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A MODEL OF AGRICULTURAL INSURANCE IN EVALUATING ASYMMETRIC INFORMATION PROBLEMS

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A Model of Agricultural Insurance in Evaluating Asymmetric Information Problems

Abstract

The main motivation for this paper is the recognition of the fact that asymmetric information in the form of moral hazard and adverse selection results in sizeable efficiency losses. These costs are passed back to producers in the form of excessively high premium rates and also passed back to the government via the crop insurance subsidy program. A secondary motivation stems from a recent debate in the literature regarding the specific effects of moral hazard on agricultural input use. Conventional wisdom suggests that moral hazard will induce producers to reduce input usage. A competing hypothesis has emerged which suggests that moral hazard may induce producers to increase their usage of risk increasing inputs.

The main objective of this paper was to develop a model of agricultural insurance to understand why asymmetric information problems might exist and to compute and evaluate the relative program costs of agricultural insurance that can be attributed to moral hazard and adverse selection. These objectives are achieved by developing a theoretical model of agricultural insurance, and by conducting numerical simulations of the model.

Simulation results indicated that insured farmers use less agricultural inputs than uninsured farmers in an attempt to maximize expected indemnities. Moral hazard was found to be a significant problem only at higher coverage levels. Expected returns (in terms of expected indemnities) to agricultural insurance were found to vary substantially between productivity (i.e., risk) types, and farmers were shown to recognize and respond to these differences. These results suggest that crop insurance is confronted with an adverse selection problem. Simulation results further indicated that program costs to a myopic insurer attributed to moral hazard and adverse selection could be substantial.

A Model of Agricultural Insurance in Evaluating Asymmetric Information Problems

I. Introduction

Insurers offering contracts to prospective agents normally face two problems as a result of asymmetric information; adverse selection and moral hazard. Rothschild and Stiglitz (1976), Wilson (1977), and Stiglitz (1977) examine insurance contracts with adverse selection. Under adverse selection the informational asymmetry arises because insureds have private information about their exogenous accident probabilities, but insurers do not have access to such information¹. As a result, insurers are unable to distinguish among individuals under hidden type asymmetric information. Because of the insurer's inability to categorize between risk types, Rothschild and Stiglitz (1977) show that if a pooling contract is offered, the low risk types would be more likely to opt out of insurance since the high risk types impose a higher cost on the premium. For a myopic insurer this is a problem as the high risk types behaviour, with insurance, is to use less inputs compared to no insurance. This in turn imposes a higher cost to the insurer of any coverage level than would be implied by any low risk types behaviour. Consequently, the actuarial structure of the policy as perceived or measured by insurers will no longer be valid, and losses may result.

Moral hazard refers to a problem whenever the insureds have a disincentive to supply proper amounts of productive inputs when their actions cannot be observed and contracted for directly. Moral hazard may alter input use in a way that deviates from social optimality because of incompatible incentives (Holmstrom, 1982). Arrow (1963) defined incompatible incentives in the context of moral hazard as those incentives that induce insured people to take fewer precautions against harm. These actions cannot generally be monitored by the insurer, and increase the probability and/or size of losses for which corresponding penalties cannot be levied by insurers (Smith and Goodwin, 1996).

Moral hazard is an example of economic interaction involving imperfect observability. Since the insurer

¹ *This is a true statement for moral hazard when the insurer cannot observe the insureds loss probability , because the insurer cannot observe the level of self-protection.*

cannot observe certain actions taken by the insured, these actions in turn have an effect upon the insurer's pay off. Hence, once insurance is purchased, the insured acts in a manner that increases the probability of loss that in turn enhances the likelihood of a large claim being filed by the insured (Rubinstein and Yaari, 1983). Such insurance contracts enhance the inefficiency caused by moral hazard. Since the resource use under moral hazard deviates from social optimality, in turn this inefficiency could impose substantial program costs. The problems associated with moral hazard and adverse selection that affect the efficiency and equity of an agricultural insurance program have major implications for farm level decision making and public policy formulation. The relationship between efficiency and equity and the program costs of the current agricultural insurance policies due to problems of moral hazard and adverse selection have not been well documented (Islam, 1996). Rather, informational asymmetry may be reducing the welfare of agents and society as a whole because agents receive less than full coverage, and devote a sub-optimal level of resources to loss prevention (Stewart, 1994).

The main motivation of this paper is the recognition of the fact that asymmetric information in the form of moral hazard and adverse selection results in sizeable efficiency losses. These costs are passed back to producers in the form of excessively high premium rates and also passed back to the government via the crop insurance subsidy program. A secondary motivation stems from a recent debate in the literature regarding the effects of moral hazard on agricultural input use. Horowitz and Lichtenberg (1993), in an econometric study, found that the purchase of crop insurance induced U.S. Midwest corn producers to increase their agricultural chemical use more than farmers who did not purchase insurance. In contrast, Smith and Goodwin (1996) found that insured wheat producers in Kansas used less agricultural inputs than uninsured farmers which may be the result of the former farmers attempting to maximize expected indemnities. In a recent paper, Babcock and Hennessy (1996), also analyzed the issue of input demand under insurance using simulation techniques and obtained results similar to Smith and Goodwin in that insurance has a negative impact on input use. The primary goal of this paper is to develop a model of agricultural insurance in evaluating asymmetric information problems such as moral hazard and adverse selection.

The paper is arranged in five sections. A model of decision making with output uncertainty and no

insurance market is presented in section II. Section III presents a model of agricultural insurance in an expected utility theoretic framework using specific examples. This section further presents the conjecture and corollaries developed using the results of the comparative static analysis. Simulations results and discussions pertaining to moral hazard and adverse selection problems are presented in section IV. Finally conclusions and policy implications are drawn in section V.

II. A Model of Optimal Input Use Without Agricultural Insurance

In this section, a model of optimal input use in the context of the no insurance scenario is developed. The purpose of developing this model is to compare and characterise the level of input use with and without insurance that will eventually lead to a greater understanding of moral hazard and adverse selection and allow for the computation and evaluation of related program costs.

Let us start with a very simple model of production; one random variable, which is the yield outcome, one unobservable variable input, x , the state of nature, ω , and an agent type specific parameter, θ . Output is related to that single input (x), farm productivity type θ , and the state of nature ω , with higher ω being more favourable, i.e., $\partial y/\partial \omega > 0$. We further assume that the insurer does not have any information about x or ω or θ . Now, let us specify the production function as follows:

$$\tilde{y} = f(x, \omega, \theta) \tag{1}$$

Before knowing the true state of nature, ω , a producer chooses an input level (x). Let us assume that the firm maximizes the expected utility of profits. Let $U(\cdot)$ be the firm's von Neumann - Morgenstern utility function where $U'(\cdot) > 0$ and $U''(\cdot) < 0$. When individual coverage crop insurance is not available, then a rational producer chooses (x) to maximize the following objective function:

$$\mathbf{Max}_x EU(\pi) = P\tilde{y} - rx \quad (2)$$

where $EU(\pi)$ is the farmer's expected utility of profits; π is the profits; P is the output price; and r is the unit cost of input x . Now, let us specify equation (1) by the following simple Cobb-Douglas production function

$$\tilde{y} = x^\alpha \theta \omega \quad (3)$$

where α is the production coefficient; ω is the state of nature which is uniformly distributed between 0 and 1, and θ is a multiplicative shifter. Assume that θ accounts for the adverse selection problem associated with differing productivity types, where $\theta \in \{\theta_L, \theta_H\}$. In other words, $\theta = \theta_L$ for a low productivity type farm and $\theta = \theta_H$ for a high productivity type farm, where $\theta_H > \theta_L$.

The insurer does not know θ a priori and therefore cannot categorize between types (i.e., cannot identify either θ_L or θ_H a priori). The insurer cannot distinguish between farm types but does know there are different types of agents. The insurer does not know whether a given farmer is type θ_L or θ_H , but does assume a presumed fraction of each type coming from the population. For example, the insurer believes that θ_L is the fraction of L- types and θ_H is the fraction of H-types. However, the insured know her type a priori with certainty before buying insurance. For simplicity, it is also assumed that each agent faces (irrespective of types) a cost function $C(x) = rx$ where x is the variable input and r is the unit price of that input.

