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ECONOMIC IMPACT OF SCAB WITH ALTERNATIVE RISK MANAGEMENT STRATEGY: THE CASE OF CROP QUALITY INSURANCE IN BARLEY

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Abstract

Managing quality risks, especially grain quality, has been a challenge facing farmers, grain merchandisers, and policymakers for many years. With the advent of genetically modified organisms (GMOs), food safety, and identity preservation, this is even more challenging today. In this paper, an equilibrium crop insurance model was developed and used to analyze the impact of quality risks on equilibrium coverage levels and risk premiums that suppliers of insurance and barley producers would be willing to provide when yield and revenue insurance instruments explicitly incorporate quality risks. The asking price concept and sensitivity analysis were used to evaluate farmers' behavior after they purchase crop quality insurance and to provide guidance and direction in the development of risk-efficient quality insurance instruments.

Key Words: crop insurance, equilibrium coverage levels, Fusarium Head Blight, premium rates, quality risks, risk aversion

ECONOMIC IMPACT OF SCAB WITH ALTERNATIVE RISK MANAGEMENT STRATEGY: THE CASE OF CROP INSURANCE IN BARLEY

E. William Nganje, Napoleon M. Tiapo, and William W. Wilson*

Introduction

Crop insurance programs have escalated in importance as a means to manage risks associated with unexpected events. Conventionally these have focused on two important sources of risk; namely, yield and price level risks. For many crops and regions, the risks associated with quality are particularly important and, at least heretofore, have not been explicitly part of crop insurance programs. For instance, crop insurance payments for barley damaged by Fusarium Head Blight (FHB)[1] covered less than 2 percent of average annual loss ($40 million) to North Dakota farmers since 1993 (U.S. GAO). In this paper, an equilibrium insurance model that incorporates quality losses and risks was developed and applied to the case of malting barley, where quality risks are particularly apparent.

Quality related losses have had significant impacts on producer income and risks. They have resulted in millions of dollars in losses and payments (Hill, Essinger, and Bekric; Johnson et al.; U.S. GAO; Nganje et al.). In some instances, quality related losses have exceeded yield and price losses covered by current insurance instruments. There are two particularly important components of quality risk. These include the impact of quality on yield and price discounts. Both of these have a critically important impact on producer incomes in many crops. In the case of FHB in malting barley, yields have been severely impacted, and price discounts have been large due to buyers being averse to shipments containing greater than nil DON (a mycotoxin associated with FHB causing variability in quality) and related food safety regulations of the Food and Drug Administration (FDA). However, similar problems have and are occurring in other crops and regions. These include, for example, hard red spring wheat and durum in the Northern Plains; each of these grains in Canada; and the periodic outbreaks in recent years of Karnal bundt in hard wheat and durum wheat in the Southern Plains. In each of these cases, the diseases have had devastating impacts on yields, price discounts, and the marketability of the crops. In addition, one of the important aspects of marketing biotech crops is the inadvertent contamination within the marketing system which can affect the marketing of non-biotech crops. Although the analysis in this paper focuses on FHB in malting barley, the methodology developed is applicable to each of these cases.

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[1] An important feature of barley is its distinction between feed and malting barley. Prior to the outbreak of Fusarium Head Blight (commonly known as scab–a fungal disease that affects small grains) and Deoxynivalenol (DON– a mycotoxin associated with scab) in 1993, the malting industry essentially considered the prescribed official grading factors, as well as some non-grading factors, in its evaluation of the quality of malting barley grown. Numerical grades are determined by the factor with the lowest quality, e.g., if all other factors would have qualified for No.1 malting barley and DON levels greater than 4ppm would qualify barley to be considered as feed barley.

FHB evolved to be of great importance as a major quality risk factor during the 1990s. Grain contaminated with DON is subject to FDA advisory limits and is refused by many end-users and/or is subject to severe quality discounts. Losses have been largest in FHB-affected regions of North Dakota and Minnesota but in more recent years there has been significant incidence in other regions as well.[2] Steffenson reported that since 1993, FHB has devastated the barley crops in the Upper Midwest region and has caused serious food safety concerns. In malting barley, DON causes gushing in beer production, affects taste profiles, and, consequently, has been subject to severe market discounts.

DON results in risks to participants throughout the marketing system including producers, end-users, and marketers. Johnson, Wilson, and Diersen studied the impact of DON on logistical costs and procurement strategies in hard red spring wheat. Results illustrate how procurement strategies were impacted by the incidence of DON, and how grain flows were changed, as well as the increased costs and risks. Finally, it is notable that an important impact of the excessive risks of DON in malting barley has resulted in a sharp reduction in production within the United States, a radical shift in production away from traditional regions, and has induced a large amount of imports from Canada. U.S. maltsters and brewers, the traditional buyers of Northern Plains barley, have reacted to FHB by expanding their imports of malting barley from Canada by about 380 percent (U.S. GAO).

This study has two objectives. First, it develops an equilibrium insurance model and uses it to analyze the impact of quality risks on equilibrium coverage levels and risk premium that suppliers of insurance and barley producers would be willing to provide when yield and revenue insurance instruments explicitly incorporate FHB risks. Second, this study uses the asking price concept and conducts sensitivity analysis on farmers' risk aversion and the cost of quality insurance to evaluate farmers' behavior after they purchase crop quality insurance instruments and provides guidance and direction in the design of risk-efficient quality insurance instruments. The rest of the report is divided into four sections. In Section 2 we discuss crop insurance instruments available for barley growers and reasons why these instruments do not explicitly cover quality losses and risks. The models used and data sources are developed and presented in Section 3. Section 4 contains the results from the model and sensitivity analysis. Finally, the core findings are summarized in the conclusion section.

Crop Insurance and FHB Risk

The Federal Agricultural Improvement and Reform (FAIR) Act of 1996 led to a new environment for U.S. growers. The Federal Crop Insurance (FCI) provides growers with insurance protection against yield losses from a variety of natural causes affecting revenue losses (Barnett and Coble). Crop insurance is a federally sponsored risk management program. The Risk Management Agency (RMA) of the U.S. Department of Agriculture (USDA) designs and rates federal crop insurance products that are then sold and serviced by private sector insurance companies. The RMA also subsidizes premiums that growers pay for federal insurance policies. Babcock noted that the overhead cost of crop insurance is incurred by the federal government.

[2] The focus is on all barley producing crop reporting districts (CRDs) in North Dakota with significant quality losses due to FHB, as reported by the U.S. GAO.

The programs include Multiple Peril Crop Insurance (MPCI), Group Risk Plan (GRP), Crop Revenue Coverage (CRC), Revenue Assurance (RA), and Income Protection (IP). The MPCI and GRP provide coverage for production shortfalls while the CRC, RA, and IP provide coverage for revenue shortfalls.

