Crop Insurance and Crop Production : An Empirical Study of Moral Hazard and Adverse Selection

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CROP INSURANCE AND CROP PRODUCTION : AN EMPIRICAL STUDY OF MORAL HAZARD AND ADVERSE SELECTION

Multiple risk crop insurance has not been very successful, at least on standard commercial criteria, in the United States or elsewhere. In the United States, indemnity payments under the scheme have consistently exceeded premium income, even in years of good weather conditions. No multiple risk crop insurance scheme has consistently earned enough premium income to cover payouts, let alone administrative costs.

The standard explanations for the failure of multiple risk crop insurance relate to problems of adverse selection and moral hazard. A number of theoretical models of these problems have been proposed (eg Ahsan, Ali and Kurian 1982, Nelson and Loehman 1987, Chambers 1989). However, there has been comparatively little empirical study of the problem, possibly because of the difficulty of distinguish between adverse selection and moral hazard in practice.

Multiple risk crop insurance problem differs from many other forms of insurance, including those which have been the subject of most theoretical attention, in that a production process is insured. Insured losses depend on the interaction of a wide range of exogenous variables such as rainfall and temperature and endogenous variables including decisions on the level and timing of input use. By contrast, most insurance contracts and standard modelling of the insurance problem deal with a simple loss event in which some particular injury is sustained or some item is destroyed or damaged. The actions of the insured person can normally be characterized fairly simply, for example in terms of the effort expended to prevent or reduce loss. This characterization also applies to commercially successful insurance contracts offered to farmers, such as hail insurance.

The object of this paper is to present a theoretical and empirical analysis of adverse selection and moral hazard. It is argued that the distinction between moral hazard and adverse selection, while enlightening in some contexts, is not really applicable in this framework. Theoretical predictions of the joint impact of these effects are derived from a model of choice under uncertainty. These predictions are tested in an empirical model based on a production function framework. A cross-section study using data from the USDA FCRS survey is used. Finally, some implications for the viability of multiple risk crop insurance are derived.

Moral Hazard and Adverse Selection

It is usual in the literature to differentiate between adverse selection and moral hazard as follows. *Moral hazard* means that the insured person's optimal decision may change as a result of taking out insurance. Because the insurance contract reduces the loss associated with the insured event, such changes in behavior will normally increase the probability of the insured event occurring or the severity of the loss. *Adverse selection* means that people who are more likely to suffer the insured event will be more willing to insure at a given rate. If the insurance company cannot detect such people, losses will occur.[1]

This distinction is useful for the purposes of analysis and exposition. Perhaps the most appealing way of formulating the distinction is due to Arrow (1985), who refers to adverse selection as a problme of ‘hidden information’ and to moral hazard as a problem of ‘hidden action.’ When individual characteristics are observable, and may be made the subject of discriminatory terms in contracts, but behavior is not, the problem is one of pure moral hazard. Analysis of this case has mostly concerned the effects of copayments and deductibles. When actions are observable but characteristics are not, the problem is one of pure adverse selection. Analysis of this case has been concerned with the design of ‘incentive-compatible’ contracts that will induce the potential insured to reveal their characteristics.

In practice, however, the distinction between adverse selection and moral hazard (or, more fundamentally, between characteristics and behavior) cannot be pushed too far. Suppose, for example, that a farmer has land that is equally suitable for growing wheat and for growing corn. Suppose further that the parameters of the insurance scheme are such that the expected payout is exactly equal to the expected premium when the farmer plants only corn or only

[1] For a general discussion of the issues of moral hazard and adverse selection, see Laffont (1989). For a discussion in the context of crop insurance see Chambers (1989).

wheat. The farmer may choose to grow wheat on low-quality land and corn on high quality land, and to insure the wheat but not the corn.

If the allocation of land is taken as given, this may be regarded as a case of adverse selection. The yield for wheat is likely to be lower, relative to the guaranteed yield, than the yield for corn. It is rational to insure wheat but not corn. From the perspective of the insurer, the average quality of insured land is lower.

On the other hand, if the decision to insure the wheat crop is taken as given, this may be regarded as a case of moral hazard. The allocation of land by the insured farmer is such as to increase the probability of a payout. The imputation of moral hazard would be even clearer if the farmer chose to allocate less (or lower quality) labor or fertilizer to the insured crop.

The key point is that the decision to insure a crop can only be made on the basis of some planned allocation of inputs. The allocation and insurance decisions must be regarded as co-determined. Thus, the distinction between adverse selection and moral hazard is an analytically convenient simplification, and not an inherent feature of the insurance problem.

