hypotheses H_0: $\gamma_j = 0$. Eq. (23) was estimated for coverage levels of 75%, 80% and 85%.

The decrease in overall yield variability due to the insurance policies was measured through monte carlo simulations at 85% coverage levels for all farms in the study. A coverage level of 85% is the maximum coverage allowed under the Ontario Crop Insurance Plan. Area yields were drawn from $\tilde{Y}_A^2\ N(\bar{Y}_A, \sigma_A)$ and individual yields were related to this by specifying $Y_i = \alpha_i + \beta_i(Y_A\ \tilde{N}(\bar{Y}_A, \sigma_A)) + (\varepsilon_i\ \tilde{N}(0, \sigma_\varepsilon))$, where the function $N(\cdot)$ denotes a Monte Carlo draw from a normal distribution. For each iteration, indemnities satisfying $\mathrm{Max}[Z_A - Y_A, 0]$ and $\mathrm{Max}[Z_i - Y_i, 0]$ were computed. After multiplying yields and indemnities by commodity prices, and subtracting indemnities and premiums, standard deviation and skewness measures were computed.

Data on detrended historical yields for 609 Ontario farms covering five crops in eleven Ontario counties were selected from a data pool of over 96000 individual farm yield observations obtained from the Ontario Crop Insurance Commission. Since the time series of yields differed by crop and county we chose only those farms which had continuous time series yield observations over the maximum possible range; alternatively a greater number of farms could have been selected but at the expense of fewer observations per farm.

3. Results

This section presents results in the following order: first, individual versus area yield premiums are presented; second, single index model parameters are obtained, discussed and used to describe differences between individual and area premiums; and third, efficiency in risk reduction is analyzed.

Table 2 provides sample statistics of the farms used in the study as well as individual and area premiums, both estimated under an assumption of normality. The premiums reported indicate two things: first, the differences in premiums across counties for like crops can be substantial, and second, individual premiums, on average, are substantially higher than area premiums. For example, 85% area coverage premiums for corn range from \$1.58/acre in Kent county (western Ontario) to \$10.86/acre in Russel county (eastern Ontario), whereas 85% individual coverage premiums for corn range from \$7.15/acre in Kent county (western Ontario) to \$20.91/acre in Prescott county (central Ontario). The following differences between area and individual premiums are notable: 85% coverage area premiums for soybeans in Perth county are only \$0.51/acre whereas 85% coverage individual premiums are 7.3 times as high, i.e. \$3.75/acre; similarly, soybeans in Middlesex county are barely priced by area yield insurance even at the 85% level (\$0.07/acre) but are \$4.08/acre on an individual yield plan. Of the 25 crops/county representations in Table 2, 100% have average individual-yield premiums higher than area-yield premiums and 60% have individual premiums which are at least twice as high as area premiums.

Estimating the parameters of Eq. (2) show that 51% of farms have $\beta_i \geqslant 1$ with intercepts (α_i) not significantly different from zero, while 43% have $\beta_i < 1$ and $\alpha_i > 0$ and 6% had $\beta_i < 1$ and $\alpha_i < 0$. Since average betas always equal 1 and average intercepts always equal 0, they are not reported here. Instead, Table 3 provides measures of systematic and non-systematic yield risks. By definition the average systematic risk equals the risk of the area average. The range of systematic and non-systematic risk (bu/acre), however, do vary.

