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Moral Hazard Analysis for Crop Yield Insurance Using Loss Prevention Model

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Zarar Önleme Modeli Kullanılarak Bitkisel Verim Sigortası için Ahlaki Tehlike Analizi

Abstract

Farmers play the most critical role in agricultural production, and to keep producing, they must safeguard themselves against the associated risks. Offering an insurance plan designed to fulfil this coverage requirement is crucial. Among agricultural insurance products, crop yield insurance has a unique role since it aims to maintain agricultural production at a specific level, which promotes ecosystem sustainability. The study addresses scenarios of asymmetric information due to the insurer's need for more complete knowledge about the farmer's efforts. It provides solutions for optimal loss prevention efforts and suggests bridging the gap between observable and unobservable efforts. Comparing optimal contracts with observable and non-observable efforts, the marginal benefit in premium reduction is omitted for non-observable efforts. This highlights moral hazard, leading to inefficient crop insurance pricing. The results are generated using the expected utility theory. The certainty equivalent approach is also used to illustrate the results numerically and graphically.

Keywords : Asymmetric Information, Certainty Equivalent, Loss Prevention, Moral Hazard, Optimal Effort.

JEL Classification Codes : D81, D82, D86, G22, Q13.

Öz

Çiftçiler tarımsal üretimde en önemli rolü oynarlar ve tarımsal üretime devam edebilmeleri için kendilerini bununla ilişkili risklere karşı korumaları gerekir. Bu teminat gereksinimini karşılamak üzere tasarlanmış bir sigorta planı sunmak çok önemlidir. Tarım sigortası ürünleri arasında, ekosistemin sürdürülebilirliğini destekleyen tarımsal üretimi belirli bir seviyede tutmayı amaçladığı için bitkisel ürün verim sigortası benzersiz bir role sahiptir. Çalışma, sigortacının çiftçinin çabaları hakkında tam bilgi sahibi olmaması nedeniyle asimetrik bilgi senaryolarını ele almaktadır. Optimum kayıp önleme çabası için çözümler sunmakta ve gözlemlenebilir ve gözlemlenemeyen çabalar arasındaki boşluğu doldurmayı önermektedir. Gözlemlenebilen ve gözlemlenemeyen çabalar ile optimal sözleşmeler karşılaştırıldığında, prim indirimindeki marjinal fayda gözlemlenemeyen çabalar için ihmal edilmektedir. Bu durum, ahlaki tehlikeyi vurgulamakta ve verimsiz ürün sigortası fiyatlandırmasına yol açmaktadır. Sonuçlar beklenen fayda teorisi kullanılarak elde edilmiştir. Kesinlik eşdeğeri yaklaşımı da sonuçları sayısal ve grafiksel olarak göstermek için kullanılmıştır.

Anahtar Sözcükler : Asimetrik Bilgi, Kesinlik Eşdeğeri, Hasar Önleme, Ahlaki Tehlike, Optimal Çaba.

1. Introduction

Purchasing an insurance policy is crucial for farmers who want to maintain an appropriate output level while preventing income loss related to farming operations. Farmers are protected financially from the effects of losses resulting from agricultural production by agricultural insurance. In this way, risks associated with natural disasters and those that could negatively impact a farmer's revenue are covered by standard agricultural insurance policies. Higher indemnity costs are brought on by the extra risks associated with moral hazard and adverse selection, though. Because they know more about their production than the insurer, insureds with asymmetric information receive undeserved benefits. As a result, the insurance provider raises premiums to reduce the detrimental effects of asymmetric information. Higher premium prices discourage people from purchasing agriculture insurance policies, even when the government bears 60% of the cost. The government's assistance with premium payments allowed the traditional agriculture insurance system to continue operating. As a result, by reducing the insured side's behavioural risks or asymmetric knowledge, the global agricultural insurance system's solvency may remain stable.

Numerous studies have examined asymmetric information in crop insurance. Akerlof (1970), Holmström (1979) and Raviv (1979) addressed asymmetric information as a paradigm for market failure. Rothschild and Stiglitz (1978) and Stiglitz (1977) examined adverse selection in the context of monopolies and competition in the insurance market. Liu and Browne (2007) expanded on the study of Rothschild and Stiglitz (1978) and demonstrated how transaction costs affect insurance markets when there is adverse selection. A competitive insurance market model incorporating the connection between insurance fraud and adverse selection was presented by Martin Boyer and Peter (2020). The impact of moral hazard on indemnity payments was examined by Chambers (1989). This study showed an increase in the probability of loss if the insurer cannot watch the insured's behaviour. Because the premium in this instance is not clearly defined, administrative costs are paid in addition to inadequate indemnity payment.

Coble et al. (1997) investigated the insurance choices made by a farmer in Kansas. According to their claims, moral hazard occurs when farmers have a low-producing year. Goodwin (1993) researched the elements influencing farmers' crop insurance decisions and determined demand elasticities for crop insurance. Du et al. (2015) argued that more enormous subsidies and lower premium rates encourage farmers to work less.

Chambers and Quiggin (2002) examined the effects of yield insurance on agricultural productivity by considering a farmer's risk preferences. They concluded that yield insurance and other financial management instruments are similar. Gunnsteinsson (2020) investigated the asymmetric data based on disparate tastes for an identical farmer. According to this study, farmers in insured areas use fewer inputs. Numerous research has been done on the optima crop insurance policy and its effects by Smith and Goodwin (1996), Coble et al. (2000), Mahul and Wright (2003) and Ligon (2003).