A more complex example arises if insurance may be taken out within some specified period after the date of planting. Suppose a farmer delays the planting date in order to gain more information on soil moisture, then takes a decision to plant without insurance if the outlook is favorable, plant with insurance if it is less favorable, and abstain from planting if it is highly unfavorable. Once again, the situation involves elements of both moral hazard and adverse selection. The farmer chooses to insure when the odds are favorable and not otherwise (adverse selection) and actions including the date of planting and the decision on whether to plant are altered because of the availability of insurance (moral hazard).[2]

A clear distinction between adverse selection and moral hazard can only be drawn in

[2] It should be noted at this point that the pejorative connotations of the term 'moral hazard' are unfortunate. In particular, these connotations appear to have led to some belief that analysts who regard moral hazard as a problem for multiple risk crop insurance are guilty of imputing immorality to American graingrowers. The fact that an insured farmer chooses to plant a crop which would not be planted in the absence of insurance fits the theoretical category of moral hazard but would not be regarded as blamable conduct under most ethical codes. Indeed, if food production is regarded as a desirable goal regardless of its efficiency consequences (a view which appears to be held by most farmers and many non-farmers), the farmer's actions would be regarded as commendable.

radically simplified models of farmers' insurance and production decisions. Such simple models are useful, but they may not prove a reliable guide to empirical analysis. The basic implication for production is the same for moral hazard and adverse selection. *Farmers who are insured will produce low yields more frequently than uninsured farmers with similar observed characteristics.* This implication will be derived formally from a theoretical model in the next section. The empirical hypothesis that insured farmers will have lower yields than uninsured farmers with similar observable characteristics will be tested further below.

The critique of the adverse selection/moral hazard distinction drawn from the examples presented above may be presented in a more general way. Moral hazard is often seen as relating to individual action and adverse selection as a property of the pool of insured individuals. However, both of these phenomena arise from the optimizing choices of individuals. In the case of adverse selection, the choice is whether or not to insure. In the case of moral hazard, the choice is how to act given that insurance has been taken out.

Both ‘moral hazard’ and ‘adverse selection’ are implications of two assumptions which are central to modern economic theory - that individuals make rational choices in the light of the constraints facing them, and that information is costly. Only when the constraint and information sets take on particularly simple forms can specific choices be regarded as examples of either ‘moral hazard’ or ‘adverse selection.’

The Model

The farmer's production decision may be modelled as follows. The farm has fixed inputs Z, and must choose observable variable inputs X and unobservable inputs (eg operator's effort) θ. Farm output[3] Y depends on the input vector (Z, X, θ) and on random variables ε, representing exogenous fluctuations such as climate, and φ representing unobservable[4] differ-

[3] As a simplification, it is assumed that the farm produces a single output. This assumption appears necessary to make the problem tractable but it does abstract from important aspects of the multiple risk crop insurance problem, most notably the option of insuring some crops but not others.

[4] That is, unobservable by the insurer. Farmers are assumed to know their own farm type. Strictly speaking what matters is not that inputs or quality levels should be unobservable by the insurer but that they

ences in land quality and farmer skills (referred to briefly as 'farm type'). The variable θ corresponds roughly to moral hazard in the usual models and the variable φ to adverse selection. The farmer must also decide whether or not to take out insurance.

The production function is assumed to be of the form

$$Y = f(Z, X, \theta)\ \eta(\varphi\varepsilon), \tag{1}$$

where f has the usual properties (positive first derivatives and cross derivatives, negative second derivatives) and $\eta(\varphi\varepsilon)$ is a multiplicative shifter. The interaction between the random farm type and climatic variables, given by $\eta(\varphi\varepsilon)$ is not specified in detail, but it is assumed that the lower the value of φ (that is, the worse the farm type) the lower is the mean and the greater is the variability of $\eta(\varphi\varepsilon)$.

This production function differs from that proposed by Pope and Just (1977), who suggest a functional form which admits both risk-increasing and risk-reducing inputs. The main problem with the Pope-Just approach is that the derivation of input demands is complex when more than one input affects risk.

The profit function in the absence of insurance may be written

$$\pi = pY - w \bullet X - C(\theta), \tag{2}$$

where:

p is the of output price;

w is the vector of prices for observable inputs; and

$C(\theta)$ is a cost function for unobservable inputs.

The farmer seeks to maximize $\mathrm{E}[U(\pi)]$ where U is a von Neumann-Morgenstern expected utility (EU) function, or, more generally, $V[F(\pi)]$ where V is a generalized utility functional (Machina 1982, Quiggin 1982) and $F(\pi)$ is the cumulative distribution function of π. For simplicity, attention will initially be focused on the EU case, and extensions to generalized

should not admit independent verification. If inputs cannot be independently verified then they cannot be made the subject of contractual conditions.

models will be discussed afterwards.

The optimization problem is to choose X and θ so as maximize E[$U(\pi)$]. The first order conditions are

$$E[U'(\pi)\,(\partial R/\partial X - w)] = 0 \qquad (3)$$

$$E[U'(\pi)(\partial R/\partial \theta - C'(\theta))] = 0$$

where

$R = p \bullet Y$ is gross revenue, and the marginal revenue products are

$$\partial R/\partial X = (\, p\partial f/\partial X\,)\,\eta(\varphi\varepsilon)$$

$$\partial R/\partial \theta = (p\partial f/\partial \theta)\ \eta(\varphi\varepsilon)$$

The solutions to the first-order conditions (3) determine input demands $X(\varphi, p, w)$ and $\theta(\varphi, p, w)$.