A simple model of optimal input use without agricultural insurance is now developed using an expected utility framework. *Without agricultural insurance*, a rational producer chooses (x) to maximize the following objective function formed by substituting (3), $\tilde{y} = x^\alpha \theta \omega$, into (2):

$$\mathbf{Max}_x EU(\pi) = \int_0^1 U [Px^\alpha \theta \omega - rx] f(\omega) d\omega \quad (4)$$

For simplicity, we assume that the random variable ω is uniformly distributed between 0 and 1. As a result, the height of the distribution $f(\omega)=1$. We also assume constant returns to scale (i.e., $\alpha=1.0$) in the production process. We use the negative exponential utility function, which exhibits constant absolute (CARA) and increasing relative risk aversion². The form of the negative exponential function is

$$U(\pi) = -e^{-\gamma\pi} \quad (5)$$

where e is the exponential and γ is the risk aversion coefficient. Since $U(\pi)$ is a CARA utility function as specified in (5), and the probability density function $f(\omega)=1$, (4) can be rewritten as

$$\text{Max}_x EU(\pi) = \int_0^1 -e^{-\gamma(Px\theta\omega - rx)} d\omega \quad (6)$$

After integrating with respect to ω , the above objective function can be fully expressed as

$$\text{Max}_x EU(\pi) = \left[\frac{1}{Px\theta\gamma} e^{-\gamma(Px\theta - rx)} - \frac{1}{Px\theta\gamma} e^{(rx\gamma)} \right] \quad (7)$$

The optimal choice of x can be characterized by differentiating equation (7) with respect to x which yields the following first-order condition

$$\begin{aligned} F(x; \theta, P, r, \gamma) &= \frac{\partial EU(\pi)}{\partial x} = \left(\frac{1}{\gamma P x^2 \theta} \right) [e^{(\gamma r x)} - e^{-\gamma(Px\theta - rx)}] \\ &+ \left(\frac{r - P\theta}{Px\theta} \right) e^{-\gamma(Px\theta - rx)} - \left(\frac{r}{Px\theta} \right) e^{(\gamma r x)} = 0 \end{aligned} \quad (8)$$

Simplifying (8) further yields the following

$$\underline{F(x; \theta, P, r, \gamma) = E'U(\pi) = \left(\frac{e^{\gamma r}}{\gamma P x^2 \theta} \right) [e^{-\gamma P x \theta} (x\gamma r - x\gamma P \theta - 1) + (1 - x\gamma r)] = 0} \quad (9)$$

² The objective function defined in (6) is formulated using a CARA utility function, as an example, because it is more convenient (since π is not equal to $-\infty$ to $+\infty$), and we do not have to worry about the negative outcome of some states of nature and therefore, would be a reasonable choice for this particular problem addressed in this study and would be easy to adopt in our simulation exercises.

Solving the above first-order condition (FOC) implicitly for x results in the utility maximizing input demand function. Since by (9), $\partial F/\partial x \neq 0$, the implicit function theorem suggests that an implicit solution for x may be found from the first order condition specified in (9) and can be implied by the following relationship

$$x_{NI}^* = x(\theta, P, \gamma, r) \quad (10)$$

Under certain conditions provided by the implicit function theorem (i.e., $\partial F/\partial x \neq 0$), the implicit function as specified by (10), implies that there is an input demand function, such as $x_{NI}^* = x(\theta, P, \gamma, r)$ and that its derivatives $\partial x/\partial \theta$, $\partial x/\partial P$, $\partial x/\partial \gamma$, and $\partial x/\partial r$ can be calculated using the relationship specified in (11a) through (11d).

Comparative Static Results

The question this section addresses is how agricultural input demands respond to changes in the exogenous variables, θ , P , γ and r . Under the neo-classical theory of production with certainty, one would expect that a rise in output price evokes an increase in input use ($\partial x/\partial P > 0$), and a rise in that input price evokes a decline in the use of that input ($\partial x/\partial r < 0$). One might also expect that the firm's productivity type and land quality would affect input use positively ($\partial x/\partial \theta > 0$). While the farmer's degree of risk aversion affecting input use negatively ($\partial x/\partial \gamma < 0$). To determine the relationship between x and θ , P , γ and r , the FOC specified in (9) is totally differentiated³.

³ Totally differentiating (9) with respect to all arguments such as θ , P , γ and r will yields the following relationship: $dF = (\partial F/\partial x)dx + (\partial F/\partial \theta)d\theta + (\partial F/\partial P)dP + (\partial F/\partial \gamma)d\gamma + (\partial F/\partial r)dr$, where setting $dF = dP = d\gamma = dr$ to zero, one would find $dx/d\theta$ as specified in (11a). In an analogous manner, we would be able to determine dx/dP , $dx/d\gamma$, and dx/dr as specified in (11b), (11c) and (11d) respectively setting the relevant total partials equal to zero.

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial \theta} d\theta = 0 \Rightarrow \frac{dx}{d\theta} = - \frac{\frac{\partial F}{\partial \theta}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (11a)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial P} dP = 0 \Rightarrow \frac{dx}{dP} = - \frac{\frac{\partial F}{\partial P}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (11b)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial \gamma} d\gamma = 0 \Rightarrow \frac{dx}{d\gamma} = - \frac{\frac{\partial F}{\partial \gamma}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (11c)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial r} dr = 0 \Rightarrow \frac{dx}{dr} = - \frac{\frac{\partial F}{\partial r}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (11d)$$

Following (11a to 11d), if $\partial F/\partial \theta$, $\partial F/\partial P$, $\partial F/\partial \gamma$, and $\partial F/\partial r$ can be signed, then we would be able to determine the sign for $dx/d\theta$, dx/dP , $dx/d\gamma$ and dx/dr respectively. For this particular problem, the denominator (i.e., $\partial^2 EU(\pi)/\partial x^2$) in each of the above equations would be unambiguously negative (i.e., $\partial F/\partial x = \partial^2 EU(\pi)/\partial x^2 < 0$) at a local maximum for x according to the second order condition. Therefore, in (11a to 11d), $dx/d\theta$ to dx/dr will have the same sign as $\partial F/\partial \theta$ to $\partial F/\partial r$. After simplifying, the comparative static results are ⁴.

⁴ For notational convenience, each of the following equations we defined $M = e^{\gamma P x \theta} (x \gamma T - x \gamma P \theta - 1) + (1 - \gamma \lambda r)$ and from the first order condition specified in (9) it is clear that $e^{\gamma P x \theta} (x \gamma T - x \gamma P \theta - 1) + (1 - \gamma \lambda r) = 0$.