Only the MPCI, IP, and RA are available for malting barley growers (Rain and Hail Insurance Service Inc.). The MPCI, IP, and RA are very similar in design. They are all reinsured, subsidized by the USDA, and use harvest-month futures prices at sign-up and at harvest to compute losses (Coble, Heifner, and Zuniga). However, the RA only provides revenue protection for feed barley. Available since 1938, a revised form of the MPCI was introduced in 1980 covering most crops in the United States. It is a yield-based insurance and the current version is typically referred to as the Actual Production History (APH) program. The MPCI provides protection against shortfalls in a grower's expected yields (or a predetermined yield known as Guarantee). Buschena and Ziegler noted that historically producers could insure crop yields of up to 75 percent of average historic yield (with 80-85 percent available in limited areas). Losses are paid when the actual yield is less than the guarantee (four years APH multiplied by the selected coverage level and the market price). The expected yield is calculated using at least four years of the grower's actual verifiable production records. Growers with less than four years of APH are penalized by receiving less insurance protection per premium dollar. In the case of barley, the four years of historic APH fall within FHB infested years, requiring a comprehensive estimation procedure (Appendix 1) to estimate insurable losses. With the APH, the federal government presently provides low level protection known as catastrophic (CAT) coverage and growers must experience a yield loss of at least 50 percent to receive an indemnity (Barnett and Coble). However, the MPCI and CAT do not explicitly cover losses due to quality risks, especially in the case of FHB (U.S. GAO).

The IP offers barley growers protection against revenue losses caused by low price, low yield, or any combination of the two. The IP eliminates farmers' concerns with MPCI that low prices can adversely affect their overall revenue or profitability even when yields are high. The IP provides downside price protection for barley, by multiplying the APH and the projected county price. However, the IP also does not explicitly cover losses due to FHB. Moral hazard concerns (that may increase costs to insurance agents) or farmers' behavior after they purchase crop quality insurance and the lack of publicly available data on quality losses have been suggested as some major reasons why quality losses are not explicitly covered by current insurance instruments.

With the absence of an explicit form of quality insurance, risks in these markets have been handled in a fairly inadvertent and inefficient manner. First, a significant component of the escalation of disaster payments from the federal government since 1996 has been attributable to losses associated with crop quality issues. Second, there were some ex post interpretations of the CRC program in the case of durum wheat to account for crop quality losses. Third, in many cases, growers have simply absorbed the risks internally. However, given that these crop quality risks in some cases are nearly as great or exceed other forms of risks (Figure 1), the fact that growers have absorbed these risks internally has resulted in a shift in production. For instance, the U.S. GAO reported that FHB losses have contributed significantly to more than a 40 percent reduction in barley acreage since 1993. Finally, in concept, it is possible to envision that these risks are being transferred to end-users via some type of contracting mechanism. However, at least so far, this has not been a common practice. Indeed, part of the risks of quality deviations

are absorbed implicitly by end-users through higher prices in the case of malting barley and durum wheat but, heretofore, these take the form of ex post price adjustments to ration limited supplies of non-disease tainted supplies, in contrast to ex ante premiums/price differentials in contracts and more explicit risk transfer. Likely, the implicit premium necessary for end-users to absorb these risks would be fairly large. It is important that none of these alternatives has resulted necessarily in desirable outcomes and has been a fairly costly way to deal ex-post with crop losses. Ultimately, a third-party quality risk transfer could be a desirable alternative for grain producers.

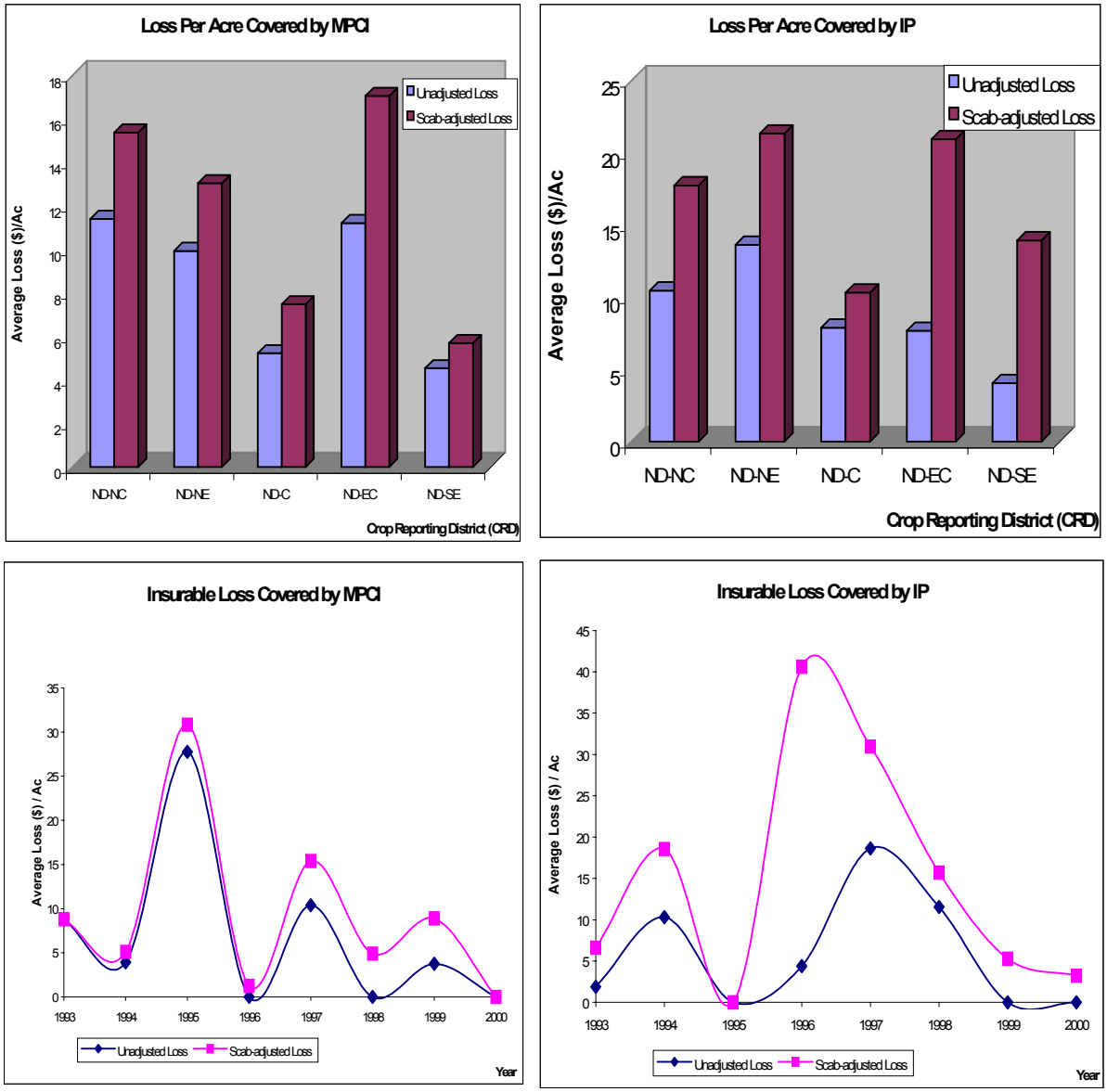

Figure 1. Revenue Loss and Insurable MPCI and IP Loss for an Average North Dakota Barley Grower by CRDs and Year
Source: Data for yield and revenue loss: U.S. GAO and Nganje et al.