The effect of insurance is to replace the revenue term $R = p \bullet Y$ in (3) with a modified revenue R^*, given by

$$R^* = \begin{cases} p \bullet Y - \rho & Y \geq Y^* \\ p \bullet Y + p^* \bullet (Y^* - Y) - \rho & Y < Y^* \end{cases} \qquad (4)$$

where y^* is the guaranteed yield, p^* is the price election (a choice variable) and ρ (a function of p^*) is the premium. Thus the benefit arising from the insurance contract is

$$\Delta = \begin{cases} -\rho & Y \geq Y^* \\ p^* \bullet (Y^* - Y) - \rho & Y < Y^* \end{cases} \qquad (5)$$

The marginal revenue product for observable inputs becomes

$$\partial R^*/\partial X = \begin{cases} p\partial f/\partial X\ \eta(\varphi\varepsilon) & Y \geq Y^* \\ (p - p^*)(\partial f/\partial X)\ \eta(\varphi\varepsilon) & Y < Y^* \end{cases} \qquad (6)$$

Thus, for low values of Y, the marginal revenue product is negative whenever $p < p^*$.

This possibility raises important questions of moral hazard, especially in relation to unobservable inputs. It seems unlikely that such inputs will be applied if their impact on revenue is negative. Hence the marginal revenue product for unobservable inputs becomes:

$$\partial R/\partial\theta \quad \begin{cases} p\partial f/\partial X\ \eta(\varphi\varepsilon) & Y \geq Y^* \\ (p - p^*)(\partial f/\partial X)\ \eta(\varphi\varepsilon) & Y < Y^*,\ p \geq p^* \\ 0 & Y < Y^*,\ p < p^* \end{cases} \tag{7}$$

The fact that the marginal value product is negative whenever $Y < Y^*$ and $p < p^*$ suggests that the moral hazard problem should be particularly severe whenever the market price falls short of the guaranteed price. To the extent that prices and average yields are negatively correlated, it would be expected that this combination of adverse outcomes would be uncommon. However, even in years when yields are generally good, some areas will suffer adverse conditions. In addition prices are affected by demand-shocks and events in the world market unrelated to United States yields. A test of the hypothesis would require the use of panel data over a number of years.

Substituting (6) and (7) into the first-order conditions (3) yields modified input demands $X^*(\varphi, p, w)$ and $\theta^*(\varphi, p, w)$ conditional on the decision to take out insurance at a given price election p^*. This in turn yields

$$V^*(p^*) = V(F(R^*) - w \bullet X^* - C(\theta^*))$$

The farmer's decision problem may thus be represented as a two-stage choice problem. The first is to choose the value of p^* from the set of available contracts that maximizes $V^*(p^*)$. The decision not to insure may be represented by the choice $p^* = 0$. The second is to choose the input demands $X^*(\varphi, p, w)$ and $\theta^*(\varphi, p, w)$ as described above.

Using the standard expected utility[5] analysis of the comparative statics of choice problems

[5] The requirement that farmers be expected utility maximizers is unduly restrictive, expecially in view of evidence that observed insurance choices are inconsistent with Expected Utility theory (see Machina 1982). Quiggin (1991) shows that a wide range of comparative static results from expected utility theory, including (ii) and (iii) above, may be extended to the more general rank-dependent expected utility model.

under uncertainty (eg Feder 1977) is straightforward to show that

(I) The lower is φ (the worse the farm type) the more profitable, for given inputs, is any given insurance contract for the insured and the more costly for the insurer.

(II) Given decreasing absolute risk aversion, for any given input choice, there exists a φ^* such that insurance will be taken out if $\varphi \leq \varphi^*$, and not if $\varphi > \varphi^*$. This is the adverse selection effect.

(III) Given decreasing absolute risk aversion, $\theta^* < \theta$ and $X^* < X$, $\forall\ \varphi, p, w$. That is, insurance leads to a reduction in the optimal levels of X and θ. This is the moral hazard effect.

Taken together, hypotheses (I) - (III) imply that farmers with low values of φ are more likely to take out insurance, and, having done so are likely to apply less variable inputs, and in particular, less unobservable inputs, than if they had been uninsured. The combination of moral hazard and adverse selection effects implies

(IV) Insured farmers will have, on average, lower output than uninsured farmers with similar observable characteristics and inputs.

A formal proof of these claims is given in the Appendix.