Table 3
Measures of systematic and non-systematic risk

County/crop	Expected average area yield (bu/ac)	Systematic risk [a]			Non-systematic risk [b]		
		Avg. [c]	Maxi. [d]	Mini. [e]	Avg. [c]	Maxi. [d]	Mini. [e]
Perth							
Winter wheat	64.25	7.55	12.03	2.26	6.80	13.39	4.02
Spring grain	65.40	11.68	22.79	5.14	13.09	18.22	7.25
Corn	99.39	16.15	29.37	5.81	14.91	26.66	4.40
Soybeans	36.23	3.44	7.35	−0.70	4.04	8.69	1.44
White beans	23.88	5.84	8.40	1.75	5.27	9.31	2.66
Essex							
Corn	102.01	21.55	35.69	17.23	14.74	26.35	9.87
Soybeans	35.42	7.48	11.67	4.71	5.99	11.55	2.80
Kent							
Corn	115.71	13.41	23.32	4.96	16.09	25.65	6.78
Soybeans	38.28	7.55	12.38	1.43	5.19	8.22	3.05
Wellington							
Spring grain	63.67	12.40	21.70	3.72	11.50	20.04	4.97
Corn	82.01	12.48	25.21	4.49	14.78	25.84	6.61
Middlesex							
Winter wheat	60.04	7.84	13.40	2.27	7.13	10.44	4.53
Corn	103.20	12.94	21.61	−0.78	15.87	27.29	8.58
Soybeans	34.80	2.37	4.85	−0.64	5.13	7.89	3.13
Prescott							
Spring grain	53.85	23.40	31.35	10.76	14.32	22.14	7.36
Corn	76.59	20.68	37.84	1.44	20.21	32.94	0
Lambton							
Winter wheat	65.96	7.99	8.94	5.90	5.97	7.07	5.32
Corn	106.50	17.47	26.74	11.13	16.09	23.71	11.43
Soybeans	33.71	5.27	8.27	2.05	5.21	8.04	3.29
Dundas							
Corn	82.76	16.19	38.05	0.97	12.12	22.44	0
Ottawa-Carleton							
Spring grain	52.60	16.90	23.13	8.10	15.87	24.48	10.94
Corn	87.78	12.81	29.46	−0.38	18.25	31.95	7.26
Russel							
Spring grain	43.28	18.04	31.02	3.61	16.99	28.22	4.34
Corn	79.35	21.08	37.53	−0.42	18.89	30.93	11.30
Norfolk							
Winter wheat	38.76	9.12	14.50	6.47	7.62	10.57	5.26

[a] Systematic risk in standard deviation format equals $\beta_i \sigma_a$.
[b] Non-systematic risk in standard deviation format equals $\sqrt{[(\sigma_i^2 - \beta_i^2 \sigma_a^2)]}$.
[c] Average for all farms in county, [d] and [e] maximum and minimum value of all farms in county.

For example average systematic risk for winter wheat in Perth county is 7.55 bushel/acre but the range about this mean is from 12.03 to 2.26 bu/acre. For non-systematic risk the average is 6.80 bu/acre with a range from 13.39 to 4.02 bu/acre. In contrast the range for soybeans is much lower; e.g. in Middlesex county, average systematic risk is only 2.37 bu/acre with a range from 4.85 to −0.64 bu/acre, whereas average non-systematic risk of 5.13 bu/acre is defined by a range from 7.89 to $0.13 bu/acre. (Negative non-systematic risk is due to a $\beta_i < 0$.)

Using these data, as well as the premium estimates, three OLS regressions defined by Eq. (23) were run, one for each of the 75%, 80% and 85% coverage levels. The dependent variable is the difference between individual and area premiums. A positive difference implies greater downside-risk protection with individual plans while a negative difference implies greater downside-risk protection with an area plan. According to the results in Table 4, (a) an increase in non-systematic risk increases individual premiums relative to area ones; (b) an increase in systematic risk or β causes individual premiums to decrease relative to area ones; (c) larger single index model intercept parameters (α) result in a decreased individual premium relative to area premiums; and (d) the relationship between individual and area premiums is crop-specific.

Although comparison of premiums and describing how the degree of correlation between individual and area yields affects them is a viable means of assessing the two policies it is none-the-less incomplete since it fails to consider the entire range of feasible outcomes. Risk reduction was therefore measured by comparison of ex post standard deviation and skewness measures via Monte Carlo simulation using @ RISK (Palisade Corporation, 1991). The results of the Monte Carlo simulations applied to all 609 farms for 85% coverage are too numerous to display here, so only a summary is presented.

First, all 609 farms showed a decrease in risk (standard deviation of gross revenues) relative to the no-insurance case whereas only 579 showed a decrease with area insurance. There were only nine cases where revenue standard deviation was lower under an area plan than an individual plan. Across all crops a 32% reduction in standard deviation for individual crop insurance was observed, while only a 9% reduction was found for area yield insurance. In comparison, and noting different approaches to coverage level determination, Miranda found a 30.8% decrease with individual yield insurance and a 22.4% decrease with area-yield crop insurance. Smith et al. (1994) found a decrease of 52.5% in yield variance for Montana wheat farmers with area-yield insurance of 90% coverage, while the decrease in yield variance for individual yield-crop insurance was 46.5% for 75% coverage. In the current study our results also showed that in all 609 cases individual crop insurance resulted in more positively skewed revenue distribution than the no insurance case and area insurance. However, in only 537 cases was area insurance more positively skewed than the no insurance case.