$$\frac{\partial F}{\partial \theta} = -e^{\gamma x r} \left[\frac{M + (\gamma^2 P x^2 \theta r) e^{-\gamma P x \theta} - (P^2 \gamma^2 x^2 \theta^2) e^{-\gamma P x \theta}}{\gamma P x^2 \theta^2} \right] > 0 \quad (12a)$$

$$\frac{\partial F}{\partial P} = -e^{\gamma x r} \left[\frac{M + (\gamma^2 P x^2 \theta r) e^{-\gamma P x \theta} - (P^2 \gamma^2 x^2 \theta^2) e^{-\gamma P x \theta}}{\gamma \theta P^2 x^2} \right] > 0 \quad (12b)$$

$$\frac{\partial F}{\partial \gamma} = e^{\gamma x r} \left[\frac{M + (\gamma^2 x^2 r^2) e^{-\gamma P x \theta} - (2r P \theta \gamma^2 x^2) e^{-\gamma P x \theta} - \gamma^2 x^2 r^2 - (\gamma^2 x^2 P^2 \theta^2) e^{-\gamma P x \theta}}{\gamma^2 P x^2 \theta} \right] < 0 \quad (12c)$$

$$\frac{\partial F}{\partial r} = \left(\frac{e^{\gamma x r}}{P x \theta} \right) (M) + \frac{(\gamma x) e^{\gamma x r}}{\gamma P x^2 \theta} (e^{-\gamma P x \theta} - 1) < 0 \quad (12d)$$

where $M = e^{-g P x q} (x g r - x g P q - 1) + (1 - g x r)$

From (12a), it is shown that $\partial F / \partial \theta$ will be unambiguously positive, implying that marginal utility of profit increases with productivity. As a result, following (11a), $dx/d\theta$ will be positive as well, since $dx/d\theta$ will have the same sign as $\partial F / \partial \theta$. For $dx/d\theta > 0$, implies that input use has a positive relationship with land quality and farm's productivity. From (12b), $\partial F / \partial P$ is found to be positive, implying that marginal utility of profit increases if output price goes up. Therefore, following (11b), dx/dP will be positive as well so that input use increases as output price increase. Following (12c), it is shown that $\partial F / \partial \gamma$ is unambiguously negative which implies that marginal utility of profit decreases with increased risk aversion. Since $\partial F / \partial \gamma$ is negative, following (11c), it can be shown that $dx/d\gamma$ will have the same sign as $\partial F / \partial \gamma$, i.e., $dx/d\gamma < 0$, which implies that the higher the degree of risk aversion the lower the level of input use. Finally, following (12d), it is clear that $\partial F / \partial r < 0$ implies marginal that the utility of profit decreases with increased per unit input cost. Therefore, following (11d), dx/dr will be unambiguously negative (since dx/dr will have the same sign as $\partial F / \partial r$), which establishes the conventional relationship between x and r .

III. A Model of Optimal Input Use With Agricultural Insurance

An implicit solution for the profit maximizing input level **without** insurance is given by equation (10). In this section we develop and extend the above model considering the possibility of agricultural insurance. We can then compare the no insurance case solution with the solution derived under individual coverage agricultural insurance in terms of optimal input use, and from this characterize the problems of asymmetric information in agricultural insurance. A simple model of optimal input use decisions under an agricultural insurance contract, in a general framework, is developed in the following section:

The Model Formulation and Implications:

As defined earlier, the information on the state of nature is given by the variable ω , and for simplicity we assume that ω is uniformly distributed between 0 and 1⁵. Therefore, the probability density function, $f(\omega)$, is equal to 1. We further assume that the insurer does not have any information about x or ω or θ *a priori*⁶.

Let us define y_c as the critical yield level so if actual yield (y) falls below the critical yield (y_c) [i.e., $y < y_c$], the insurer makes up the difference. In this situation the insured obtains an indemnity, $P_e(y_c - y)$ because of yield short fall, where P_e is the elected price level on which insurance is determined. Also, consider the same production function as specified in (3), $\tilde{y} = x^\alpha \theta \omega$, where θ and ω is defined in section II. Let us represent the cost of insurance (i.e., premium cost) as r . Now the insured's profits under agricultural insurance can be defined as

$$\begin{aligned} \pi &= Py_c - rx - \rho \text{ if } y < y_c \text{ (i.e., if } x\theta\omega < y_c) \\ &= Py - rx - \rho \text{ if } y \geq y_c \text{ (i.e., if } x\theta\omega \geq y_c) \end{aligned} \quad (13)$$

⁵ For the general formulation of the model we use $\omega \in [\omega_L, \omega_H]$ and later we use $\omega_L=0$, $\omega_H=1$ for simplicity, in our specific example. The assumption $\omega \in [0, 1]$ is a very special case about the probability distribution for ω .

⁶ It makes a big difference in terms of strategies that the insurer can take- whether he can observe either ω and/or θ . For example, if ω and θ are observed then x can be inferred from the actual yield. If ω but not θ (or if θ but not ω) can be observed then x can not so easily be inferred. However, if ω can be observed then insurance contracts can be written conditional on ω and non observability of θ will then lead to a true adverse selection (unknown types) problem. Only if both x and ω are not observable (although θ may be observed) will there be a significant deviation between ex ante and ex post outcomes/expectations and a true moral hazard (unknown action) problem. However, if ω , and x are observed, then θ can be inferred from the actual yield. Similarly, if θ , and x are observed, then ω can also be inferred from the

In (13), the output price (P) is assumed to be equal to the elected price level (P_e). Also keep in mind that under actuarially fair insurance $\rho = E(\text{Indemnity})$ ⁷. Let $\tau(x)$ be the probability that $y \leq y_c$. This probability clearly depends on input use level, x. Now formally we can define $\tau(x)$ as

$$\tau(x) = Pr[y \leq y_c] = Pr[x\theta\omega \leq y_c] = Pr[\omega \leq \frac{y_c}{x\theta}] = Pr[\omega \leq \omega_c] \quad (14)$$

where ω_c is the critical value of the state of nature, ω when actual yield falls below the critical yield. Alternatively, (14) can be redefined as

$$\tau(x) = \int_0^{\omega_c} f(\omega) d\omega = \int_{\frac{y_c}{x\theta}}^{\frac{y_c}{x\theta}} 1 d\omega = \frac{y_c}{x\theta} \quad (14a)$$

which confirms the tautology that the chance of actual yield falling below the critical yield corresponds to a bad state of nature. From (14a), $\tau'(x) < 0$ (where $\tau'(x) = \partial\tau(x)/\partial x = -(y_c\theta)/(x\theta)^2 < 0$). If x increases, output also increases, thereby reducing the probability that $y \leq y_c$ holding risk constant (i.e., the relevant yield distribution can be thought of as mean augmenting but variance preserving). The probability distribution for ω , $f(\omega)$, in conjunction with the level of input used, x, induces a probability distribution on output y, $h(y)$. Let us define $h(y)$ to be the height of the probability distribution function for y. Formally, the expected utility maximization problem **with agricultural insurance** can be specified by the following objective function:

$$\text{Max}_x EU(\hat{\pi}) = \tau(x) U(Py_c - rx - \rho) + \int_{y_c}^{\bar{y}(x,\theta)} U(Py(x) - rx - \rho) h(y) dy \quad (15)$$

where $\bar{y}(x,\theta)$ is the maximum attainable yield given x and θ . The maximum yield $\bar{y}(x,\theta)$ for x occurs at the value $\omega=1$ and so $\bar{y}(x,\theta)=x\theta$. The insured's profit is comprised of two terms: the first term, $\tau(x) U(Py_c - rx - \rho)$ falls as x rises but the second term, $\int U(Py(x) - rx - \rho) h(y) dy$, does not necessarily fall as x rises. In equation (15), let's define

actual yield as well.

⁷ This will be so under actuarially fair insurance, however, here we want to consider other possibilities as well. If high and low productivity types are offered the same insurance contract, which may lead to adverse selection problems, then it would not be the case that $\rho=E(\text{Indemnity})$ for either type.

the first term of RHS as term T_1 and the second term of RHS as term T_2 . T_1 can alternatively be defined as the benefit (pay off) part of insurance if actual yield falls below the coverage yield (i.e., $y \leq y_c$) and corresponds to bad states of nature (i.e., $\omega \leq \omega_c$) in which the insured receives an indemnity. The first term occurs only when the actual yield fall below the coverage yield and the farmer collects an insurance payment. Using less input (which will drive y to falls below y_c for higher values of ω) can trigger that benefit. Moreover, even if x is sufficiently high, a very low ω (low yield) may also trigger that benefit. Intuitively, the benefit part of the insured's profit function associated with collecting an insurance payment decreases as he increases his input use level (provided that increasing input use is risk reducing).