Eeckhoudt and Gollier (2005) provide moral hazard considerations, which enable us to model moral hazard in a crop insurance policy. We build on this research to determine the optimal strategy of action for farmers in terms of loss avoidance and mitigation.

Some research considers the certainty equivalent as an alternative to the expected utility theory (EUT). Carter et al. (2007) use the Constant Relative Risk Aversion model to examine farmer preferences. Using a stochastic optimisation model, Berg (2002) employed a mean and variance approach to assess yield insurance and revenue insurance.

Ehrlich and Becker (1972) explored the concepts of self-insurance (loss reduction) and self-protection (loss prevention) within the EU framework. Their study yielded intriguing insights into the interplay among market insurance, self-insurance, and self-protection. According to Dionne and Eeckhoudt's (1985) analysis of risk behaviour, those who are risk averse are more likely to favour loss reduction (self-insurance) than loss prevention (self-protection).

Based on the concept of risk aversion, De Donder and Hindriks (2009) offered a straightforward model with asymmetric information. They showed that risk-averse people are more willing to pay for insurance and take more precautions to lower their risk.

Roll (2019) examined farmers' technical efficiency in Norwegian salmon farming by analysing input utilisation and yield through a stochastic frontier method. The study revealed the presence of moral hazard within the industry.

This study examines how asymmetric information affects agricultural yield insurance's solvency. We offer an optimisation technique to improve a farmer's predicted utility for crop yield insurance. It is thought that the effort made by the farmer affects the frequency of yield loss; that is, it reduces the probability of loss occurrence (loss prevention). Examples of loss prevention include regular medical checkups and the installation of smoke alarms (Seog & Hong, 2024). We address these two scenarios independently, considering that effort might be observable and non-observable. We examine every scenario using the EUT while employing the certainty equivalent (CE) approach, where effort is considered non-observable.

The remainder of the paper is arranged as follows. Section 2 introduces the yield insurance basic model setup to analyse the expected utility to the insured under different conditions. Section 3 presents a method for calculating the optimal effort in the loss prevention scenario in the framework of the optimal contract using both visible and invisible efforts. Numerical examples are presented in Section 4 to assess the implications of the loss prevention model. The CE technique is used to study the insured's behaviour about the risk. Section 5 concludes the study.

2. Main Model Setting of Yield Insurance

The EUT is a widely used tool for studying a person's actions in an uncertainty situation. It is thought that for a farmer who is risk averse, the utility function, U_I, is strictly increasing concave, i.e, $U_I'(.) > 0, U_I''(.) < 0$ and $U_I'(.)$ represents the first derivative (marginal utility).

Whether indemnity payments have been made or not will decide the farmer's wealth at the conclusion of the time. The following attributes describe this wealth:

$$W = W_0 + A[yp_c + I(\alpha) - [1 + \beta(\alpha)][1 - s(\alpha)]P(\alpha)] \quad (1)$$

where W_0 is initial wealth. y denotes the crop yield of the farmer per decare $y \in [0, y_{max}]$, where y_{max} is the highest yield level. harvested area (A) and crop price per decare (p_c) are the respective values. A and p_c are thought to be equivalent to one. The cost of insurance for a specific coverage level, denoted as $P(\alpha)$, is referred to as the crop insurance premium. Additionally, the premium loading factor, represented by $\beta(\alpha)$, accounts for transaction costs, while $s(\alpha)$ reflects the rate at which premiums are subsidised varies based on the chosen coverage level α.

Determining the loss payment $I(\alpha)$ for crop yield insurance involved examining two scenarios. In the first scenario, if the yield y falls below a specified threshold αy^*, the insurer provides an indemnity payment $I(\alpha)$. No payment is paid in any other case. The long-term average yield is shown here by y^*. Consequently, the indemnity payment $I(\alpha)$ was probabilistically momodelledtreating yield insurance akin to a put option, expressed as $I(\alpha) = \max(\alpha y^* - y, 0)$. To simplify the discussion, specific notations were introduced to represent the farmer's end-of-period wealth.

$$W_l = W_0 + y + (\alpha y^* - y) - [1 + \beta(\alpha)][1 - s(\alpha)]P(\alpha), y < \alpha y^* \quad (2)$$

$$W_h = W_0 + y - [1 + \beta(\alpha)][1 - s(\alpha)]P(\alpha), y \geq \alpha y^* \quad (3)$$

In this context, W_l and W_h indicate, respectively, the wealth at the conclusion of the term that is below and above the designated threshold yield. W_h doesn't include a loss payment because the y exceeds the threshold αy^*. The profit of the insured (Π_I) can be described in terms of the contract for crop yield insurance using the formula below:

$$\Pi_I = \begin{cases} (\alpha y^* - y) - [1 + \beta(\alpha)][1 - s(\alpha)]P(\alpha), & \text{if } y < \alpha y^* \\ -[1 + \beta(\alpha)][1 - s(\alpha)]P(\alpha), & \text{if } y \geq \alpha y^*. \end{cases} \quad (4)$$

3. Optimal Effort Level Under Loss Prevention

To lessen the effects of natural disasters, it is proposed that the farmer chooses an effort level e between 0 and infinity while accepting the insurance contract. The level e decreases the probability of risk occurrence, denoted as $\pi(e) \in (0,1)$. It is assumed that $\pi(e)$ exhibits a strictly decreasing and convex behaviour, meaning that as the effort level e

increases, the probability of loss decreases. Moreover, the rate of decrease in probability $\pi'(e) < 0$ is negative while its rate of change $\pi''(e) > 0$ is positive. This reflects that an increase in effort leads to a diminished probability of risk events, and incremental increases in effort result in smaller reductions in the probability of risk occurrence.