Model Estimation

The crucial problem for modelling is that θ and φ (as well as ε) are unobservable. However from the results (I)-(IV) above, the observed insurance decision, denoted δ, may be used as a proxy for φ and θ. Hence it is possible to estimate a system consisting of a production function and input share equations

$$Y = f(X, Z, \delta) \tag{8}$$

$$Si = w_i X_i / p\, Y = h(Z, p, w, \delta) \tag{9}$$

The analysis above, and in particular Results III and IV, suggests that the hypothesis that farmers make rational insurance and input allocation decisions may be modelled as

H_1 The coefficient on δ is negative in both the production function and the input demand functions;

which may be tested against the null hypothesis

H_0: The coefficient on δ is zero in both the production function and the input demand functions;

In the empirical analysis reported here, a simple Cobb-Douglas functional form is used for *f*. Although the Cobb-Douglas functional form imposes restrictive assumptions (such as unit elasticities of substitution), these relate to issues which are not of central concern in the present study. The advantages of the Cobb-Douglas form, including the simplicity of the derived input demand equations, the robustness derived from the fact that it is a first-order approximation to an arbitrary functional form, the fact it displays reasonable behavior for all input values, and its parsimony in parameters, make it an appropriate choice for this study. Thus, the functions (8) and (9) may be estimated in the standard log-log and input share forms with the addition of a dummy indicating insurance

$$\ln Y = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln X_i + \sum_{i=1}^{n} \beta_j \ln Z_j + \delta_0 \quad (10)$$

$$w_i X_i / p\, Y = \gamma_i + \delta_i \quad (11)$$

As noted above, the insurance dummy variables δ are expected to have negative signs. Under the assumption of profit maximization, the input demands and production function satisfy the cross-equation constraint $\gamma_i = \alpha_i$. Under the hypothesis of risk-aversion, assuming maximization of expected utility or some appropriate generalized functional, the equality constraint is replaced by an inequality $\gamma_i \leq \alpha_i$. Usage of the variable inputs is expected to be lower than the level which would equate marginal cost with expected marginal value product

There may also be some interest in more traditional hypothesis associated with the Cobb-Douglas functional from, such as those concerning returns to scale. Since insurance is offered on a per acre basis, non-constant returns to scale will automatically generate adverse selection problems. If for example, there are increasing returns to scale over some range, small farms will have lower expected yields and will be more likely to take out insurance. Just and Calvin point out that, if returns on different parts of a large farm are not perfectly correlated, the variance for the farm as a whole is likely to be lower, resulting in further adverse selection effects. If production is extended into the range of decreasing returns to scale (as would be expected on the basis of textbook micro theory), the mean and variance effects will work in opposite directions. In the long-run, the availability of insurance will lead to sub-optimal scale decisions, so that moral hazard and adverse selection effects are intertwined.

Data

The data set for this study was derived from the 1988 *Farm Costs and Returns Survey* undertaken by National Agricultural Statistical Services. Over 4000 farmers were interviewed for the original survey. For the present study, it was desired to confine attention to a population of grain farmers sufficiently homogeneous to permit the estimation of a production function. For this reason, attention was confined to a subset of 18 major grain producing states. Farmers who derived more than 15 per cent of their income from either cotton or vegetable production or allocated more than 10 per cent of their land area to pasture were excluded. Along with editing and consistency checks, these restrictions resulted in a sample of 535 producers.

In surveys of this kind, data on outputs is typically more reliable and accurate than data on inputs. A number of problems arise with measures of inputs. Some inputs such as labor, are subject to quality variations. Others, such as fertilizer may be purchased in one season and applied in another. All inputs are affected by errors in farmers' estimates and by the difficulty of determining state-level input prices. These difficulties make it more difficult to disentangle effects of insurance that arise through changes in measured inputs and that arise through unobservable differences in farm quality. However, estimates of the overall effect of insurance on yields (the key variable in the insurance contract) are more reliable.

Estimation of the model specified above requires data on output, variable and fixed inputs and insurance status. Output is measured in value terms, in order to permit the aggregation of a heterogenous output mix. Output value was measured as the sum of gross receipts from farm crop sales, total production bonuses, CCC loans and cash receipts from the sale of livestock products. For an accurate measure of livestock input, it would be desirable to include a measure of the change in livestock holdings, but this was not feasible because the only available measure (change in value of livestock) conflates quantity and value changes. This difficulty, as well as the desire to focus on cropping enterprises, was a motive for the exclusion of farmers with large livestock operations (more than 10 per cent of land area).

Two fixed inputs - land and capital - were included. Each of these inputs was measured in stock value terms. Capital is formed as the aggregate value of farm buildings (barns, silos, cribs, equipment shops, grain bins, storage sheds) and plant and machinery (trucks, tractors, machinery, tools and implements). Variables inputs were partitioned into five categories - labor, fertilizer, pesticides, energy and other.

All were measured in value terms. The only input where this presented difficulties was labor. Information on operator and family labor inputs was available in hours worked. Hired labor was available as an expense item. In order to provide an aggregate wage measure, an imputed wage was adopted. The imputed wage for operator and family labor was $10/hr, based on estimated average farm returns net of returns to capital, and for other labor $4/hr, based on the minimum wage[6].