The type specific parameter θ plays an important role, particularly by affecting both the first and second terms of the insured's profit function as specified in (15). The parameter θ has a positive relationship with insured's profit in terms of the second term of the profit function. However, a higher θ has a negative effect on the first term of farmer returns as specified in (15). By definition $\tau(x) = y_c/x\theta$, so if θ increases, the probability of collecting an indemnity decreases since $\tau'(\theta) = -(y_c x)/(x\theta)^2 < 0$, because τ is also a function of θ . In other words, the higher the productivity of the farm, the lower the probability that actual yield falls below the coverage yield. The impact of θ on the first term of (15) could be either less than or equal to zero (i.e., $\partial\pi/\partial\theta \leq 0$), but, $\partial\pi/\partial\theta$ must be positive in regards to the second term of (15). Thus, the net effect on profits from a change in productivity type under an optimal choice of x is ambiguous.

The objective function specified in (15) can be reexpressed in terms of the probability density function (pdf) for ω as

$$\begin{aligned} EU(\hat{\pi}) &= \tau(x) U(P y_c - rx - \rho) + \int_{\omega_c}^{\bar{\omega}} U(Py(x) - rx - \rho) d\omega \\ &= \left(\frac{y_c}{x\theta} \right) U(P y_c - rx - \rho) + \int_{\frac{y_c}{x\theta}}^l U(Py(x) - rx - \rho) d\omega \end{aligned} \quad (16)$$

In (16), the probability of collecting an indemnity (i.e., $\tau(x)=y_c/x\theta$) must be bounded between 0 and 1. It is clear from (16) that an increase in x reduces $\tau(x)$ (since $\tau(x)=y_c/x\theta$) and $U(Py_c -rx-\rho)$ and so clearly $dT_1/dx < 0$. This is intuitively obvious since the greater input one uses, the less the chance the individual will make use of the insurance program⁸ (i.e., there is a chance of collecting lower expected indemnities) as actual yields are increased, everything else being equal. Moreover, higher input use increases costs with no compensating advantage for states of the world in which the insured's actual yield falls below the critical yield (i.e., $y < y_c$) and yields are bumped up to y_c regardless of the level of x . This suggests that with insurance there will be a point of input reduction which leads the farmer to use no input at all. In other words, if the coverage level increases, the likelihood of extreme moral hazard would also increase. Note that MPP_x is equal to zero for $y \leq y_c$. So that using less input will always increase the benefit (i.e., the chance of collecting higher expected indemnities) of having insurance.

The effect of input usage on T_2 (i.e., the second term of RHS in equation 16) is not as obvious as on T_1 . T_2 explains the expected utility of profit an insured farmer could obtain if actual yield is above the critical yield (i.e., $y > y_c$) and corresponds to good states of nature (i.e., $\omega > \omega_c$) in which no indemnities are paid. In T_2 increasing x increases the yield conditional on ω , but also the cost of production. Also, for greater x we have a greater range of states of world, $\omega \in [y_c/x\theta, 1]$, in which the insurance policy provides no benefits. This increases the benefits (since increasing x , increases profits until $MPP_x = r/P$) from using more input when MPP_x is positive.

Using CARA, the expected utility maximization problem specified in (16), can be re-specified as

$$\text{Max}_x EU(\hat{\pi}) = - \left(\frac{y_c}{x\theta} \right) e^{-\gamma(Py_c - rx - \rho)} + \int_{\frac{y_c}{x\theta}}^1 - e^{-\gamma(Px\theta\omega - rx - \rho)} d\omega \quad (17)$$

⁸ This may be generally true. If increased application of an input raises $E(Y)$ and variance, however, this may not actually increase the likelihood that insurance indemnities will be collected. Because within a single planting year, the critical yield (y_c) that triggers indemnity under the existing Multiple Peril Crop Insurance (MPCI) program is determined by a farm's yield history. Therefore, any increase in $E(Y)$ due to increased use of an input basically reduces the probability that actual yield will fall below the coverage yield, which in turn lowers the probability that indemnities will be collected.

After integrating the second term of RHS of equation (17) with respect to the random state of nature ω , the above maximization problem can be expressed fully as

$$\text{Max}_x EU(\hat{\pi}) = - \left(\frac{y_c}{x\theta} \right) e^{-\gamma(P y_c - rx - \rho)} + \frac{I}{Px\theta\gamma} \left[e^{-\gamma(Px\theta - rx - \rho)} - e^{-\gamma(P y_c - rx - \rho)} \right] \quad (18)$$

Differentiating (18) with respect to x and after collecting terms, results in the following first order condition

$$\begin{aligned} F(x; \theta, P, r, \gamma, \rho, y_c) = \\ \frac{\partial EU(\hat{\pi})}{\partial x} = \left(\frac{y_c}{x^2\theta} \right) e^{-\gamma(P y_c - rx - \rho)} [I - xr\gamma] + \frac{I}{P x^2 \theta \gamma} \left[e^{-\gamma(P y_c - rx - \rho)} - e^{-\gamma(Px\theta - rx - \rho)} \right] \\ + \left(\frac{r - P\theta}{Px\theta} \right) e^{-\gamma(Px\theta - rx - \rho)} - \left(\frac{r}{Px\theta} \right) e^{-\gamma(P y_c - rx - \rho)} = 0 \end{aligned} \quad (19)$$

Simplifying (19) further yields the following

$$\begin{aligned} F(x; \theta, P, r, \gamma, \rho, y_c) = E'U(\pi) = \left(\frac{y_c}{x^2\theta} \right) e^{-\gamma(P y_c - rx - \rho)} [I - \gamma r] \\ + \left(\frac{e^{\gamma(xr + \rho)}}{\gamma P x^2 \theta} \right) \left[e^{-\gamma P x \theta} (x\gamma r - x\gamma P \theta - I) + e^{-\gamma P y_c} (I - x\gamma r) \right] = 0 \end{aligned} \quad (20)$$

$$x_{WI}^* = x(\theta, P, r, y, \rho, y_c) \quad (21)$$

As no explicit function exists for (20) it is impossible to determine the sign of these derivatives (i.e., $\partial x/\partial P$, $\partial x/\partial \theta$, $\partial x/\partial \gamma$, $\partial x/\partial r$, $\partial x/\partial \rho$, and $\partial x/\partial y_c$) by direct means. Instead, simulation models are used to determine the relationships between input demand (x) and P , θ , γ , r , ρ , and coverage level, y_c . From the first-order condition specified in (20), an input demand function under individual coverage agricultural insurance is described by the following implicit function:

The implicit function theorem tells us that as long as $\partial F/\partial x \neq 0$ in equation (20), then at a point $(x^0, \theta^0, P^0, r^0, \rho^0, \text{ and } y_c^0)$ that satisfies $F(.) = 0$, then a plausible input demand function such as $x_{WI}^* = x(\theta, P, \gamma, r, \rho, y_c)$ can be defined in the neighbourhood of that point. Consequently, the derivatives $\partial x/\partial P$, $\partial x/\partial \theta$, $\partial x/\partial \gamma$, $\partial x/\partial r$, $\partial x/\partial \rho$, and $\partial x/\partial y_c$ are also well defined. This, of course, assumes sufficient conditions are satisfied (i.e., $\partial F/\partial x = \partial^2 EU(\pi)/\partial x^2 < 0$).