The Model

The expected utility maximization framework is used in this study to characterize the utility of private insurance agents and growers, faced with quality risks, and to explain the asking price concept. Analysis consistent with the expected utility theory assumes that each individual has a von Neumann - Morgenstern utility function that allows investment appraisal. If the expected utility criteria is adopted, the question of how much certainty wealth would provide a decision maker with the same satisfaction level as that proportioned by the sum of initial wealth, together with a portfolio of uncertain income $\tilde{x}$, is raised. This concept, certainty equivalent, can be expressed as (Eeckhoudt and Gollier; Serrao and Coelho):

$$(1) \qquad U(W^*) = \int U(W_0 + \tilde{x}) f(x) dx \ .$$

Where, W* is the certainty equivalent, W_0 is initial wealth, $\tilde{x}$ is a portfolio of uncertain income added to initial wealth, U(.) is expected utility of wealth, and f(.) is a density function of $\tilde{x}$. Equation 1 shows what should be the certainty level of wealth level without quality risk (in this context) that originates the same utility level as an investment with quality risk. Equation 1 can be used to derive the level of risk aversion, the risk premium, and the asking price (amount farmers are willing to pay to transfer quality risks). If $U(W^*) > EU(W_0 + \tilde{x})$ for all outcomes of the risky investment and $E(\tilde{x}) = 0$, then the investor's utility function is said to be risk averse (Ingersoll). This definition implies that the utility of wealth is strictly concave at all relevant wealth levels. Using a Taylor expansion with Lagrange reminders for $U(W_0 + \tilde{x})$, the Arrow-Pratt absolute risk aversion function can be written as:

$$(2) \qquad \phi \approx \frac{1}{2}\left[- \frac{U''(W)}{U'(W)} \right] \text{var}(\tilde{x})$$

Where ϕ is the risk aversion parameter, $U'(W)$ and $U''(W)$ are the first and second derivatives of the utility of wealth, and $\text{var}(\tilde{x})$ is the variance of the risky investment. A comparable measure of risk aversion is relative risk aversion, useful in analyzing risks expressed as a proportion of a risky investment. If an individual has greater (less) absolute or relative risk aversion at higher wealth levels, then he or she displays increasing (decreasing) absolute or relative risk aversion. We assume barley growers are risk averse, such that 1) they will either exhibit constant, decreasing or increasing risk aversion to crop quality insurance if investments in quality insurance do not significantly affect their returns, increase and decrease their returns; and 2) growers will be willing to pay a risk premium to transfer crop quality risk to private insurance agents. The risk premium can be derived from the asking price concept. The fair term of exchange between uncertainty $(W_0 + \tilde{x})$ and certainty (W*) is known as the asking price, given in Equation 3 as:

$$(3) \qquad P_a = W^* - W_0$$

Where, P_a is the asking price or the price that an investor is willing to sell the investment (Serrao

and Coelho). A positive asking price implies the investment has a positive effect on wealth, so the decision maker evaluates it positively. A negative asking price implies that the individual is prepared to pay whoever is willing to take the investment. The notion of negative asking price corresponds to the insurance concept, since individuals get rid of an initial risk for payment of a certain monetary amount, the risk premium (Equation 4).

(4) $$\pi = \mu - P_a.$$

Where, π is the risk premium of an additive investment (in this case quality risk), and μ is the expected value of uncertain income (or income without quality variability). The concept of risk premium and asking price can be used to analyze barley growers' behavior after they purchase crop quality insurance, by comparing premiums they are willing to pay with and without quality risks, under three scenarios: no reinsurance, reinsurance, and subsidized reinsurance.

An equilibrium model similar to that of Duncan and Myers, with the exception that the distribution of quality losses across CRDs is different and the covariance between each CRD and the entire state is not identical, was developed to analyze the impact of quality risks on premium levels and to determine the asking price. Other studies (Serrao and Coelho) have used a mathematical programing model to estimate premium rates required by insurance agents and premium rates farmers are willing to pay separately, and then proposed that the difference shown be subsidized by the government. In the United States, however, crop insurance is a federally subsidized program and such an approach will require added complexity to model the impact of quality risk. The equilibrium model developed in this study has three parts: a model to derive the demand for insurance, a model to derive the supply of insurance, and a competitive equilibrium model equating demand and supply to derive equilibrium coverage levels and premiums, with and without reinsurance. The model developed in this paper assumes providers of insurance are risk averse, based on uncertainties (monitoring costs and the catastrophic nature of FHB) or potential moral hazard behavior of growers.

The Demand for Insurance

The problem facing a representative farmer is the choice of coverage level that maximizes their end-of-period income given the quality risk they face. To model this situation, we specify the farmer's end-of-period wealth and use a mean-variance (M-V) preference function (Robinson and Barry) to characterize the demand for insurance that incorporates quality risk.[3] The end-of-period income of farmers who buy insurance that covers quality risk is given by Equation 5.

(5) $$I_{\mathbf{d}} = M - w\varphi_{\mathbf{d}} - (1-\varphi_{\mathbf{d}})l.$$

Where M is a known potential income, $w\varphi_{\mathbf{d}}$ is the insurance premium ($\varphi_{\mathbf{d}}$ is the expected coverage level per acre and w is the premium set by competition in the insurance market), and l is the stochastic loss (l takes the value L with known probability P and 0 with probability 1-P).

[3] Although the M-V framework has some limitations, it is adequate to demonstrate the main results of this study.