The expected utility of the insured in the context of a normal insurance contract is predicated on the idea that the insured is risk-averse and possesses initial wealth, which is designated as W_0, after agreement on the insurance terms. In these cases, the insured pays a premium P to obtain coverage over potential unexpected losses, represented as d. Consequently, if such a loss d occurs, the insured will receive an indemnity payment I. Thus, the expected utility is formulated as:

$$E(U) = [1 - \pi(e)]U(W_0 - P) + \pi(e)U(W_0 - P - d + I) - c(e) \quad (5)$$

In this equation, $U(.)$ denotes the utility function of the insured, while $c(e)$ signifies the cost of effort function e. $c(e)$ is strictly increasing and convex, implying that $c'(e) > 0$ and $c''(e) > 0$. Importantly, the cost of effort $c(e)$ remains constant regardless of whether the risk event occurs. Within this model, it is presumed that the insured can influence the probability of risk occurrence, denoted by $\pi(e)$, which aligns with the concept of loss-prevention.

The utility of the insured, as depicted in equation (5), is based on two scenarios: (a) the probability of the risk occurring, denoted by $\pi(e)$, and (b) the possibility of the risk not occurring, represented by $1 - \pi(e)$. Crop yield insurance requires that the yield (y) fall below a specific threshold (αy^*) to receive compensation. This introduces two distinct outcomes when the risk occurs: low yield and high yield. Consequently, three states are delineated: (i) Risk with low yield ($y < \alpha y^*$) with probability q, (ii) Risk with high yield and no risk ($y \geq \alpha y^*$) with probability $1 - q$, and (iii) No risk The compensations for these states under crop yield insurance are outlined individually in Table 1.

Table: 1
Design of Crop Yield Insurance for Loss Prevention Model

State	Probability	Premium	Indemnity	Wealth
Risk with low yield	$\pi(e)q$	$P(\alpha)$	$\alpha y^* - y$	$W_l = W_0 + y_l + (\alpha y^* - y_l) - P(\alpha)$
Risk with high yield	$\pi(e)(1-q)$	$P(\alpha)$	0	$W_h = W_0 + y_h - P(\alpha)$
No risk	$1 - \pi(e)$	$P(\alpha)$	0	$W_h = W_0 + y_h - P(\alpha)$

Table 1 illustrates the farmer's payouts under crop yield insurance, which are defined as follows: Supposing the probability of the risk occurring is represented by the $\pi(e)$, if the actual yield, y, falls below the predetermined threshold yield, αy^*, (so-called as low yield), the insured receives compensation from the insurer. Conversely, if y exceeds αy^* under the Risk with high yield scenario, no payment is made to the insured. Moreover, if there's no loss $(1 - \pi(e))$, the insured doesn't receive any payment. y_l and y_h denote the farmer's low yield and high yield, respectively. The loading factor $\beta(\alpha)$ and premium subsidy rate $s(\alpha)$ are not treated as functions, as the gross premium case is not accounted for.

3.1. Optimal Contract with Observable Effort

If the farmer's expected utility exceeds their reservation utility U_0 (where $U_0 = [1 - \pi(e)]U(W_0 + y_h) + \pi(e)U(W_0 + y_l)$) represents the utility without crop yield insurance), they will agree to the contract, denoted by $E(U_I) > U_0$ (also referred to as the participation constraint, where U_I denotes the utility with contract). The farmer then determines how much effort to put in after agreeing to the contract, which could be either low or high and incurs different costs ($0 \leq c(e_{low}) < c(e_{high})$).

In this case, it is assumed that the insurer has full insight into the insured's effort level, i.e., the insurer has all the information about what the farmer does. Consequently, $P(\alpha, e)$ can be defined as a function of e, and level α. Thus, based on the three states outlined in Table 1, the expected utility for an insured farmer can be written as:

$$E(U_I) = [1 - \pi(e)]U(W_h) + \pi(e)(1 - q)U(W_h) + \pi(e)qU(W_l) - c(e) \quad (6)$$

where $W_l = W_0 + y_l + (\alpha y^* - y_l) - P(\alpha, e)$ and $W_h = W_0 + y_h - P(\alpha, e)$ represent the insured's wealth for low and high yields, respectively. $[1 - \pi(e)]U(W_h)$ signifies the EU of the farmer in the 'No risk' state, $\pi(e)(1 - q)U(W_h)$ depicts the EU of the farmer in the 'Risk with high yield' state, and $\pi(e)qU(W_l)$ represents the insured's EU in the case of risk and low yield. Equation (6) can be reformulated as follows:

$$E(U_I) = [1 - \pi(e)q]U(W_h) + \pi(e)qU(W_l) - c(e) \quad (7)$$

Equation (7) illustrates two instances where the indemnity payment with probability $\pi(e)q$ and not with probability $1 - \pi(e)q$. Using the EU expressed in equation (7), the farmer selects the optimal e by maximizing the expected utility of their last period wealth:

$$\max E(U_I) = [1 - \pi(e)q]U(W_h) + \pi(e)qU(W_l) - c(e) \quad (8)$$

subject to the condition that ensures zero profit for the insurer, expressed as:

$$P(\alpha, e) - \pi(e)qI(\alpha) = 0 \quad (9)$$

where $I(\alpha) = (\alpha y^* - y_l)$. It is assumed that the insurer operates with zero profit, and the market is characterised by competitiveness. Consequently, the insurer's expected profit is expected to be zero in equilibrium.