Comparative Static Results

This section addresses how an individual's input demands respond to changes in P , θ , γ , r , ρ , and coverage level, y_c when he buys insurance. Even in the insurance scenario, one would expect that a rise in output price would evoke an increase in the use of the input and a rise in that input price would evoke a decline in the use of that input. One might also expect that the firm's productivity type and land quality may affect input use positively, with the farmer's degree of risk aversion affecting input use negatively (Babcock and Hennessy, 1996). Moreover, one might also expect that the coverage level (y_c) may affect input use negatively (Babcock and Hennessy, 1996; Smith and Goodwin, 1996), and the cost of insurance (i.e., premium, ρ) may have no impact on input use at all if the premium is unsubsidized. Therefore, one would expect the following comparative static results on input use under insurance:

$\partial x/\partial P > 0$, $\partial x/\partial \theta > 0$, $\partial x/\partial \gamma < 0$, $\partial x/\partial r < 0$, $\partial x/\partial \rho = 0$, and $\partial x/\partial y_c < 0$. With insurance, totally differentiating (20) with respect to θ , P , γ , r , ρ and y_c yields complex and long equations from which determination of signs are impossible using direct means and also difficult to evaluate. Therefore, we will make use of numerical simulation exercises to address this defined by issue. By totally differentiating (20), the relationships between x and θ , P , γ , r , ρ and y_c can be

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial \theta} d\theta = 0 \Rightarrow \frac{dx}{d\theta} = - \frac{\frac{\partial F}{\partial \theta}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (22a)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial P} dP = 0 \Rightarrow \frac{dx}{dP} = - \frac{\frac{\partial F}{\partial P}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (22b)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial \gamma} d\gamma = 0 \Rightarrow \frac{dx}{d\gamma} = - \frac{\frac{\partial F}{\partial \gamma}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (22c)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial r} dr = 0 \Rightarrow \frac{dx}{dr} = - \frac{\frac{\partial F}{\partial r}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (22d)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial \rho} d\rho = 0 \Rightarrow \frac{dx}{d\rho} = - \frac{\frac{\partial F}{\partial \rho}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (22e)$$

$$dF = \frac{\partial F}{\partial x} dx + \frac{\partial F}{\partial y_c} dy_c = 0 \Rightarrow \frac{dx}{dy_c} = - \frac{\frac{\partial F}{\partial y_c}}{\frac{\partial^2 EU(\pi)}{\partial x^2}} \quad (22f)$$

Following (22a to 22f), if we can assign signs on $\partial F/\partial \theta$, $\partial F/\partial P$, $\partial F/\partial \gamma$, $\partial F/\partial r$, $\partial F/\partial \rho$, and $\partial F/\partial y_c$, then we would be able to determine the signs for $dx/d\theta$, dx/dP , $dx/d\gamma$, dx/dr , $dx/d\rho$, and dx/dy_c respectively. For this particular problem, the denominator (i.e., $\partial^2 EU(\pi)/\partial x^2$) in each of the above equations would be unambiguously negative at a local maximum for x according to the second order condition. Therefore, in (22a to 22f), $dx/d\theta$ to dx/dy_c will have the same sign as $\partial F/\partial \theta$ to $\partial F/\partial y_c$.

For example, here we only consider the case $\partial F/\partial y_c$, the relationship between optimal input use and the coverage level because this one is very critical/important for this study. Moreover, the general moral hazard effect of insurance on input choice can also be found from this comparative static result. The effect of coverage level (y_c) on the optimal input use is found by differentiating (20) with respect to y_c yielding the following comparative static result.

$$\frac{\partial F}{\partial y_c} = (\gamma P y_c) e^{-\gamma(P y_c - r x - \rho)} \left[\frac{\gamma x r - 1}{x^2 \theta} \right] < 0 \quad (23)$$

The product of the terms outside the brackets in equation (23) is positive. The denominator inside the brackets is also positive (since $x, \theta > 0$). Under risk aversion the numerator inside the brackets will be negative if and only if $(\gamma x r - 1) < 0$ (i.e., the necessary condition is $\gamma < 1/xr$). Intuitively, higher risk aversion may mean less input with or without insurance. Same as the no insurance scenario, with agricultural insurance, the more risk averse is the insured, the lower will be the input use and subsequently expected yields which increases the relative chance of collecting more expected indemnities. However, this behaviour can not be generally construed as moral hazard

since moral hazard is really the difference in input use between the two environments of insurance versus no insurance. However, the necessary condition $\gamma < 1/xr$ is likely to hold under insurance, which in turn implies $\partial F/\partial y_c$ must be negative and consequently optimal input use decreases with an increase in coverage level (y_c). Based on the comparative static result of the theoretical model that insurance affects input use negatively (i.e., perceived moral hazard), the chance of collecting more indemnities can increase. Consequently, the following conjecture can be stated.

Conjecture 1: *An increase in coverage level (y_c) decreases the optimal level of input use (x) under agricultural insurance for a given level of risk aversion (i.e., $\partial x_{WI}/\partial y_c < 0$), holding risk aversion coefficient, $\gamma = \text{constant}$).*

One corollary can be stated from this conjecture as follows:

Corollary 1: *Using less inputs always increases the benefit (i.e., the chance of collecting higher expected indemnities) of having agricultural insurance, i.e., $\partial EI_{WI}/\partial x_{WI} < 0$.*

Conjecture 1 outlines the conventional moral hazard effect that insurance reduces input use. This theoretical result is consistent with Smith and Goodwin (1996), and Babcock and Hennessy (1996). However, it contradicts with Horowitz and Lichtenberg (1993), as they pointed out that increases in the insurance coverage level (y_c) tend to increase input use because of scale of production risk decreases. The difference between the optimal input use level implied by (21), in the insurance scenario, and (10), in the no insurance scenario, depends on the probability density function for ω , $f(\omega)$, the parameters θ , γ , r and y_c and also depends on the cost of the input (r) and the marginal physical product (MPP_x) of that input. The input level chosen by the insured implied by (21) may be greater or less than that implied by (10). Whether insurance increases or decreases the input use is an empirical issue and will be analyzed and discussed fully through simulation exercises in section IV. As mentioned at the

beginning of the model development that the difference between the level of input use in the no insurance scenario to an insurance scenario will lead to a greater understanding of the moral hazard issue and would allow us to compute and evaluate the relative program costs. Given that, an attempt has been made in the following section to evaluate optimal input decisions and to compute and evaluate the related program costs that may be attributed to the problems of asymmetric information such as moral hazard and adverse selection.

IV. Simulations Results and Discussions⁹

The broad objectives of this paper are to characterize the benefits of agricultural insurance; analyze the issue of optimal input decisions with and without insurance; and simulate and evaluate the program costs attributed to the problems of asymmetric information. To address these issues, a theoretical decision making model with output uncertainty and no insurance was developed and extended to include agricultural insurance in the previous sections. In this section, simulation exercises are designed to evaluate the effects of agricultural insurance on optimal input decisions with asymmetric information and allowing for the computation and evaluation of the consequential program costs related to moral hazard and adverse selection problems. Simulation exercises were performed using the objective functions without and with insurance as specified in (7) and (18) in sections II and III respectively. In model simulations, the following base parameter values were used.

$P = \$5.0$ (per unit output price);
 $r = \$2.0$ (per unit input cost);
 $\theta \in \{1, 2\}$ = productivity index (1 for low productivity type and 2 for high productivity type);
 $\gamma \in \{0.05, 0.5, 1.0\}$ = risk aversion coefficient;
and $x_i = i/100$; $I = 1..2500$.

⁹ A detail description of model simulations procedure, key input equations used, variables parameterized and solutions obtained for the choice variable, x and the expected utility values for moral hazard and adverse selection problems, can be obtained from authors. The software "MathCad PLUS 6.0" was used to perform numerical simulations.

Characterising the Moral Hazard Problem: Optimal Input Decisions

A model of optimal input use in the no insurance scenario as developed in equation (7), and a model of optimal input use under insurance, as developed in equation (18) are used to compute optimal levels of input use, output, premiums, expected indemnities and the program costs of moral hazard and adverse selection. This section presents simulation results pertaining to the moral hazard problem. Conjecture 1 and corollary 1 outlined in section III are supported by the simulation results presented in Tables 1 and 2. All results are derived under the assumption of constant returns to scale.

With no insurance, optimal input use for high productivity types is 9.6 units under the given price and risk aversion assumptions (Table 1), which is graphically expressed in Figure 1. Optimal level of input with insurance at a 10% coverage level for high productivity types is found to be 9.58 units and is depicted in Figure 2. Optimal levels of input without and with insurance at various coverage levels are reported in columns 3 and 4 respectively in Table 1.