The distribution of l will be estimated for MPCI and IP with and without explicit consideration of FHB losses. The basic assumption is that the probability of loss P is known by all participants. This assumption is based on the fact that the RMA mandates that DON data be collected at the time the grains are delivered to the elevator. The M-V specification of the demand for insurance is given by Equation 6.

$$U = M - w\varphi_{\mathbf{d}} - (1-\varphi_{\mathbf{d}})\bar{l} - 0.5\lambda(1-\varphi_{\mathbf{d}})^2\sigma_l^2. \tag{6}$$

Where $\bar{l} = PL$ is the stochastic loss per acre, $\varphi_{\mathbf{d}}L$ *is* the proportion of the loss reimbursed by insurance if there is a FHB outbreak, σ_l^2 is variance of loss, and λ is the risk aversion parameter. The first-order conditions for optimal coverage level for crop insurance with quality risk are given by Equation 7.[4]

$$-w + \bar{l} + \lambda\sigma_l^2(1-\varphi_{\mathbf{d}}) = 0 \tag{7}$$

Equation 7 represents the demand for crop insurance at premium *w,* quality loss $\bar{l}$, and variance of loss σ_l^2 . From Equation 7 it can be observed that the demand for crop insurance decreases as the premium increases, and increases with increases in expected loss, risk aversion (λ), and with variance of loss (σ_l^2).

The Supply of Insurance

Equation 8 presents the end-of-period profits for firms selling insurance to farmers and reinsuring some proportion α of its policies.

$$I_{\mathbf{s}} = n\varphi_{\mathbf{s}}\left[(1-\alpha)(w-c)\right] - \varphi_{\mathbf{s}}(1-\alpha-\delta)\sum_{\mathbf{i}=1}^{n} l_{\mathbf{i}}. \tag{8}$$

Where **s** refers to the supply of insurance, n is the number of policies, *1* -α is the proportion of premium left after reinsurance [the insurance company gives up some proportion, $(0 \le \alpha \prec 1)$, of its premium to a reinsurer, in return, the reinsurer accepts the responsibility to pay some proportion (α+δ) of indemnity with the value of δ satisfying $0 \le \delta \prec 1-\alpha$], and *c* is the insurance costs per acre of coverage. As in the case of the demand for insurance, risk averse insurance firms are assumed to have linear M-V preferences. With Equation 8, the supply for insurance can be written as:

$$V_{\mathbf{s}} = n\varphi_{\mathbf{s}}\left[(1-\alpha)(w-\bar{l}-c)+\delta\bar{l}\right] - 0.5\Theta n\varphi_{\mathbf{s}}^2\sigma_l^2(l-\alpha-\delta)^2\left[1+(n-1)\rho\right]. \tag{9}$$

[4] The second order condition for a maximum is satisfied because $-\lambda\sigma_l^2 \prec 0.$

Where Θ is the risk aversion parameter for the private insurance agents. Duncan and Myers noted that the coefficient of risk aversion is smaller for insurance companies as compared to growers because insurance companies are assumed to be more diversified and larger than barley producers. The estimation of the variance term is presented in Appendix 1A. It can be shown using comparative statics that with the M-V framework, wealth will decrease as Θ increases and remain constant if Θ is equal to zero. The correlation coefficients of losses between any two farmers is ρ, a measure of the catastrophic nature of FHB losses (given by $\frac{Cov(l_i, l_j)}{\sqrt{Var(l_i)Var(l_j)}}$.).

Other assumptions for the supply of insurance are that the values of α and δ are set exogenously by government policy and with no FHB losses ρ = 0. The supply of insurance coverage for a provider who covers FHB losses is given by Equation 10.[5]

$$(10) \qquad (l-\alpha)(w-\bar{l}-c)+\delta\bar{l}-\Theta\varphi_S\sigma_l^2(1-\alpha-\delta)^2\left[1+9n-1)\rho\right]=0$$

From Equation 10 it can be observed that the margin between premium received and cost of insurance is (w – c), and there is no subsidy from the reinsurer when $\delta = 0$. Following Duncan and Myers' specification, the competitive equilibrium in the model with quality risk and subsidized reinsurance is a premium level w^0, coverage level φ^0, and number of policies n^0, which satisfy:

$$(11) \qquad -w^0+\bar{l}+\lambda\sigma_l^2(1-\varphi^0)=0$$

$$(12) \qquad (l-\alpha)(w^0-\bar{l}-c)+\delta\bar{l}-\Theta\varphi^0\sigma_l^2(1-\alpha-\delta)^2\left[1+(n^0-1)\rho\right]=0$$

$$(13) \qquad n^0\varphi^0\left[(1-\alpha)(w^0-\bar{l}-c)+\delta\bar{l}\right]-0.5\Theta n^0(\varphi^0)^2\sigma_l^2(l-\alpha-\delta)^2\left[1+(n^0-1)\rho\right]-b=0$$

Equation 11 is the demand for insurance by a farmer experiencing FHB losses, Equation 12 is the short-run supply for insurance by a competitive firm, and Equation 13 is the long-run equilibrium condition that the preference level of each firm equals the reservation level b (coverage and premium levels without FHB risk). The properties of Equation 13 have been studied and discussed by Duncan and Myers. By solving for *w* in Equation 11 and substituting its value into Equation 10, we obtain the equilibrium conditions, given in Equation 14.

$$(14) \qquad \varphi^*=\frac{(1-\alpha)(\lambda\sigma_l^2-c)+\delta\bar{l}}{(1-\alpha)\lambda\sigma_l^2+\Theta\sigma_l^2(1-\alpha-\delta)^2\left[1+(n-1)\rho\right]}.$$

[5] The second order condition for a maximum is satisfied because $-\Theta\varphi_S\sigma_l^2(1-\alpha-\delta)^2\left[1+9n-1)\rho\right]\prec 0$.

Theoretically, it can be observed from Equation 14 that the supply for insurance increases with increasing w, and decreases with increasing expected loss $\bar{l}$, ρ, and variance of loss, σ_l^2 (Appendix 1B). For any given n, Equation 14 gives the equilibrium coverage level that equates the demand and supply for insurance. However, if quality risks are uncorrelated ($\rho=0$), an equilibrium will always exist. In this particular case, the supply of insurance does not depend on n, neither does the equilibrium premium and coverage levels. If quality risks are significantly correlated across geographical regions, coverage levels may decrease and premiums may increase (partially reflecting the providers of insurance aversion to quality risks). This methodology illustrates how quality losses could be effectively incorporated into crop insurance contracts. The role of reinsurance and subsidized reinsurance is explored to analyze farmers' behavior under these scenarios. The analysis of farmers' behavior to quality risk and the application of this methodology to FHB distinguishes this research from prior studies in this area.

Data and Simulation Procedure

Data on yield, price, and revenue loss due to FHB from all North Dakota barley producing CRDs affected by FHB from 1993-2000 were used for the analysis. These data were obtained from the U.S. GAO and Nganje et al. These studies used annual data on DON levels, published by the Cereal Science Department, North Dakota State University, from 1993 (depicting the onset of scab outbreak) to 2000. The distribution of revenue losses and insurable losses due to FHB, for the MPCI and IP programs, is presented in Figure 1. The procedure to estimate insurable losses for MPCI and IP are presented in Appendix 2. In most CRDs and years, FHB losses are greater than conventional yield and revenue losses currently covered by MPCI and IP. Data on average production history (APH) yields and actual market prices for malting barley and feed grain barley from 1959 through 2000 were obtained from the North Dakota and National Agricultural Statistics Service web sites and the National Grain and Feed Association.