Table 4
Regression results for premium differences [a]

Dependent variable [b]	Constant	Estimated coefficients [c]						R^2
		Risk ratio (NSR/SR)	Intercept (α)	Spring grain	Corn	Winter wheat	White beans	
DIF75	1.54	0.03	−0.08	1.88	3.67	0.93	4.22	0.43
	(3.20)	(0.02)	(0.0045)	(0.55)	(0.50)	(0.54)	(0.76)	
DIF80	2.05	0.04	−0.09	1.68	4.14	1.11	4.38	0.46
	(3.43)	(0.03)	(0.004)	(0.59)	(0.54)	(0.58)	(0.82)	
DIF85	2.62	0.05	−0.11	1.39	4.52	1.33	4.40	0.48
	(3.67)	(0.03)	(0.005)	(0.63)	(0.58)	(0.62)	(0.88)	

[a] Standard errors are presented in the parenthesis.
[b] Dependent variables are individual yield insurance premiums minus area yield insurance premiums.
[c] Coefficients not significantly different than zero.

Finally, we ran two additional regressions, identical to Eq. (23) but with $d\sigma_I$, the change in risk due to individual insurance, substituted as the dependent variable in the first and the change in risk due to area insurance, $d\sigma_A$, in the second. With standard errors in parenthesis, the results were:

$$\begin{aligned} d\sigma_I = {} & \underset{(6.81)}{6.904} + \underset{(0.052)}{0.0418}\,\text{RR} - \underset{(0.009)}{0.126}\alpha_i \\ & + \underset{(1.17)}{5.71}\,\text{DC2} + \underset{(1.08)}{9.269}\,\text{DC3} + \underset{(1.15)}{3.408}\,\text{DC4} \\ & + \underset{(1.63)}{12.782}\,\text{DC5} + \varepsilon_1 \end{aligned}$$

$$R^2 = 0.336 \tag{24}$$

and

$$\begin{aligned} d\sigma_A = {} & \underset{(5.05)}{2.512} - \underset{(0.038)}{0.0286}\,\text{RR} - \underset{(0.007)}{0.0448}\alpha_i \\ & + \underset{(0.866)}{3.138}\,\text{DC2} + \underset{(0.797)}{2.161}\,\text{DC3} + \underset{(0.854)}{1.339}\,\text{DC4} \\ & + \underset{(1.206)}{5.177}\,\text{DC5} + \varepsilon_2 \end{aligned}$$

$$R^2 = 0.099 \tag{25}$$

These equations are informative. In Eq. (24) risk reduction in individual yields increases with non-systematic risk (the numerator in RR) and decreases with systematic risk (the denominator in RR) whereas in Eq. (25) risk reduction decreases with increased non-systematic risk while increasing with systematic risk. Hence, the more uncorrelated a farmer's yields is with the area average the less effective area-yield insurance will be in reducing risk. In addition, results show that for a given level of coverage (85% here) the location parameter, α, matters. For example, holding risk constant, a higher α_i implies a higher expected yield. As yields increase relative to risk, farmers have more risk reduction under individual yield insurance than area insurance (-0.126 vs. -0.0448). Finally, by examination of the intercepts and crop dummy variable coefficients in Eqs. (24) and (25) the mean change in risk is greater for individual insurance. For example, DC2 represents spring grain. All other things being equal, the change in risk for spring grain yields is 5.71 bu/acre for individual yield insurance and 3.14 bu/acre for area-yield insurance, a difference of 2.57 bu/acre.

4. Conclusions

The research conducted here confirms results previously reported by Miranda (1991), Carriker et al. (1990,1991 and Williams et al. (1991); mainly individual crop insurance is more effective in terms of risk reduction than fixed coverage area yield insurance. In addition area insurance premiums tend to be lower than individual crop insurance premiums. In either case, it was shown both in theoretical and empirical contexts that the more highly correlated individual yields are to area yields, the greater is the amount of risk reduction from area-yield crop insurance.

In the opening paragraph two propositions were stipulated. First, area yield insurance is less efficient than individual yield insurance, and second area-yield insurance is less equitable than individual yield crop insurance. The empirical results of this study confirm both propositions. Area yield crop insurance does not efficiently provide universal coverage for farmers. The greatest beneficiaries of area yield insurance accrue to those farms with yields most highly correlated with the area average. General adoption of this policy would reduce benefits for about 50% of farmers participating in the pool. These farmers would select individual coverage, if available, leaving a reduced population pool of high-risk types. But the distribution of area indemnities would change in response to different weightings attached to pooled risks, so that again, relatively lower risk types would demand individual plans. Because of asymmetric information and adverse selection area-yield insurance is inefficient and because benefits are not fairly distributed across pooled participants, inequitable. It is therefore unlikely that area-yield crop insurance can succeed as an alternative to individual yield crop insurance.

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