Insurance Coverage and Response of Input use

Optimal input use is smaller with insurance from the no insurance scenario. At low coverage levels (i.e., at 10% to 35% in our example), optimal input use with insurance is very close to the no insurance solution (Table 1). For example, input use with insurance at a 35% coverage level is 9.47 units as compared to the no insurance case of 9.60 units. At low coverage levels, the chances of collecting expected indemnities is very low since it is difficult to drive actual yield below the critical yield even if the insured practices extreme moral hazard. Therefore, there is no compensating advantage of lowering input usage significantly when coverage levels are low. However, if coverage levels increase, the likelihood of extreme moral hazard also increases. With insurance, there comes a point of insurance coverage at which the farmer may (theoretically) decide to use no input at all. In the case of high productivity (i.e, low risk) types, the

insured uses no inputs at all with a coverage level at or above 40% (Table 1). Coverage levels at or above 40%, substantially increase the insured's chance of collecting higher indemnities.

At the 35% coverage level where the level of input use of 9.47 units with insurance is close to the no insurance solution of 9.6 units, the expected indemnity (EI_{WI}) that an insured could claim is only \$1.49. At higher coverage levels, EI_{WI} increases at an increasing rate which in turn incurs a higher program costs to the insurer. For example, at a 40% coverage level, expected indemnities with insurance, EI_{WI} is \$19.15, while at a 80% coverage level, EI_{WI} is \$38.35.

Let us explain the case of high productivity types. The rational behind this behaviour is rather straight forward. First, it must be recalled that input demand is an implicit function of expected utility, and from section III it was shown that $\partial x_{WI}/\partial y_c \leq 0$ would hold in general. In Figure 1, $EU(\pi)$ is seen as a concave function of x ; input will increase to the point of maximum expected utility. However, with insurance there are two local maximums as illustrated in Figure 2. The first local maximum is a corner point solution with $x=0$ while the global maximum is that $x=9.58$ units. As coverage level (y_c) increases from 10% to 35% the corner point increases, which implies that there can be expected utility gains to extreme moral hazard. However, this corner solution at no point prior to 35% coverage exceeds the expected utility associated with using approximately 9.5 units of input. In fact, over this range input use declines with an increase in y_c , as predicted in theory, but only marginally.

At about 40% coverage the expected utility from using 0 units of input exceeds the expected utility of using about 9.5 units of input (Table 1), and it becomes the new global maximum. Consequently, around this level of coverage there is a chance from marginal moral hazard to extreme moral hazard, and there is a greater expected utility from insuring and using no inputs, than insuring and using some inputs (recall that for low productivity type, this situation occurs even at a 20% coverage level, Table

2). The reason that this can happen, is because the premium charged under existing insurance, is based on past yield histories and is independent of current optimizing behaviour. The obvious caveats, relating to multi-period monitoring as discussed by Dionne (1983) and Vercammen and van Kooten (1994), is that such behaviour cannot persist. However, simulation results illustrate what could possibly happen if ex post monitoring is not a part of everyday business of insureds. Furthermore, in subsequent periods any moral hazard decisions would only serve to increase yield variance and hence, all other things being equal, increase premium rates.

**Table 1: Characterizing Moral Hazard Under Constant Returns to Scale:
The Case of High Productivity Types**

(Parameter Values: $P=\$5$, $r=\$2$, $\theta=2$, $\gamma=0.05$, and $a=1$ (CRS))

Coverage Level (% of EY)	y_c	Optimal Input Use		Premium (ρ)	Expected Utility of Profit: No Insurance $EU(\pi)$	Expected Utility of Profit: With Insurance $EU(\pi^*)$	Expected Indemnities Under Insurance (EI_{WI})	Program Costs Under Insurance (C_P)
		No Insurance (X_{NI})	With Insurance (X_{WI})					
10	0.96	9.60	9.58	0.12	-0.54	-0.529	0.122	0.001
20	1.92	9.60	9.55	0.48	-0.54	-0.506	0.482	0.002
25	2.40	9.60	9.53	0.75	-0.54	-0.491	0.756	0.006
30	2.88	9.60	9.50	1.08	-0.54	-0.476	1.09	0.01
35	3.36	9.60	9.47	1.47	-0.54	-0.460	1.49	0.020
40	3.84	9.60	0	1.92	-0.54	-0.422	19.15	17.23
45	4.32	9.60	0	2.43	-0.54	-0.384	21.55	19.12
50	4.80	9.60	0	3.00	-0.54	-0.350	23.95	20.95
60	5.76	9.60	0	4.32	-0.54	-0.294	28.75	24.43
65	6.24	9.60	0	5.07	-0.54	-0.271	31.15	26.08
70	6.72	9.60	0	5.88	-0.54	-0.250	33.55	27.67
75	7.20	9.60	0	6.75	-0.54	-0.232	35.95	29.20
80	7.68	9.60	0	7.68	-0.54	-0.215	38.35	30.67
100	9.60	9.60	0	12.0	-0.54	-0.165	47.95	35.95

**Table 2: Characterizing Moral Hazard Under Constant Returns to Scale:
The Case of Low Productivity Types**

(Parameter Values: $P=\$5$, $r=\$2$, $\theta=1$, and $\gamma=0.05$)

Coverage Level (% of EY)	y_c	Optimal Input Use		Premium (ρ)	Expected Utility of Profit: No Insurance $EU(\pi)$	Expected Utility of Profit: With Insurance $EU(\pi^*)$	Expected Indemnities Under Insurance (EI_{wl})	Program Costs Under Insurance (C_p)
		No Insurance (X_{NI})	With Insurance (X_{WI})					
10	0.25	4.92	4.87	0.03	-0.941	-0.941	0.031	0.001
20	0.49	4.92	0	0.125	-0.941	-0.891	2.45	2.32
25	0.61	4.92	0	0.19	-0.941	-0.867	3.05	2.86
30	0.74	4.92	0	0.275	-0.941	-0.844	3.65	3.38
35	0.86	4.92	0	0.375	-0.941	-0.823	4.30	3.90
40	0.98	4.92	0	0.49	-0.941	-0.802	4.90	4.41
45	1.11	4.92	0	0.62	-0.941	-0.783	5.50	4.88
50	1.23	4.92	0	0.77	-0.941	-0.765	6.10	5.33
60	1.48	4.92	0	1.11	-0.941	-0.732	7.35	6.24
65	1.60	4.92	0	1.30	-0.941	-0.716	7.95	6.65
70	1.72	4.92	0	1.51	-0.941	-0.702	8.60	7.09
75	1.84	4.92	0	1.73	-0.941	-0.688	9.20	7.47
80	1.97	4.92	0	1.97	-0.941	-0.675	9.80	7.83
100	2.46	4.92	0	3.08	-0.941	-0.631	12.27	9.19

Fig. 1: Optimal Level of Input Use in No Insurance Case (parameter values: $p = \$5.0$, $r = \$2.0$, $\gamma = 0.05$, and $\theta = 2$)