Proposition 1. Let the function $\pi(e)$ with $\pi'(e) < 0$, the insurance premium function $P(\alpha, e)$ with $P'_e(\alpha, e) < 0$, and a positive cost function $c(e)$ with $c'(e) > 0$, then the optimal effort e^* exists in the presence of observable effort case where the expected utility is maximum in equation (8) and is determined by the equilibrium condition where the marginal benefit of effort, including both risk prevention and premium reduction, equals the marginal cost of effort.

Proof: The optimal e is obtained by calculating the derivative of equation (8) with respect to e under the condition of zero profit.

$$\frac{\partial E(U_I)}{\partial e} = \pi'(e)q[U(W_l) - U(W_h)] - P'_e(\alpha, e)([1 - \pi(e)q]U'(W_h) + \pi(e)qU'(W_l)) - c'(e) \quad (10)$$

where $P'_e(\alpha, e)$ shows the partial derivatives of $P(\alpha, e)$ with respect to e ($P'_e(\alpha, e) = \pi'(e)qI(\alpha)$). The optimal level of the effort, has to confirm the first order condition, i.e. $\frac{\partial E(U_I)}{\partial e} = 0$. Therefore, equation (10) can be rewritten as:

$$\pi'(e)q[U(W_l) - U(W_h)] - P'_e(\alpha, e)([1 - \pi(e)q]U'(W_h) + \pi(e)qU'(W_l)) = c'(e) \quad (11)$$

high-wealthinal cost of applying additional effort. It is assumed to be positive, indicating that the cost increases as more effort is exerted. The term $\pi'(e)q[U(W_l) - U(W_h)]$ shows the impact of reducing the probability of risk, $\pi(e)$. The marginal benefit comprises the second term of left side , illustrating the marginal benefit in premium reduction as $P(\alpha, e)$ lowers with e. The left and right sides of equation (11) are positive because $\pi'(e) < 0$, $P'_e(\alpha, e) = \pi'(e)qI(\alpha) < 0$ ($q > 0$ and $I(\alpha) > 0$, and $c'(e) > 0$). All of the following: $\pi'(e)q[U(W_l) - U(W_h)]$ can be interpreted as a measurement of the expected utility change. This evaluation takes into account the utility difference between the two states low and high, the probability of the outcome risk with low yield (q), and the sensitivity of the probability $\pi'(e)$. By weighing the difference in utilities between the low and high wealth states, this term captures the benefit of lowering risk and reflects the effect of effort on the probability of the risky event. The term $-P'_e(\alpha, e)([1 - \pi(e)q]U'(W_h) + \pi(e)qU'(W_l))$ represents the advantage gained from a lower insurance premium as effort increases. In this context, $P'_e(\alpha, e)$ signifies that greater effort results in a reduced premium. The term $[1 - \pi(e)q]U'(W_h) + \pi(e)qU'(W_l)$ is a weighted average of the marginal utilities in the two states, considering the probability of the event.

By calculating the derivative of equation (10) concerning e, the requirement for second-order conditional is met.

$$\begin{aligned}\frac{\partial^2 E(U_I)}{\partial e^2} &= \pi''(e)q[U(W_l) - U(W_h)] \\ &- \pi'(e)qP'_e(\alpha, e)[U'(W_l) - U'(W_h)] \\ &- P''_e(\alpha, e)\big([1 - \pi(e)q]U'(W_h) + \pi(e)qU'(W_l)\big) \\ &- P'_e(\alpha, e)[\pi'(e)q(U'(W_l) - U'(W_h)] \\ &+ (P'_e(\alpha, e))^2([1 - \pi(e)q]U''(W_h) + \pi(e)qU''(W_l)) \\ &- c''(e),\end{aligned} \quad (12)$$

To determine the sign in equation (12), the following equations are defined for simplicity:

$$a = \pi''(e)q[U(W_l) - U(W_h)],$$

$b = -\pi'(e)qP'_e(\alpha,e)[U'(W_l) - U'(W_h)]$,

$c = -P''_e(\alpha,e)([1-\pi(e)q]U'(W_h) + \pi(e)qU'(W_l))$,

$d = -P'_e(\alpha,e)[\pi'(e)q(U'(W_l) - U'(W_h)]$,

$f = (P'_e(\alpha,e))^2([1-\pi(e)q]U''(W_h) + \pi(e)qU''(W_l))$.

The signs of variables a,b,c,d,f can be determined based on the following assumptions:

1. $U'(W) > 0, U''(W) < 0$.
2. $U(W_l) - U(W_h) < 0$, $(W_h > W_l)$.
3. $U'(W_l) - U'(W_h) > 0$,
4. $\pi'(e) < 0$ and $\pi''(e) > 0$.
5. $P_{e\prime}(\alpha,e) < 0$ and $P_{e\prime\prime}(\alpha,e) > 0$.
6. $c''(e) > 0$.

Equation (12) can be rewritten as follows using the assumptions provided above:

$$\frac{\partial^2 E(U_I)}{\partial e^2} = \underbrace{a}_{<0} + \underbrace{b}_{<0} + \underbrace{c}_{<0} + \underbrace{d}_{<0} + \underbrace{f}_{<0} - \underbrace{c''(e)}_{>0} < 0 \tag{13}$$

As seen in equation (13), the second-order condition is met at the optimal level e, i.e. $\frac{\partial^2 E(U_I)}{\partial e^2} < 0$. Thus, effort level e is the optimal option for agricultural yield insurance under perfect information.