Simulation Procedure

Equation 14 is used to simulate the impacts of quality losses and risk from FHB on the equilibrium coverage level (φ^*) and premiums for MPCI and IP. Simulations were conducted using *@Risk* software for the two insurance programs, MPCI and IP, under three scenarios: no reinsurance, reinsurance, and subsidized reinsurance.

The first task was to determine the correlation matrix (ρ) and use it to determine the catastrophic nature of FHB (the "true magnitude" of FHB risk). From an insurance perspective, a catastrophe can be defined as an infrequent event that has undesirable outcomes for a sizeable subset of the insured population (Duncan and Myers). In the case of FHB, outbreaks are particularly severe in years with higher rainfall and humidity, and losses have been highly correlated across insureds from different geographical regions (CRDs).

Step two involved selecting distributions for $\bar{l}$ (insurable loss presented in Appendix 1), α (the cost for reinsurance), and δ (subsidy from reinsurance). A normal distribution was assumed for stochastic loss (the results did not vary significantly when the true distributions from *BestFit* software were substituted). A risk-uniform distribution was defined for α and δ in the scenario of reinsurance, with the value of α ranging from greater than nil to one. With no

reinsurance, the values of α and δ are both equal to zero. The value of δ was equated to zero in the case of non-subsidized reinsurance. To calibrate the degree of risk-aversion a risksimtable in *@Risk* (assuming values from 0 to 5) was defined for both λ (the risk aversion parameter of the farmer) and Θ (the risk aversion parameter of the insurers).

After determining the distribution of all variables, Equations 11 and 14 were used to simulate equilibrium coverage levels and premiums for both the MPCI and the IP insurance markets, with and without FHB losses and risks, using *@Risk* software. A total of 10,000 iterations (so that output distributions converge to within acceptable stopping criteria) and five insurance agents was used for each CRD. A sensitivity analysis was performed using λ, to understand the behavior of growers after they purchase crop quality insurance. Sensitivity analysis on c (potential moral hazard monitoring cost) was performed to provide guidance and direction on the efficient design of crop quality insurance instruments (currently, only about 2 percent of quality losses are covered by insurance even though the RMA provides crop quality insurance guidelines).

Results

Table 1 illustrates the catastrophic nature of FHB and shows that FHB losses are significantly correlated across all CRDs in this study, ranging from 0.836 to 0.967 for MPCI. These correlation values are undoubtably high and indicate that scab is a catastrophic event for barley growers in North Dakota. Two types of models are used to address the question of how much farmers will be willing to pay to mitigate FHB risk; an equilibrium CAT model without and with FHB risk intended to determine MPCI and IP coverage levels and premiums. As noted earlier, the difference in premiums with and without FHB risk serve as the asking price. The sign of the asking price, especially under the scenario subsidized reinsurance, will enable policy makers and providers of insurance to understand how growers may behave after they purchase crop quality insurance. If this asking price is positive, then growers may view subsidized reinsurance as beneficial to grow barley. However, a sensitivity analysis on growers' risk aversion and cost of monitoring quality losses provides indications on whether moral hazard tendencies can be minimized. 1

Table 1. Correlation of Scab Risks Across CRDs and North Dakota

	ND-NC	ND-NE	ND-C	ND-EC	ND-SE	ND
ND-NC	1					
ND-NE	0.83644	1				
ND-C	0.94779	0.86484	1			
ND-EC	0.87446	0.9288	0.87618	1		
ND-SE	0.84086	0.86131	0.94155	0.92426	1	
ND	0.94229	0.94202	0.96683	0.96746	0.95515	1

Effects of FHB Risk on Equilibrium Coverage Levels and Premiums

Prevailing coverage levels for the MPCI and IP programs range from 65 to 85 percent, while the catastrophic (CAT) coverage levels, as set by the RMA, are greater than or equal to 50 percent. Under normal yield and revenue loss situations, Babcock noted that the incremental cost of coverage should be $0.50 for a dollar of loss. It should also be noted that the premium rate varies between $3.30 to $6.60 for every $100 of loss in barley (Rate Mate). Crop insurance premiums are subsidized by the RMA. These values serve as benchmarks in this study when comparing the results of no reinsurance, reinsurance, and subsidized reinsurance.

No Reinsurance Case

Table 2 presents a summary of the no reinsurance simulation results. As noted earlier, if an equilibrium exists prior to catastrophic risk (FHB in this case) without reinsurance, then a marginal increase in quality risk increases the equilibrium premium and reduces the equilibrium coverage level. For both the MPCI and IP programs, FHB risks lead to increased premiums and decreased coverage levels.[6] For example, coverage levels per acre for the IP program dropped from 22.6 percent to 17.43 percent, and premiums per acre increased from $18.55 to $35.18 when the risk aversion levels of the insurance agents and the farmers are equal to 0.5.[7] Two things to note are: 1) in the absence of reinsurance and subsidized reinsurance, the equilibrium coverage levels fall below the prevailing 65-85 percent level and even below the CAT coverage level of 50 percent and 2) the increase in premiums does not coincide with the expected $0.50 premium to $1.0 loss (Babcock).

Premiums required by private insurance agents are not proportional to coverage levels they are willing to provide. In the case of MPCI, for approximately the same coverage levels with or without FHB (17.92 percent and 17.46 percent, respectively, for scenario 2 or $\lambda = \Theta$), the premiums are significantly different ($17.54 and $31.93). The asking price in this case is $14.39, positive for both the MPCI and IP programs. This implies that farmers may view crop quality insurance as a profitable investment for MPCI and IP. However, reinsurance and subsidized reinsurance may be needed to prevent crop quality insurance market failure because barley growers may be averse to coverage levels significantly lower than the 65-85 percent range.

[6] Similar results and trends were obtained for all CRDs in North Dakota.

[7] As mentioned earlier, it is more likely the risk aversion coefficient of the insurance agents and the reinsurers is smaller ($\lambda > \Theta$), because they are much bigger than barley growers and can absorb more risk. However, the scenario with ($\lambda < \Theta$) can also occur if insurance agents do not have public information or data on quality losses and are concerned about potential moral hazard behavior of the growers. We use the result of ($\lambda = \Theta$) as benchmark to facility comparison of results.