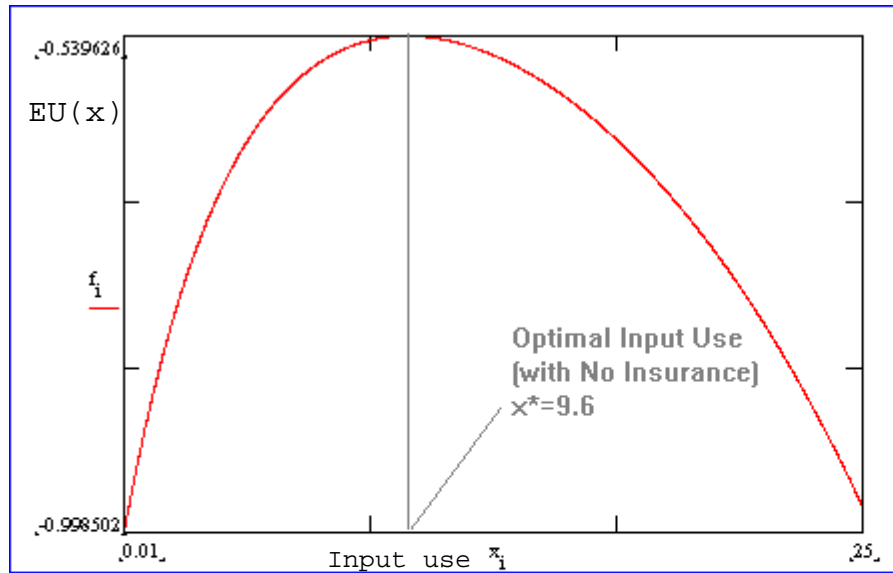
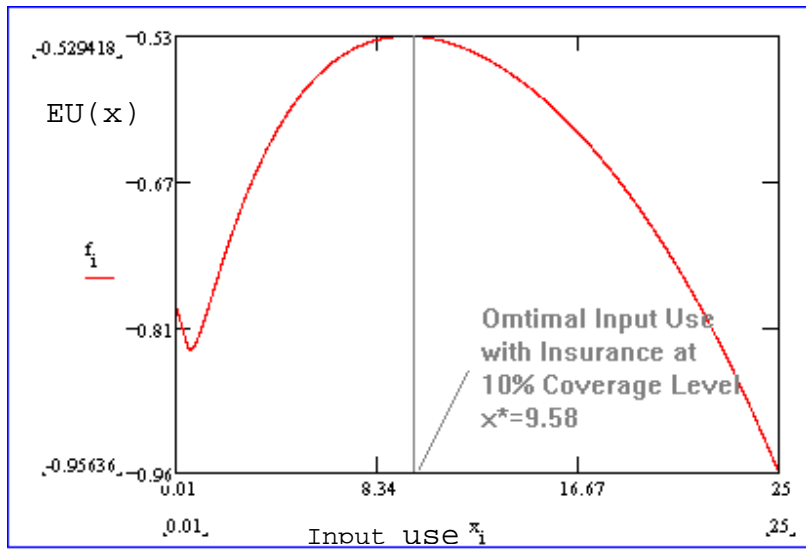


Fig. 2: Optimal Input Use with Insurance at a 10% Coverage Level (parameter values: $p = \$5.0$, $r = \$2.0$, $\gamma = 0.05$, and $\theta = 2$)



Given the structure of the model, and the coefficients used, the results discussed above suggest that moral hazard is a significant problem with crop insurance only at high coverage levels. According to the simulations, at high coverage levels, the expected indemnities to the insured from using no inputs is greater than the returns from using inputs at the no insurance level. The result suggests that the likelihood of moral hazard increases at an increasing rate with insurance coverage. The general conclusion from our simulation results that optimal input use decreases as the insurance coverage level increases, still holds.

The simulation results of this study strongly indicate that agricultural insurance affects input use negatively. This findings is not surprising and is consistent with most previous studies (Smith and Goodwin, 1996; and Babcock and Hennessy, 1996). Our simulation results support the econometric findings of Smith and Goodwin (1996), and the simulation findings of Babcock and Hennessy (1996), who found that farmers who buy crop insurance tend to decrease their agricultural input use compared to the farmers who do not buy agricultural insurance. In addition, the results of the study also indicate that the farmers who buy higher coverage are more likely to practice extreme moral hazard than those who buy insurance at a lower coverage level. The intuition is that at higher coverage, using less inputs (or no inputs at all), increases the probability that actual yields fall below the coverage yield, which in turn increases the chance of collecting expected indemnities.

Program Costs¹⁰ of a Myopic Insurer Attributed to Moral Hazard

Program costs are calculated by taking the difference between the ex post expected indemnity, EI_{wi} , (i.e., that an insured would claim from a particular insurance contract if $y \leq y_c$), and the premium actually charged to the insured, p , and then multiplying it by the elected price level (P_e) for a particular insurance contract¹¹.

Expected indemnities, premiums (p) and the related program costs at different coverage levels for both high and low productivity types are presented in Tables 1 and 2 respectively. The results indicate that there is a substantial difference in program costs at every coverage level between productivity types. For example, at a 20% coverage level, high productivity types impose a cost of only \$0.002 as opposed to \$2.32 by low productivity types since the latter practice extreme moral hazard. In contrast, high productivity types impose a cost of \$30.67 as opposed to only \$7.83 by low productivity types at a 80% coverage level implies program costs should be less until the threshold coverage level.

There are two reasons for such a difference at higher coverage levels. First, high productivity types practice extreme moral hazard at relatively higher coverage levels. Second, the choice of optimal input under the no insurance scenario (based on which p is computed) for high productivity types is significantly higher than for low productivity types. This implies that given the critical yield y_c , the probability of loss under the yield distribution relevant to high productivity types would be substantially higher compared to

¹⁰ Precisely, the program costs of agricultural insurance that can be attributed to the problems of asymmetric information can be broken down into two main components. The first component is associated with only the monetary transfer from public insurers to insureds. This is the result of insurers not being able to costlessly monitor insureds post insurance behaviour or not being able to set an ex ante premium computed based on farmers uninsured behaviour which would be ex post actuarially sound. The second component is associated with the distortion in resource use as a result of implicit moral hazard which would in turn result in sizeable efficiency losses. Thus, the true efficiency loss (i.e., economic cost) of agricultural insurance that can be attributed to the problems of asymmetric information could be substantially higher than the program costs characterized within this model. Therefore, it must be noted that the methods proposed in this study in computing the consequential program costs of moral hazard and adverse selection problems only deals with the first component of true efficiency loss.

¹¹ To conserve space, the methodology to compute program costs of a myopic insurer from moral hazard and adverse selection are not presented here. However, the detail methodology of computing program costs that can be attributed to the problems of asymmetric information such as moral hazard and adverse selection can be obtained from authors.

the yield distribution relevant to low productivity types. This is a general result which will hold if both productivity types faced the same variance ($\sigma^2_H = \sigma^2_L$) or the coefficient of variation ($CV = \sigma/y$) for low productivity types is not greater than that for high productivity types.

Characterising the Adverse Selection Problem

In the previous sections, we characterized the moral hazard problem in terms of input choice and program costs. In this section, the adverse selection problem is characterized in terms of optimal input decisions by productivity types and the consequential program costs given an insurance contract is offered based on pooled premiums. The insurer offers a premium rate based on average losses for a group because of the inability to categorise between risk types. Rothschild and Stiglitz (1976) showed that under pooling contract only high risk individuals would tend to participate in the programs, and low risk individuals would opt out of insurance since the high risk types impose a higher cost on the premium. Along the lines of Rothschild and Stiglitz, the following conjecture can be stated:

Conjecture 2: *An insurance contract that is not actuarially sound (i.e. when premium rates do not accurately reflect loss risk), may lead to an adverse selection problem which in turn increases program costs.*

For this paper, this can also be treated as a proposition and can be tested empirically. To this end, the motivation of this section is to test and evaluate this conjecture based on simulation results pertaining to the adverse selection problem. A simple Cobb-Douglas production function was defined by equation 3, where variable θ accounts for the adverse selection problem associated with differing productivity types. As assumed earlier, the insurer does not know θ a priori and therefore cannot distinguish between types. The insurer's lack of knowledge about productivity types can be described by a presumed fraction of each type coming from the population. To this effect, we hypothesised a premium pooling scenario based on the combinations of high and low productivity types that comprise the population. In this case, we considered

50% of each type comprises the population. Simulation results under this premium pooling scenario are presented in Table 3 and conjecture 2 is fully supported by the simulation results.