3.2. Optimal Contract with Non-Observable Effort

In the preceding section, it was explained that the insured must achieve at least the reservation utility U_0 to enter into an agreement with the insurer. The premium was also defined as contingent upon the effort level e. However, in the case of moral hazard, the farmer possesses private knowledge regarding their choice of crop insurance. Consequently, the insurer is unable to observe the farmer's effort e, hence giving rise to the moral hazard problem. In such circumstances, the premium cannot be formulated as a function of effort; it solely depends on the coverage level α, denoted as $P(\alpha)$, rather than $P(\alpha,e)$. In the instance of unobservable effort, the problem can be expressed as follows:

$$\max E(U_I) = [1-\pi(e)q]U(W_0 + y_h - P(\alpha)) + \pi(e)qU(W_0 + y_l + (\alpha y^* - y_l) - P(\alpha)) - c(e) \tag{14}$$

which is subject to the zero profit condition of the insurer:

$$P(\alpha) - \pi(e)qI(\alpha) = 0 \tag{15}$$

Proposition 2. Let the function $\pi(e)$ with $\pi'(e) < 0$, the insurance premium function $P(\alpha)$ independent of e, and a positive cost function $c(e)$ with $c'(e) > 0$, the optimal effort e^* exixts in the presence of observable effort case where the expected utility is maximum in equation (14) and is determined by the equilibrium condition where the marginal benefit of effort, expressed as $\pi'(e)q[U(W_l) - U(W_h)]$, equals the marginal cost of effort $c'(e)$.

Proof: By calculating the derivative of equation (14) with respect to e, the first-order condition can be obtained as follows.

$$\pi'(e)q[U(W_l) - U(W_h)] = c'(e) \tag{16}$$

where $W_l = W_0 + y_l + (\alpha y^* - y_l) - P(\alpha)$ and $W_h = W_0 + y_h - P(\alpha)$. The equality of the left and right sides implies a balance between the marginal benefit and the marginal cost of effort. This equation guarantees that the decision-maker weighs the advantages of loss prevention against the expenses of increasing effort, thereby attaining an ideal effort level in situations where effort cannot be observed and insurance premiums are solely influenced by coverage levels.

The second-order condition is met and written as:

$$\frac{\partial^2 E(U_I)}{\partial e^2} = \pi''(e)q[U(W_l) - U(W_h)] - c''(e) < 0 \tag{17}$$

Clearly, the term $U(W_l) - U(W_h)$ is negative because of the concavity of U, and $\pi''(e) > 0, c''(e) > 0$. Thus, the sign of $\frac{\partial^2 E(U_I)}{\partial e^2}$ is negative.

Analysing equations (11) and (16) to compare the optimal contract outcomes with observable and non-observable efforts is essential. For the case of non-observable effort, the marginal benefit in premium reduction described in equation (11) is omitted. This highlights the implication of moral hazard, resulting in an inefficient pricing mechanism for crop insurance.

This study assumes that the insurer cannot observe the insured's effort, e. To assess the impact of alfa on level e, the total differential of equation (16) with respect to e and alfa must be computed utilising the implicit function theorem.

$$\frac{\partial e}{\partial \alpha} = -\frac{\frac{\partial^2 E(U_I)}{\partial e \partial \alpha}}{\frac{\partial^2 E(U_I)}{\partial e^2}} \tag{18}$$

By calculating the derivative of equation (16) with respect to α with $P(\alpha) = \pi(e)qI(\alpha)$, then $P(\alpha)$ is inserted into equation (16) for W_l and W_h, which results in:

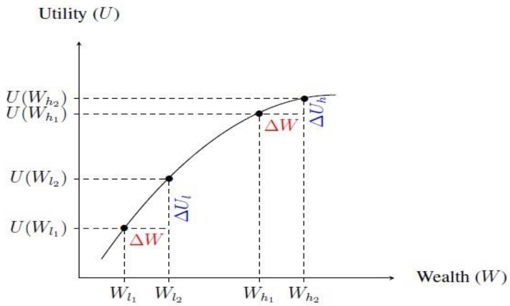
$$\frac{\partial^2 E(U_I)}{\partial e \partial \alpha} = \pi'(e)q[y^*[(1 - \pi(e)q)U'(W_l) + \pi(e)qU'(W_h)]] \tag{19}$$

where $P'(\alpha) = \pi(e)qy^* > 0$, and because of the concavity of U and $\pi'(e) < 0$, this concludes that equation (19) is negative, i.e. $[\frac{\partial^2 E(U_I)}{\partial e^2 \partial \alpha}] < 0$. Hence, equation (18) is negative because the signs in the terms $[\frac{\partial^2 E(U_I)}{\partial e \partial \alpha}]$ and $[\frac{\partial^2 E(U_I)}{\partial e^2}]$ are negative in equations (17) and (19). This results in:

$$\frac{\partial e}{\partial \alpha} = -\frac{\frac{\partial^2 E(U_I)}{\partial e \partial \alpha}}{\frac{\partial^2 E(U_I)}{\partial e^2}} < 0 \qquad (20)$$

According to equation (20), the optimal effort exerted by the farmer decreases as the coverage level α increases. When the farmer is in a low-wealth state, a higher coverage level α yields greater marginal utility compared to that in a high-wealth state, expressed as $U'(W_l) > U'(W_h)$, due to the principle of diminishing marginal utility. Consequently, a higher coverage level α implies that the farmer will exert less effort to attain a high-wealth state, leading to a lack of motivation for farmers to increase their wealth. This conclusion can also be observed in Figure 1. As depicted in Figure 1, as wealth W increases, the additional utility gained diminishes, particularly for higher wealth levels. When the same increment ΔW is applied to two wealth states (denoted as W_l and W_h), the change in marginal utility is greater in the lower wealth state compared to the higher wealth state, expressed as $\Delta U_h < \Delta U_l$.