Table 2. Equilibrium Coverage Levels and Premiums Per Acre for MPCI and IP with and without FHB Risks

Quality Risk	No Reinsurance			Non-subsidized Reinsurance			Subsidized Reinsurance		
	Equil Cov.	St. Dev.	Premium	Equil. Cov.	St. Dev	Premium	Equil. Cov.	St. Dev.	Premium
MPCI									
Scab = 0^1	0.3026	0.0006	16.1783	0.5121	0.0014	13.8606	0.8173	0.0021	10.4860
Scab >0^1	0.2959	0.0009	28.9592	0.5051	0.0018	23.8392	0.8135	0.0013	16.2951
Scab = 0^2	0.1792	0.0004	17.5424	0.3712	0.0010	15.4191	0.7206	0.0018	11.5554
Scab >0^2	0.1746	0.0005	31.9281	0.3648	0.0019	27.2724	0.7124	0.0022	18.7680
Scab = 0^3	0.1274	0.0002	18.1161	0.2978	0.0011	16.2313	0.6535	0.0023	12.2972
Scab >0^3	0.1238	0.0003	33.1707	0.2918	0.0015	29.0600	0.6470	0.0048	20.3672
IP									
Scab = 0^1	0.3650	0.0059	16.7925	0.5658	0.0093	14.2464	0.8803	0.0147	10.2587
Scab >0^1	0.2959	0.0010	32.4858	0.5073	0.0022	27.7958	0.8042	0.0034	21.2068
Scab = 0^2	0.2260	0.0037	18.5548	0.4249	0.0067	16.0331	0.7885	0.0137	11.4224
Scab >0^2	0.1743	0.0006	35.1848	0.3652	0.0023	30.9492	0.7020	0.0040	23.4733
Scab = 0^3	0.1637	0.0026	19.3445	0.3471	0.0057	17.0194	0.7257	0.0141	12.2189
Scab >0^3	0.1236	0.0004	36.3114	0.2932	0.0017	32.5476	0.6364	0.0027	24.9297

With superscript 1 ($\lambda > \Theta$), 2 ($\lambda = \Theta$), 3 ($\lambda < \Theta$). Scab implies presence or absence of FHB risk.
St. Dev. stands for standard deviation and Equil. Cov. stands for equilibrium coverage levels.

Reinsurance Case with No Subsidy

Duncan and Myers noted that reinsurance comes in two main forms, proportional and step-loss. With proportional reinsurance, insurance firms share a specified portion of both policy premium (and costs) and indemnities with the reinsurer. This is the conceptual framework used in Equation 8. With step-loss reinsurance, the reinsurer agrees to reimburse the insurance firms if their total indemnity payments exceed a predetermined level. In practice, the RMA is presumably providing reinsurance with the goal to facilitate a crop insurance equilibrium, increase coverage levels, and minimize risk aversion tendencies of insurance firms.

Results in Table 2 show that for both the MPCI and IP programs, reinsurance leads to increases in the equilibrium coverage levels and decreases in the potential premium charged for the three risk aversion scenarios. For example, coverage levels for scenario 2 increased from 17.43 percent (with no reinsurance) to 36.52 percent (with reinsurance) and premiums decreased from $35.1848 per acre (with no reinsurance) to $30.9492 (with reinsurance) for IP. These empirical results validate the findings by Duncan and Myers, who noted that reinsurers are bigger, able to absorb more risks, and enable private insurance agents to increase coverage levels and reduce premiums charged to growers. However, increased coverage levels are still by far lower than the 65-85 percent levels and premiums are still proportionately higher as in the case of no reinsurance. Under this scenario, farmers may still be averse to crop quality insurance if these markets are not subsidized.

Subsidized Reinsurance

The opportunity for subsidized reinsurance leads to a significant increase in the coverage levels and a decrease in premiums for MPCI and IP and for all CRDs (Table 2). For instance, with the incorporation of FHB risk, the coverage levels with reinsurance increase from 36.48 percent to 71.24 percent and from 36.52 percent to 70.20 percent for the MPCI and IP markets for scenario 2, respectively. Premium levels fall from $27.2724 per acre when there is reinsurance, to $18.7680 per acre when there is subsidized reinsurance. This happens because the subsidy increases the supply of insurance, which puts downward pressure on premiums and upward pressure on coverage levels.

Subsidized reinsurance is more appealing when FHB risks are explicitly incorporated in to crop insurance markets. The empirical results in this report validate the fact that subsidized reinsurance will facilitate increased coverage levels (to the 65-85 percent range) and will lower premiums. However, if farmers view crop quality insurance as profitable (asking prices are still positive but much lower), they may engage in moral hazard behavior, producing low quality barley. Two approaches can be used to analyze such tendencies: 1) analyze the impacts of increased supervision cost and farmers' risk aversion with crop quality insurance and 2) incorporate recommended RMA guidelines for the estimation of insurance loss as in Appendix 2.

Sensitivity of Equilibrium Coverage Level and Premiums to Farmers' Risk Aversion (λ)

Figure 2 indicates the sensitivity of the equilibrium coverage levels and premiums to changes in the farmers' risk aversion parameter with and without FHB risks. As is expected, the more risk averse the farmer is (as λ increases), the higher the coverage level and premium for the three scenarios of no reinsurance, non-subsidized reinsurance, and subsidized reinsurance.

For both MPCI and IP, subsidized reinsurance provides more coverage and lower premiums for all values of λ. This emphasizes the relevance of reinsurance and subsidized reinsurance for quality risk management. As farmers' aversion to FHB risk increases, they are willing to pay more to protect themselves against these risks. It should be noted that coverage levels lower than 85 percent minimize moral hazard tendencies. The sensitivity analysis results indicate that even with subsidized reinsurance, barley growers are in the 65-85 (precisely 63.64 - 81.35) percent coverage level range, minimizing moral hazard tendencies.

Sensitivity of Equilibrium Coverage Level and Premiums to Cost

In practice, crop insurance is a federally subsidized program, the government bares all the overhead costs (Babcock). Recall that for every $100 of loss farmers pay between $3.3 to $6.6 (Rate Mate). However, in the case of crop quality insurance testing and monitoring, costs may be incurred by private insurance agents who may in turn pass it on to farmers. Simulating the impact of this cost on equilibrium coverage levels and premiums may provide guidance for the effective design of crop quality insurance instruments. As expected, Figure 3 shows that equilibrium coverage levels and premiums vary significantly as costs increase. Again, without subsidized reinsurance, farmers may not be able to afford coverage levels in the 65-85 percent level. It should be noted that this range occurs when cost (as a percent of loss) is within the 5 to

25 percent range. When cost is equal to zero, coverage levels for MPCI are greater than 85 percent, indicating potential moral hazard behavior of farmers may arise. On the other hand, farmers may be averse to crop quality insurance when costs are greater than 25 percent.