It is common to aggregate fertilizer and pesticides into a more general input category. Because of the primary concern with the risk characteristics of inputs, it was not clear whether this approach was appropriate for the present study. Pesticides are generally viewed as a risk-reducing input and fertilizer as a risk-increasing input. However, testing revealed no significant loss in power from aggregating the two inputs. This aggregation had the side benefit of permitting the inclusion of certain observations with zero values in one of the two categories, usually pesticides. The need to have positive values for all inputs is a weakness of the Cobb-Douglas production function (one shared by many other popular functional forms). In the present study, this problem arose only in relation to the fertilizer and pesticide category.

[6] For the purposes of estimation, all that matters is the ratio of the wages imputed to operators and hired workers. The wages chosen here imply that operator labor is 2.5 times as effective as hired labor.

The relationship between fertilizer and pesticides is discussed further by Horowitz and Lichtenberg (1991), who use the same data set as in the present study.

Fertilizers are defined here to include expenses for seed and plants, lime and soil conditioners. Pesticides include insecticides, herbicides and fungicides. The energy input includes fuel, motor oils, electricity, water and telephone. All other cash outlays are aggregated into the 'other' input.

Insurance status was defined by a dummy variable taking the value 1 if the farmer participated in the Federal Crop Insurance Corporation program in 1988 and zero otherwise. An alternative would be to employ a continuous variable reflecting total premiums paid or total coverage. This approach would have the advantage of capturing information on levels of insurance coverage and on whether farmers insured all or only some crops. However, because of variations in premium rates between counties and between farmers within counties, the extraction of this information would be difficult, and the introduction of errors would be likely. The phenomenon of insuring one crop but not others is more complex, and requires separate study.

Finally, state-level dummies were incorporated in the analysis. In the production function, this permits the incorporation of multiplicative differences in total factor productivity between states. Given the sampling rate, it would not be feasible to include more finely specified geographical dummies. However, a theoretically preferable approach would be to include information on soil characteristics and on climatic characteristics (both 'normal' characteristics and 1988 experience) in place of a simple geographical dummy.

Results

The system of equations given by (8) and (9) was estimated by Ordinary Least Squares. Re-estimation using Zellner's SUR technique did not result in significant changes in estimated coefficients. The main results are presented in Tables 1 and 2. State-level dummy variables were included in the estimation but are not reported. The results for the production function are discussed first.

The Cobb-Douglas production function is well-behaved, with all input variables being right-signed and significant at the 5 per cent level. The $\bar{R}^2$ was 0.77, which is very satisfactory for a cross-section equation. The coefficients on the six input variables add to 1.18, indicating weak economies of scale. The hypothesis of constant returns to scale cannot be rejected at standard levels of significance. The absence of scale economies is a necessary, though not a sufficient condition for the successful operation of a crop insurance scheme based on expected yields per acre determined on a geographical basis. If large farms have consistently higher yields per acre than small ones, this pricing approach generates adverse selection, with small farms choosing insurance and large ones choosing to self-insure.

The joint null hypothesis that all of the insurance coefficients, in the production function and share equations, are zero, may be rejected, at the 5 per cent level, in favor of the alternative hypothesis, based on the assumption of economic rationality (or equivalently, adverse selection and moral hazard), that all coefficients should be negative.

The coefficient on insurance is negative, but statistically significant only at the 10 per cent level. The impact of insurance in the factor share equations is once again negative, but insignificant. The estimated coefficients indicate that insured farmers tend to use less variable inputs to produce a given output than do uninsured farmers. In combination with the previous observation that output for a given vector of inputs is lower for insured farmers, this implies that insured farmers use less variable inputs in relation to fixed inputs, and in particular less inputs per acre of land than do uninsured farmers. This result is conducive to a moral hazard explanation. However, as noted above, it is also consistent with adverse selection. The estimated reduction in cost share is generally of the order of 10 per cent.

Although individual coefficients are estimated with considerable error, the result that insured farmers will tend to have lower average yields than uninsured farmers is relatively robust, as is reflected in the rejection of the null hypothesis in the one-sided joint test referred to above. The difficulty in partitioning the yield reduction between input demand effects and production effects reflects the difficulties in the measurement of inputs, referred to above.

Insurance implications

Although the results presented above are not statistically conclusive, they indicate that insured farmers have lower observed levels of variable inputs and lower total factor productivity than uninsured farmers. This result has fundamental implications for the operation of crop insurance schemes. These two effects may be combined and their impact analyzed in a simulation model.

The parameters estimated from the econometric model will be used as a basis for simulation. Since these parameters are not estimated with great precision, the results presented here should be taken as illustrative of the insurance implications of moral hazard and adverse selection, rather than as definitive estimates of the loss experience of the multiple risk crop insurance scheme operating in the United States. However, as is shown below, the results obtained to correspond fairly well to recent loss experience.