Figure: 1
Comparisons of the Wealth States Using the Utility Function *U* (strictly increasing, concave)

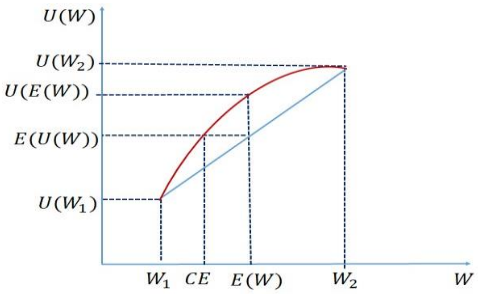


4. Analyzing Loss Prevention under the CE Approach

Here, we will provide numerical examples to assess the impact of the loss prevention model. The EUT is commonly utilised to evaluate farmer preferences, where potential losses are measured in terms of utility. However, in this analysis, we employ the CE approach to examine insured individuals' behaviour towards risk. Unlike EUT, which evaluates outcomes based on utility, CE converts uncertain outcomes into equivalent monetary values. It reflects the fixed sum of money that provides the same utility as the uncertain consequence of potentially greater wealth. CE is determined by $CE = U^{-1}(E(U))$. The EU and CE for a risk-averse person are presented below.

As illustrated in Figure 2, a farmer exhibiting a concave utility function (indicative of risk aversion) favours expected wealth over random wealth outcomes, expressed as. $U(E(W)) \geq E(U(W))$. In Figure 3 above, we observe a scenario where the insured individual is risk-averse, and the CE value is less than the average wealth value. The disparity between the expected wealth $E(W)$ and CE is termed as the risk premium. This is the additional money that an insured individual is willing to pay to reduce the related risk.

Figure: 2
Graphical Representation of CE and EU



Through the CE method, we can assess the efficacy of the models (Zhang, 2008; Luckstead & Devadoss, 2019). Several studies have investigated the CE to model crop insurance using the mean and variance of wealth (Berg, 2002; Sherrick et al., 2004; Gunnsteinsson, 2020).

The following equation is used to calculate the CE of the insured:

$$CE(W) = E(W) - \frac{r}{2} Var(W) - c(e) \tag{21}$$

where $r \geq 0$ denotes the risk aversion coefficient of the insured. $E(W)$ and $Var(W)$ denote the expected wealth and the variance of wealth, respectively Asai and Okura (2011), Shen and Odening (2013).

The loss-prevention model incorporating moral hazard is elaborated on in Section 3. To calculate the CE for this model, we begin by determining the expected value and variance of wealth. The expected value of wealth, denoted as $E(W)$, is defined by the following equation:

$$E(W) = [1 - \pi(e)q]W_h + \pi(e)qW_l \tag{22}$$

where $W_l = W_0 + y_l + (\alpha y^* - y_l) - P(\alpha, e)$, $W_h = W_0 + y_h - P(\alpha, e)$ and $P(\alpha, e) = \pi(e)q(\alpha y^* - y_l)$. Equation (22) can be written as follows:

$$E(W) = [1 - \pi(e)q]y_h + \pi(e)qy_l \quad (23)$$

The variance of wealth is given below:

$$\begin{aligned} Var(W) &= [1 - \pi(e)q](W_h - E(W))^2 + \pi(e)q(W_l - E(W))^2 \\ &= \pi(e)q[1 - \pi(e)q](y_h - \alpha y^*)^2. \end{aligned} \quad (24)$$

When a farmer with an expected low yield holds an insurance policy, αy^* represents the maximum indemnity they could receive from the insurer. Conversely, if the farmer achieves a high yield, the disparity $(y_h - \alpha y^*)$ signifies the portion of indemnity that cannot be obtained through the insurance policy. Consequently, the variance of this difference reflects the loss. Thus, the CE can be expressed as follows:

$$CE(W) = W_0 + [1 - \pi(e)q]y_h + \pi(e)qy_l - \frac{r}{2}\pi(e)q[1 - \pi(e)q](y_h - \alpha y^*)^2 - c(e) \quad (25)$$

Below is a numerical example illustrating the model employing the CE approach. Initially, we examine the correlation between the coverage rate α and the CE across various crop yield levels. The parameters utilised for the CE analysis are outlined in Table 3.

Table: 3
The Parameter Values in the CE

W_0	y_l	y^*	e	$\pi(e)$	q	r
10,000	200	270	0,37	0,4	0,25	2

It is assumed that $\pi(e) = (1 - e)^2 \in (0,1)\ for\ e \in (0,1)$ and $c(e) = e^2$.