Optimal Input Decisions by Productivity Types

In the no insurance scenario, optimal input choices are found to be 9.60 and 0.49 units for high and low productivity types respectively under the given parameter values. In this premium pooling scenario,

Table 3: Characterising Adverse Selection Problem: Optimal Input Use and Program Costs by Productivity Type (Considering 50% of Each Type)

(Parameter Values: $P=5$, $r=2$, $\gamma_H=0.05$, and $\gamma_L=0.5$)

Parameters and Variables	Coverage Levels (% of EY)							
	10	15	25	50	60	70	80	100
Optimal Input Use: No Insurance Case								
High Productivity Type: X_H	9.60	9.60	9.60	9.60	9.60	9.60	9.60	9.60
Low Productivity Type: X_L	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Expected Output (EY)	4.92	4.92	4.92	4.92	4.92	4.92	4.92	4.92
Coverage Level (y_c)	0.492	0.738	1.23	2.46	2.95	3.45	3.94	4.92
Pooled Premium (ρ)	0.62	1.235	2.465	5.54	6.77	8.0	9.235	11.69
Optimal Input Use: Insurance Scenario								
High Productivity Type: X_H	9.59 ^a (-0.553)	9.59 (-0.565)	9.58 (-0.587)	9.53 (-0.621)	9.50 (-0.628)	9.46 (-0.631)	0.01 (-0.593)	0.01 (-0.525)
Low Productivity Type: X_L	0.01 ^b (-0.402)	0.01 (-0.295)	0.01 (-0.16)	0.01 (-0.034)	0.01 (-0.019)	0.01 (-0.01)	0.01 (-0.005)	0.01 (-0.002)
Expected Indemnities: EI								
High Productivity Type: EI(H)	0.03	0.07	0.198	0.795	1.15	1.57	19.64	24.56
Low Productivity Type: EI(L)	2.435	3.665	6.13	12.28	14.745	17.2	19.67	24.59
Program Costs: C_P								
When H- Type Buys Insurance: $C_P(H)$	-0.59 [*]	-1.16	-2.27	-4.75	-5.62	-6.43	10.41	12.87
When L- Type Buys Insurance: $C_P(L)$	1.82	2.43	3.66	6.74	7.97	9.20	10.43	12.89
Total Program Costs (Weighted Average)	0.62	0.64	0.70	0.99	1.18	1.39	10.42	12.88

^{a,b} Expected utility of profits with insurance, $EU(\pi^*)$ for each type are presented in the parentheses underneath the input use. The expected utility of profits with no insurance, $EU(\pi)$ is -0.54 and -0.941 for high and low productivity types respectively.

^{*} Program costs "negative" implies profit gain to the insurer, since in this case $EI_{WI} < r$.

optimal input decisions under insurance for H-types are generally close to the no insurance solution. For instance, at a 10% coverage level, input choice by H-types is 9.59 units under insurance as opposed to 9.6 units in the no insurance case. Even at high coverage levels (eg, 70%), optimal input choice under insurance is 9.46 (Table 3). In contrast, irrespective of coverage level, the optimal input choice under insurance for L-types is only 0 units as compared to 0.49 units in the no insurance case. This result implies that low productivity (high risk) farmers practice extreme moral hazard under insurance with pooled premiums.

The substantial differences in input choice with insurance between productivity types clearly indicates that if premium rates do not accurately reflect loss risks, returns to insurance are distorted and therefore, high risk individuals could increase their chance of collecting higher expected indemnities by choosing no inputs at all. Consequently, they would be more likely to buy insurance at a given premium compared to low risk individuals¹².

¹² We examined the expected utility of profit, $EU(\pi)$, with and without insurance to be able to determine whether insurance will be purchased. Expected utility of profits with and without insurance for both productivity types are computed under pooled premium scenario to determine the insurance purchase decisions between risk types. Results pertaining to the expected utility of profits with insurance are reported in Table 3 in the parentheses underneath the input use. Comparing $EU(\pi)$ with $EU(\pi^*)$ in this premium pooling scenario, it is clear that at a given premium, high risk individuals would be more likely to buy insurance (since $EU(\pi^*) > EU(\pi)$), while low risk individuals would be likely to opt out of the program (since $EU(\pi^*) < EU(\pi)$) irrespective of coverage levels (where $EU(\pi^*)$ and $EU(\pi)$ are respectively the expected utility of profits with and without insurance).

Program Costs from Adverse Selection

As mentioned earlier, if pooled premiums are offered for a particular insurance coverage, low productivity (high risk) agents will be undercharged and high productivity (low risk) agents will be overcharged at that premium. High risk individuals that are undercharged will have higher expected indemnities, while low risk individuals will have lower expected indemnities than premiums. Under such mispricing, high risk types would impose more program costs than low risk types. Simulation results pertaining to the expected indemnity payouts and a single period program costs for a myopic insurer attributed to adverse selection are also presented in Table 3.

The chance of collecting indemnities by productivity types differ substantially for any coverage level at a given premium. For example, at 70% coverage level, the pooled premium assuming equal proportion of productivity types is found to be \$8.0. In the absence of an actuarially sound insurance market, both types receive the same coverage level at that premium. However, there is a substantial difference in expected indemnities given the purchase of that insurance contract at that premium rate. The expected indemnities are \$1.57 for H-types as opposed to \$17.2 for L-types. Given the purchase of that insurance contract, a high productivity type individual would generate a return to the program \$6.43 while it would cost the program \$9.20 (\$17.20 - \$8.00) if a low productivity type would have bought this particular contract.

The total program costs are also reported in the last row of Table 3. For instance, at a 70% coverage level, total program costs under this premium pooling scenario are found to be \$1.39¹³. If the

¹³ These are the weighted average program costs assuming both types would have bought this particular contract at a given pooled premium. However, if we assume that high productivity types will not buy insurance at that pooled premium rate, then the program cost would be \$9.20 rather than \$1.39 at this particular coverage level in this premium pooling scenario.

presumed fraction of high productivity (low risk) types is substantially larger than the fraction of low productivity (high risk) types, then an insurer may gain since in this case the total premium collected will be greater than the total expected indemnity payouts. These results further indicate that if the insurer cannot categorise between types then program costs attributed to adverse selection can be partly explained by the presumed fraction of each type coming from the population in an insured's pool.

Simulation results presented in Table 3 further indicate that the consequence of offering a pooled contract to all agents irrespective of risk types undermine the actuarial soundness of an insurance contract and in turn imposes a substantial single period cost to the insurer since only high risk agents would find such a contract more profitable and therefore, would buy it. The general conclusion from these results is that if premium rates do not accurately reflect the likelihood of loss, returns to insurance are distorted and low productivity (high risk) types are more willing to buy insurance at a given premium rate (i.e., pooled premium) than high productivity (low risk) types.

V. Conclusions

This paper presented a theory of the effect of agricultural insurance on optimal input decisions and also provided simulation results which explain the sources of program costs from moral hazard and adverse selection. Simulation results, within an expected utility framework, indicated that insured farmers use less agricultural inputs than uninsured farmers in an attempt to maximize expected indemnities.

The extent of program costs of moral hazard and adverse selection is being debated in the insurance literature with some academics questioning the relative magnitude of these problems. This research has contributed to the debate by illustrating the costs of moral hazard and adverse selection. Moreover, it provided a methodology which could form the basis of a realistic approach to compute program costs

attributed to moral hazard and adverse selection.

The presence of moral hazard and adverse selection is identified in this paper. Simulation results indicated that the magnitude of program costs to a myopic insurer attributed to moral hazard and adverse selection could be substantial. This paper has demonstrated that existing agricultural insurance contracts are inappropriate in mitigating the severity of moral hazard problem. The results suggest that policy makers and insurers need to direct their attention to various measures, such as ex ante regulation and monitoring, to mitigate moral hazard problems.

Simulation results further indicate that the expected return (in terms of expected indemnities) to insurance was found to vary substantially between productivity types, and farmers were shown to recognize and respond to these differences. This clearly supports the arguments that the existing Crop Insurance is confronted with an adverse selection problem. The implications of this results is that policy makers need to direct their attention to refinements in premium setting techniques in order to address the adverse selection problem.

Finally, the simulation results also indicated that empirical tests are not totally robust to alternative model specifications and risk measures. However, taken as a whole, these simulation results suggest the presence of asymmetric information problems in the existing agricultural insurance contract without casting any doubt in the minds of insurers, policy makers and the researchers.

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