Contrary to current federal policy where the government incurs almost all of the overhead cost related to crop insurance and subsidizes a large percent of the premium, the study findings suggest this strategy may lead to potential moral hazard behavior with quality risk. A better strategy may be to use cost (between the 5 to 25 percent range) as a control variable to set premium rates and coverage levels rather than doing so arbitrarily. This cost will enable private insurance agents to monitor farmers' behavior on the effective use of fungicide and other recommended barley production practices prescribed in the USDA loss adjustment manual.

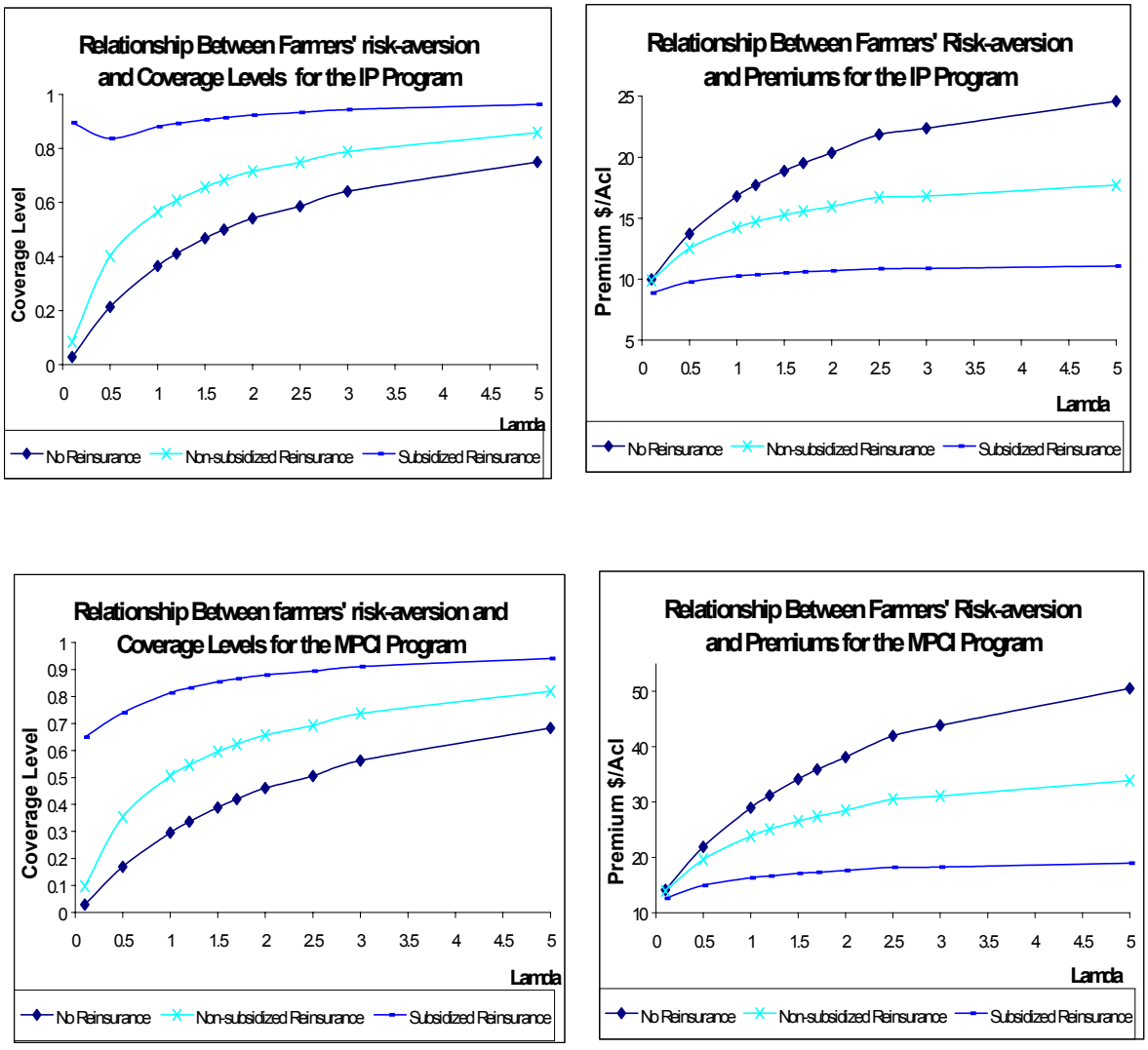

Figure 2. Effects of Farmers' Risk Aversion on MPCI and IP Coverage Levels and Premiums