Figure: 3
Coverage Effects Under the Different Yield Levels in CE

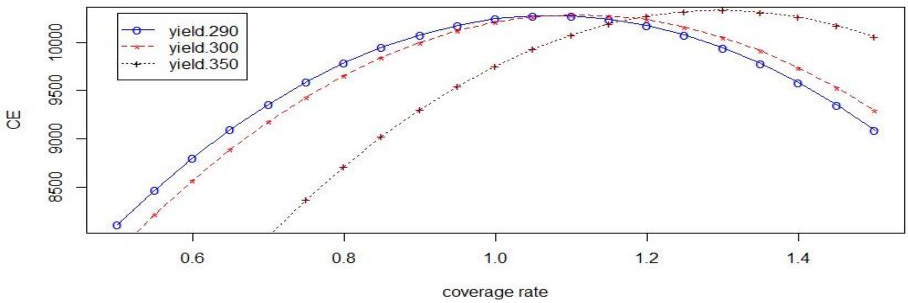


Figure 3 illustrates the Certainty Equivalent (CE) values corresponding to each coverage level α for three different crop yield levels. In this example, we selected three yield amounts: 290, 300, and 350, to examine the relationship between yield level and coverage rate. It's important to note that the chosen values surpass the strike yield level αy^*. Furthermore, we assume that the insured achieves a high yield y_h ($y \geq \alpha y^*$). The table below provides the optimal coverage rates (α^*) along with the associated CE values for the selected yield levels.

Table: 4
Optimal Coverage Levels for the Selected Yield Levels

	$y_h = 290$	$y_h = 300$	$y_h = 350$
α^*	1,05	1,10	1,30
CE	10.275,10	10.287,09	10.332,81

As shown in Figure 3, the optimal coverage rates maximise the CE value. Beyond these optimal coverage rate points (1,05, 1,10, and 1,30, respectively), the CE values for each yield level decrease. Notably, the yield $y_h = 290$ the highest CE value with the smallest coverage rate. A significant inference drawn from this is that the required coverage rate increases as the difference $(y_h - \alpha y^*)$ grows. Because the appropriate coverage rate is lower, the premium is likewise lower at the point $\alpha^* = 1{,}05$. Moreover, $y_h = 290$, the variance of wealth is likewise smaller since the indemnity amount that cannot be obtained from the insurer $(y_h - \alpha y^*)$ is smaller (see to equation (24)). Consequently, the policy utilising the loss-prevention model is more appealing to farmers with $y_h = 290$, which also yields the highest CE value calculated from equation (25). This example can be extended by incorporating various risk aversion coefficients, such as $r = 1; r = 2$ and $r = 4$. The parameters for the analysis are presented in Table 5.

Table: 5
The Parameter Values in the CE

W_0	y_l	y_h	y^*	e	$\pi(e)$	q
10,000	200	300	270	0,37	0,4	0,25

The relationship between the risk aversion coefficients and the CE is represented in Figure 5.

Figure: 4
The CE Values with Different Risk Aversion Coefficients

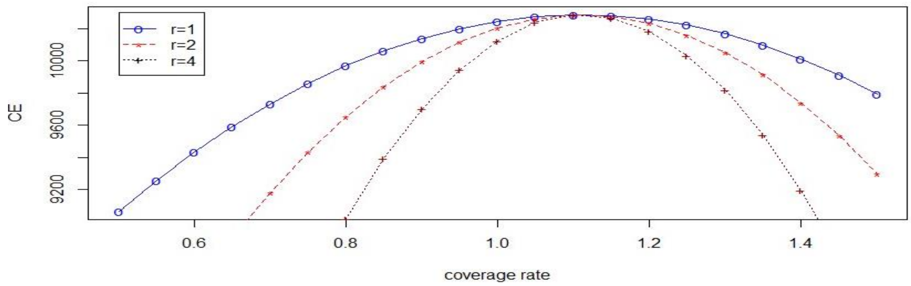


Figure 4 illustrates the relationship between the risk aversion coefficients and the CE. Across all risk aversion coefficients, the highest CE value is achieved at a coverage rate of $\alpha = 1.10$. Notably, the lowest risk aversion coefficient, $r = 1$, yields the highest CE value for all coverage rates. Consequently, individuals with lower risk aversion coefficients may lean towards the policy offered through the loss-prevention model.

At $\alpha = 1{,}10$ the risk aversion coefficients all attain their maximum CE value. For all coverage rates, the risk aversion coefficient with the smallest value, $r = 1$, has the highest CE. Therefore, people with low-risk aversion coefficients may prefer the policy offered using the loss prevention model.

5. Conclusions

This paper explores how a farmer's moral hazard affects the effectiveness of yield insurance. It investigates the optimal level of effort by the farmer to maximise their profit under various scenarios where their effort influences preventing yield loss. Specifically, it addresses situations where the insurer may not have full information about the farmer's effort, leading to asymmetric information. The study's key contribution lies in providing solutions for optimal effort in loss prevention. Furthermore, it suggests accounting for the information gap between observable and non-observable efforts as part of addressing this asymmetry.

By introducing the model loss prevention and employing the EUT, the CE approach facilitates a numerical examination of these models. The efficacy of these models is evaluated through analysis considering various factors such as coverage rates, risk aversion coefficients, crop yield levels, and effort levels. As numerical examples demonstrate, the loss-prevention model may be preferable for farmers facing high risks due to its lower required effort and costs. These models could serve as alternatives to conventional crop yield insurance practices, especially given existing government support for agricultural insurance premium payments. It is suggested that implementing incentive-based pricing models rooted in farmers' effort levels can foster both agricultural and financial sustainability while promoting ecosystem protection instead of relying solely on premium subsidy schemes. In future studies, exploring moral hazard and adverse selection within decision theory entails analysing non-observable risk tendencies. The goal is to integrate asymmetric information and risk perception to determine the optimal farmer effort in agricultural insurance. Extending the proposed methodology would involve obtaining farmer-based data on crop yield and covariates like demographic, socio-economic, and meteorological variables to estimate crop yield while accounting for the farmer's effort.