Normalize the system of equations (10) and (11) by setting $w = p_i = 1, \forall\, i$. (This was done in the econometric estimation by expressing output and all variable inputs in value terms.) Substituting from the share equations into the production function and cancelling common terms yields ρ, the ratio of expected output per acre for insured farmers to expected output per acre for uninsured farmers:

$$\log \rho = \delta_0 + \sum_{i=1}^{n} \alpha_i \log((\gamma_i + \delta_i)/\gamma_i) \qquad (12)$$

Substituting the estimated coefficients from Table 1 yields an estimated value $\ln \rho = -0.21$ or $\rho = 0.81$. That is, an insured farmer would be expected to experience yields 20 per cent lower than an uninsured farmer with the same observed levels of fixed inputs (i.e. the same observed land quality and capital stock per acre).

To determine the impact of such a differential in an insurance scheme, it is necessary to incorporate uncertainty, arising from variation across farms and over time. Because the insurance scheme operates on the basis of output per acre, it is natural to treat uncertainty in terms of the coefficient of variation. For a given distribution, such as the normal or lognormal, and an insurance policy which specifies a given insured yield level, the coefficient of variation determines both the probability of a payout and the expected value of payouts[7].

The insurance implications of adverse selection and moral hazard are most easily assessed when the parameters of the insurance policy are set in an actuarially fair fashion on the basis of observations of uninsured farms. Table 2a gives the probability of payout and the actuarially fair premium for the uninsured groups for various levels of coverage and coefficients of variation of 0.2 and 0.3. Table 2b gives the same information for a lognormal distribution. Tables 3 and 3b give the corresponding payout probabilities, expected payouts and loss ratios for a group with similar variance and 20 per cent lower expected yields.

As an illustration, with a coefficient of variation of 0.3, and a guaranteed yield equal to 65 per cent of the expected yield an actuarially fair scheme would charge a premium equal to 1.7 per cent of expected yield, and would expected to make payments on about 12 per cent of its policies on average. If the same policy were offered to a group with a 20 per cent lower expected output, payments would be made on 24 per cent of policies and expected payments would be equal to 4.4 per cent of the original expected yield.

The loss ratio (the ratio of payouts to premiums) would exceed 2.5. If the premium were calculated in line with normal insurance practice, to include a 10 to 20 per cent margin in addition to administrative costs, but still using the uninsured group as a basis, the observed loss ratio would fall to between 2 and 2.25. The loss ratio is greater for the lognormal distribution than for the normal, and greater for lower levels of coverage. This is because, in these cases, the probability of a payout derived from observations of the uninsured population is very low, leading to low premiums.

A more interesting case is when the premium is set on the basis of average yield for all farms, insured and uninsured. This is the basis that would be used if problems of adverse

[7] One problem with the use of the coefficient of variation in the present study arises from the observation that insured farmers have lower expected yields per acre than uninsured farmers. If the coefficient of variation is the same for the two groups, the insured farmers will have a lower variance and standard deviation. Since, as shown above, both moral hazard and adverse selection imply that insured farmers should be characterized by high variability the assumption of equal coefficients of variation seems inappropriate. It will be assumed here that insured and uninsured farmers have the same variance, implying a higher coefficient of variation for insured farmers.

selection and moral hazard were ignored in setting premiums. Assuming 40 per cent of farmers are insured, the loss ratio would be about 1.6. This is quite close to the actual loss ratio for the Federal Crop Insurance System, which was about 1.8 over the 1980s (Gardner 1990). Thus, on the basis of the parameter estimates derived above, the observed poor performance of the scheme may be accounted for by adverse selection and moral hazard. However, in view of the lack of precision with which the parameters are estimated and the inevitable problems with the data set, this result should not be regarded as definitely established.

The final possibility that may be considered is the use of the loss experience for insured farmers as the basis for rate-setting (which has been the historical practice of the FCIC) combined with premiums calculated on an actuarially fair basis (as opposed to the subsidized rates that have applied in the past). Yield differences between insured and uninsured groups of the magnitude estimated here pose a critical problem for the operation of a system of crop insurance. Rates high enough to yield a positive expected return for the currently insured group would be so high as to make insurance unattractive to all but extremely risk-averse members of the uninsured group.

In practice farmers do not fall into two discrete groups. Rather among farmers (and farms) with similar observed characteristics there will be a continuum of ability levels, soil quality and ability to adjust input mix in response to economic incentives. This does not change the fundamental problem. It may be that there is no insurance policy which will be attractive to a significant group of farmers while having prices sufficiently high to yield a positive return on the inevitable bad risks.

Policy implications

The results presented in the previous sections indicate some of the difficulties associated with a system of multiple risk crop insurance. They suggest that the losses observed in such schemes around the world cannot be attributed primarily to mismanagement or lack of private sector expertise, but are inherent in this type of insurance. Policies for the reform of crop insurance must be formulated in this light. In most respects, the implications for policy depend mainly on the robust conclusion that inusred producers will tend to have lower average yields than uninsured farmers and only to a limited extent on the more problematic partitioning of the yield gap between input use effects and adverse selection effects.