References

Akerlof, G.A. (1970), “The market for lemons: Quality and the market mechanism. Quarterly”, *Journal Economics*, 84(3), 488-500.

Asai, Y. & M. Okura (2011), “How Do Cost and Regulation Change Loss Control Activities and Insurers' Monitoring?”, *Journal of Insurance Issues*, 34(2), 172-188.

Berg, E. (2002), "Assessing the farm level impacts of yield and revenue insurance: an expected value-variance approach", *Contributed Paper Submitted for the Xth Congress of the European Association of Agricultural Economists (EAAE)*, 28-31 August 2002 Zaragoza, Spain, (August), 28-31. Zaragoza, Spain.

Carter, M.R. et al. (2007), "Underwriting area-based yield insurance to crowd-in credit supply and demand", *Savings and Development*, 31(3), 335-362.

Chambers, R.G. & J. Quiggin (2002), "Optimal producer behavior in the presence of area-yield crop insurance", *American Journal of Agricultural Economics*, 84(2), 320-334.

Chambers, R.G. (1989), "Insurability and moral hazard in agricultural insurance markets", *American Journal of Agricultural Economics*, 71(3), 604-616.

Coble, K.H. et al. (1997), "An expected-indemnity approach to the measurement of moral hazard in crop insurance", *American Journal of Agricultural Economics*, 79(1), 216-226.

Coble, K.H. et al. (2000), "Implications of crop yield and revenue insurance for producer hedging", *Journal of Agricultural and Resource Economics*, 25(2), 432-452.

De Donder, P. & J. Hindriks (2009), "Adverse selection, moral hazard and propitious selection", *Journal of Risk and Uncertainty*, 38(1), 73-86.

Dionne, G. & L. Eeckhoudt (1985), "Self-insurance, self-protection and increased risk aversion", *Economics Letters*, 17(1-2), 39-42.

Du, X. et al. (2015), "Marketing contracts and crop insurance", *American Journal of Agricultural Economics*, 97(5), 1360-1370.

Eeckhoudt, L. & C. Gollier (2005), "The impact of prudence on optimal prevention", *Economic Theory*, 26(4), 989-994.

Ehrlich, I. & G.S. Becker (1972), "Market Insurance, Self-Insurance, and Self-Protection", *Journal of Political Economy*, 80(4), 623-648.

Goodwin, B.K. (1993), "An empirical analysis of the demand for multiple peril crop insurance", *American Journal of Agricultural Economics*, 75(2), 425-434.

Gunnsteinsson, S. (2020), "Experimental identification of asymmetric information: Evidence on crop insurance in the Philippines", *Journal of Development Economics*, 144, 102414.

Holmström, B. (1979), "Moral hazard and observability", *The Bell Journal of Economics*, 10(1), 74-91.

Ligon, E. (2003), "Optimal risk in agricultural contracts", *Agricultural Systems*, 75(2-3), 265-276.

Liu, J.W. & M.J. Browne (2007), "First-Best Equilibrium in Insurance Markets with Transaction Costs and Heterogeneity", *Journal of Risk and Insurance*, 74(4), 739-760.

Luckstead, J. & S. Devadoss (2019), "Implications of commodity programs and crop insurance policies for wheat producers", *Journal of Agricultural and Applied Economics*, 51(2), 267-285.

Mahul, O. & B.D. Wright (2003), "Designing optimal crop revenue insurance", *American Journal of Agricultural Economics*, 85(3), 580-589.

Martin-Boyer, M. & R. Peter (2020), "Insurance fraud in a Rothschild-Stiglitz world", *Journal of Risk and Insurance*, 87(1), 117-142.

Raviv, A. (1979), "The design of an optimal insurance policy", *The American Economic Review*, 69(1), 84-96.

Roll, K.H. (2019), “Moral hazard: the effect of insurance on risk and efficiency”, *Agricultural Economics*, 50(3), 367-375.

Rothschild, M. & J. Stiglitz (1978), “Equilibrium in competitive insurance markets: An essay on the economics of imperfect information”, in: *Uncertainty in Economics* (257-280), Elsevier.

Seog, S.H. & J. Hong (2024), “Moral hazard in loss reduction and state-dependent utility”, *Insurance: Mathematics and Economics,* 115, 151-168.

Shen, Z. & M. Odening (2013), “Coping with systemic risk in index-based crop insurance”, *Agricultural Economics,* 44(1), 1-13.

Sherrick, B.J. et al. (2004), “Factors influencing farmers' crop insurance decisions”, *American Journal of Agricultural Economics,* 86(1), 103-114.

Smith, V.H. & B.K. Goodwin (1996), “Crop insurance, moral hazard, and agricultural chemical use”, *American Journal of Agricultural Economics*, 78(2), 428-438.

Stiglitz, J.E. (1977), “Monopoly, non-linear pricing and imperfect information: the insurance market”, *The Review of Economic Studies*, 44(3), 407-430.

Zhang, L. (2008), “Three essays on agricultural risk and insurance”, *PhD Dissertation*, Department of Economics, Iowa State University.