The results presented above may be used in the assessment of proposals to improve the operation of the current multiple risk crop insurance scheme. Two examples are the use of individual farm records to overcome the problem of adverse selection using and the use of deductibles and copayments to overcome moral hazard. Consideration of the examples presented above indicates that neither of these approaches is likely to be adequate.

Consider first the use of policies based on individual farm records. The longest history which could reasonably be obtained for any large group of farms is of the order of 10 years. Given a coefficient of variation of 30 per cent, the relative standard error associated with a mean estimate based on 10 observations will be of the order of 10 per cent. This is a lower bound estimate, which would apply in the case when expected yields for all farms were stable over time, at least in relative terms. In fact, over any period of ten years, some farms will enjoy increases in efficiency and others will experience decline. It seems likely, then, that even with individual rating, the adverse selection problem is likely to remain of the same order of magnitude as that estimated in the present study.

Similar problems arise with attempts to resolve the moral hazard problem. Economic analysis of insurance provides conditions for the existence of an optimal contract involving deductibles and, in some cases, copayments. In the present case, however, even a 35 per cent deductible appears to be to small to make insurance feasible. As a practical matter, it appears unlikely that any insurance scheme with a significantly larger deductible would be politically feasible, since the payouts would be insufficient to cover variable costs for many farmers. Informal evidence suggests that any insurance policy which does not ‘make farmers whole’ in this respect will be rejected as unfair, regardless of its actuarial properties. Equally importantly, the calculations presented here indicate that as the deductible becomes larger, the proportional difference between the payout probability for the currently insured and that for the uninsured group becomes larger. Thus, the device of increasing deductibles deals with the moral hazard problem only at the expense of increasing the severity of the adverse selection problem.

A further approach to the adverse selection would be an attempt to identify instrumental variables which could be used to estimate the risk status of different producers. Possible indicator variables include educational status, farming experience and perhaps debt status. It seems likely, however, that most of the differences between farms and farmers will not be captured by instrumental variables of this kind.

All of this is not to suggest that the use of individual farm records, deductibles and copayments would not improve the performance of the current multiple risk crop insurance scheme. However, it is unlikely that these improvements will be sufficient to permit the program to operate without a substantial subsidy.

There are a number of approaches to policy reform based on alternatives to the standard multiple risk crop insurance model. Given the theoretical prediction, supported by the estimates presented here, that insured farmers will have lower yields than uninsured farmers with similar observed characteristics, a natural approach is to propose insurance schemes in which the payout is independent of individual yields. Examples of this approach include regional yield insurance schemes, advocated by the Australian Industries Assistance Commission (1978) and rainfall insurance schemes, discussed by Bardsley, Abey and Davenport (1984) and Quiggin (1986).

As is argued by Quiggin (1990), this approach will not in general be optimal. A preferred approach will typically involve a payment which is defined by the observed yield loss, in combination with some deductible, as in the standard multiple risk crop insurance schemes, but is contingent on the occurrence of some insured event. The insured event could be the failure of regional average yield to reach some predefined value, or a predefined climatic event, as in the rainfall insurance literature.

A final possibility is the abandonment of insurance altogether in favor of a system of disaster relief, either *ad hoc* or based on some formal criteria. A scheme based on formal criteria is essentially equivalent to free insurance. The choice between the two approaches depends on administrative simplicity and on the general problem of choice between subsidy and free provision of goods. An *ad hoc* scheme may approach the characteristics of a lump-sum transfer if eligibility is determined on essentially arbitrary criteria such as the political weight of representatives from an area experiencing low yields. However, precisely in this case, its risk-reducing and distributional benefits are likely to be small or negative.

Concluding Comments

The theory of insurance predicts systematic differences between insured and uninsured firms. These predictions may be tested by a variety of comparisons between the two groups. The present paper is based on the view that the most relevant comparison for a system of production insurance is one based on an explicitly specified production function. A number of modifications of the approach adopted here may be worth considering.

The Cobb-Douglas function used in the estimation here is simple and robust. One modification to the analysis presented here would be based on the use of more sophisticated and flexible functional forms. In particular, it would be desirable to employ a more general system of input demand equations. Horowitz and Lichtenberg (1991) have investigated input demand, but not in a production function context. Because not all products are covered by crop insurance and because multi-output producers may choose to insure some but not all of their crops, it would also be desirable to extend the analysis presented here to include explicit modeling of multi-output production.

Finally, the data used here represent only a single year, 1988. All years are atypical, but 1988 was more so than most. An extension from cross-section to panel data would be desirable for a number of reasons. First, it would improve the reliability of estimates. Second, the relationship between variation over time and variation between farmers is critical to the operation of insurance schemes. An insurance scheme will work well when the output of individual farmers is independently and identically distributed over time, and will work badly when farmers with similar observed characteristics have different output distributions or when output is highly correlated across farmers.

Despite these *caveats*, the estimates presented here support the view that farmers' production and insurance decisions are responsive to economic incentives, and that these incentives work in a way which undermines the viability of multiple risk crop insurance.

Table 1

Estimated Coefficient values - Production function

Intercept	-0.44	(0.40)
Land	0.11	(0.03)
Capital	0.11	(0.05)
FrtPest	0.32	(0.04)
Labor	0.08	(0.04)
Energy	0.16	(0.06)
Other	0.40	(0.04)
Insurance	-0.10	(0.07)

N = 535
$R^2 = 0.78$

Factor shares

	Share		Insurance effect	
FrtPest	0.32	(0.16)	-0.03	(0.09)
Labor	0.08	(0.04)	-0.01	(0.02)
Energy	0.16	(0.06)	-0.03	(0.03)
Other	0.40	(0.04)	-0.05	(0.04)

(Standard errors in parentheses)

Table 2a

Parameters of fair insurance schemes: normally distributed yields

	CV = .2		**CV = 0.3**	
Coverage[a] level	Expected[b] payout	Probability[c]	Expected payout	Probability
65	0.3	3.6	1.7	12.0
70	0.6	6.5	2.4	15.7
75	1.0	10.4	3.3	20.0

Table 2b

Parameters of fair insurance schemes: log-normally distributed yields

	CV = .2		**CV = 0.3**	
Coverage level	Expected payout	Probability	Expected payout	Probability
65	0.1	1.8	0.8	9.4
70	0.2	4.5	1.4	14.5
75	0.6	9.3	2.2	21.0

a: As percentage of expected yield
b: As percentage of expected yield
c: Per cent

Table 3a

Parameters of insurance schemes with mean yields reduced 20 per cent: normally distributed yields

	CV = 0.2			CV = 0.3		
Coverage[a] level	Expected[b] payout	Probability[c]	Loss[d] ratio	Expected payout	Probability	Loss ratio
65	1.5	15.0	5.0	4.4	24.3	2.6
70	2.5	22.2	4.2	5.8	30.0	2.4
75	3.8	30.1	3.8	7.4	35.9	2.2

Table 3b

Parameters of insurance schemes with mean yields reduced 20 per cent: log-normally distributed yields

	CV = 0.2			CV = 0.3		
Coverage level	Expected payout	Probability	Loss ratio	Expected payout	Probability	Loss ratio
65	1.2	15.6	12.0	3.4	26.5	4.3
70	2.1	23.6	8.5	5.0	34.7	3.6
75	3.5	32.9	5.8	7.0	42.3	3.2

a: As percentage of expected yield
b: As percentage of expected yield
c: Per cent
d: Ratio of payouts to premiums determined from Table 2

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Appendix - Proof of results

(I) From (5)

$$\Delta = \begin{cases} -\rho & Y \geq Y^* \\ p^* \bullet (Y^* - Y) - \rho & Y < Y^* \end{cases} \qquad (5)$$

Hence, $\partial \Delta / \partial \varphi$ is zero for $Y > Y^*$ and negative for $Y \leq Y^*$. This proves the required claim.

(II) The benefit from insurance Δ is monotonically decreasing in Y. A decrease in ϕ corresponds to a reduction in the mean and an increase in the riskiness of Y. Proposition 6 of Quiggin (1993) shows that, under these conditions, and assuming decreasing absolute risk aversion, if $EU(Y+\Delta) \geq EU(Y)$ for some ϕ^0, then $EU(Y+\Delta) \geq EU(Y)$ for any $\phi' \leq \phi^0$. Hence, if an individual with characteristics ϕ^0 prefers insurance to noninsurance, so will any individual with $\phi' \leq \phi^0$.

(III) First we prove that, for given θ, and X_j, $j \neq i$, if X_i^0 is optimal in the absence of insurance, the optimum $X_i^*(\varphi, p, w)$ with insurance must satisfy $X_i^* \leq X_i^0$. The first-order condition in the absence of insurance is

$$E[U'(\pi)\,(\partial R/\partial X - w)] = 0$$

The second-order condition is

$$D = E[U''(\pi)\,(\partial R/\partial X - w)^2 + U'(\pi)\partial^2 R/\partial X^2]$$

Insurance strictly reduces $\partial R/\partial X$, so the second-order condition yields the desired result. Similarly, for any given X and θ_j, $j \neq i$, $\theta_i^* \leq \theta_i^0$. The result now follows from the positivity of the cross derivative.

(IV) From (II) all uninsured farmers have higher values of ϕ than all insured farmers. The results of Feder show that in the absence of insurance farmers with low values of ϕ will choose lower values of θ for any given value of X. Result (III) shows that insurance will further lower the preferred θ for any given X. The result now follows from (1).