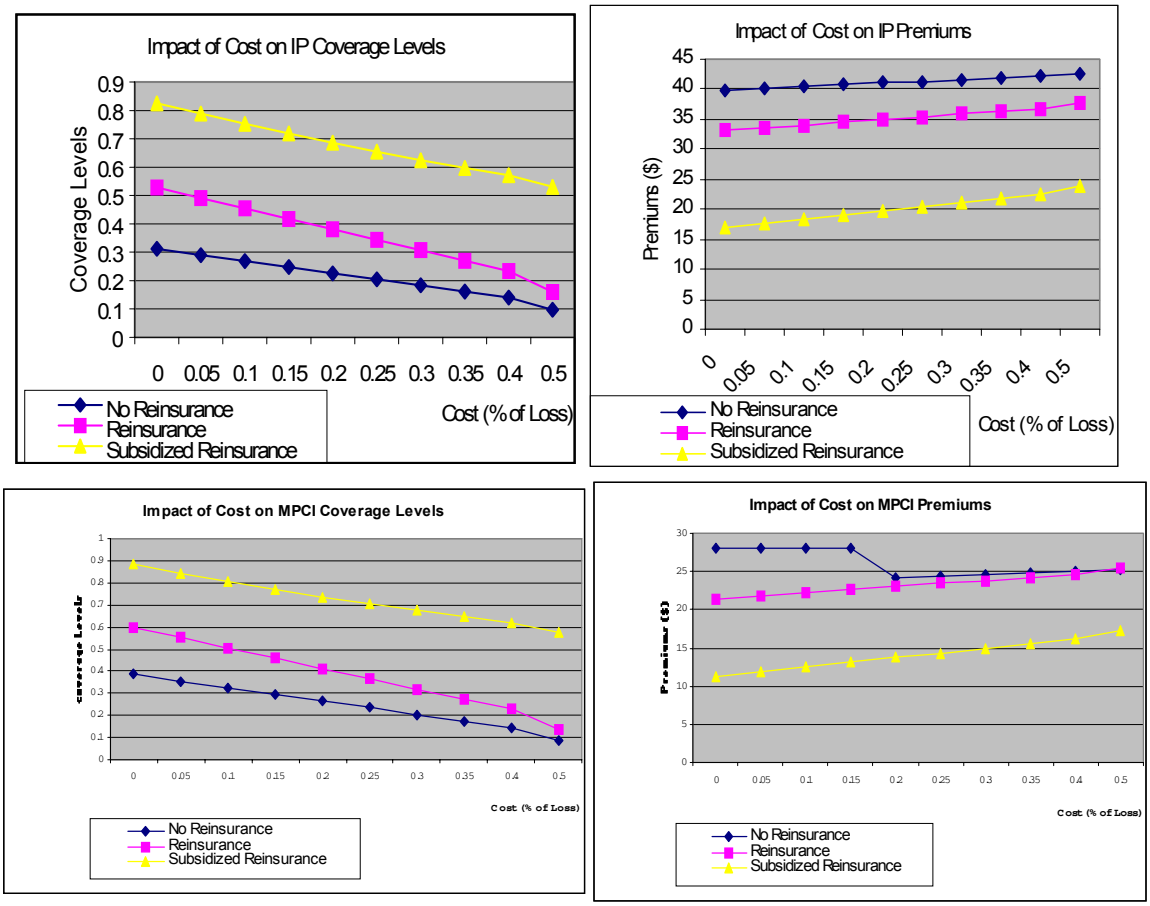

Figure 3. Impact of Cost on Equilibrium Coverage Levels and Premiums

Conclusion and Policy Implications

Managing quality risks, especially grain quality, has been a challenge facing farmers, grain merchandisers, and policymakers for many years. With the advent of genetically modified organisms (GMOs), food safety, and identity preservation, this is even more challenging today.

This research work studies the problem of reducing yield and revenue variability due to FHB, a case where quality risks are particularly apparent, using MPCI and IP crop quality insurance instruments. Crop quality insurance procedures and guidelines have covered a very small percent (2 percent) of FHB losses in barley (U.S. GAO), partly because of the uncertainties associated with monitoring costs and potential moral hazards behavior of farmers after they purchase insurance as a tool to mitigate quality risk. An equilibrium crop insurance model is developed to analyze two objectives. The first objective determines equilibrium coverage levels and premium rates that maximize the expected utility of barley producers in North Dakota and private insurance agents when insurance markets explicitly incorporate quality risks. The second objective uses the asking price concept and sensitivity analysis on cost and farmers' risk

aversion to evaluate the farmers' behavior after they purchase crop quality insurance instruments under three scenarios: no reinsurance, reinsurance, and subsidized reinsurance.

The model results allow verification that farmers are willing to pay a premium to minimize quality risks, especially when they are catastrophic, as is the case of FHB. However, coverage levels are significantly lower than the 65-85 percent range without subsidized reinsurance, posing a potential market failure problem when quality risks are explicitly incorporated into insurance markets. The results suggest that contrary to the federal government policy of incurring all the overhead cost of crop insurance, this cost should range from 5 to 25 percent of estimated quality losses. If costs incurred by farmers are zero, coverage levels may be higher than the 85 percent recommended limit (as in the case of the MPCI market, Figure 3), resulting in potential moral hazard problems. On the other hand, costs greater than 25 percent may cause farmers and private insurance agents to be averse to crop quality insurance instruments, resulting in a very small level of coverage as is currently the case with FHB and barley. In this case, all parties agree there may be substantial monitoring costs. However, it is not clear who will incur these costs.

The implementation of effective crop quality insurance programs has several advantages to barley producers in North Dakota and in the United States as a whole. The farmers, through crop quality insurance, get to transfer a part of their quality risk to insurance companies and this reduces the underling risk to barley production. This has, as a consequence, the effect of decreasing the farmers' risk aversion, which reduces their compensation for the assumed risk and may lead to the choice of alternative agricultural production technologies with larger risk. On the other hand, the barley farmer is not dependent on federal subsidies and farm disaster payments; the insurance guarantees the farmer a minimum income. According to the Environmental Working Group (EWG) Farm Subsidy Data Base, "ten percent of the biggest (and most profitable) crop producers absorbed two-thirds of all subsidies," rendering farm subsidy an inefficient manner to deal with ex-post crop losses. For example, North Dakota barley growers received approximately $27.2 million (or $0.23/bu) in disaster payments, of which a significant portion was attributable to crop quality and FHB. Such revenues may be efficiently redistributed or reduced with crop quality insurance. Although the estimation of insurable loss in this study follows RMA quality loss adjustment guidelines, which is intended to minimize moral hazard tendencies, this is an area where further research is needed.

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Appendix 1

Appendix 1A: The Variance of Profit

The variance profit is presented in Equation 1A.1 as the variance of loss, the only stochastic variable in the profit function.

$$\text{(1A.1)} \qquad \text{Var}\left(\sum_{i=1}^{n} l_i\right) = \sum_{i=1}^{n} \text{Var}(l_i) + \sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq 1}}^{n} \text{Cov}(l_i, l_j).$$

If CRDs have different distributions for losses, then the covariance and correlation between any two random variables is $\rho_{ij} = \dfrac{\text{Cov}(l_i, l_j)}{\sigma_l^2}$. The variance of loss, given the profit function in Equation 8 is:

$$\text{(1A.2)} \qquad \text{Var}\left(\sum_{i=1}^{n} l_i\right) = n\sigma_l^2\left[1 + (n-1)\rho_{ij}\right]$$

Substituting ρ into the variance expression then gives the result used in Equation 9.

Appendix 1B: Comparative Statics Results [Adapted from Duncan and Myers (2000)].

Equations 7 and 9 can be rewritten as a vector of Equations $F(x, \theta) = 0$ where x = (ω, φ, n) *and* θ = (c, $\bar{l}$, Θ, λ, σ_l^2 , ρ, α ,δ) are the exogenous variables. Assuming the conditions of the implicit function theorem are satisfied, then an equilibrium x = G(θ) is an implicit function defined by F[G(θ), θ] = θ and characterized by Equation 1B.1

$$\text{(1B.1)} \qquad F_x(x, \theta).G_\theta(\theta) = F_\theta(x, \theta)$$

where the subscripts indicate matrices of partial derivatives. Particular derivatives, like the one such as $dw/d\rho$, $d\varphi/d\rho$, *and* $dn/d\rho$ can be computed via Cramer's rule. Differentiating Equations 7 and 9 and rearranging terms we see that

$$(1B.2)\quad F_x(x,\ \theta) = \begin{bmatrix} -1 & -\lambda\sigma_l^2 & 0 \\ 1-\alpha & -\Theta\sigma_l^2(1-\alpha-\delta)^2 \text{ x } [1+(n-1)\rho] & -\Theta\varphi\sigma_l^2 \text{ x } (1-\alpha-\delta)^2\rho \\ n\varphi(1-\alpha) & 0 & 0.5\Theta\varphi^2\sigma_l^2 \text{ x } (1-\alpha-\delta)^2 \text{ x } (1-\rho) \end{bmatrix}$$

Furthermore,

$$(1B.3)\quad -F_\rho(x,\ \theta) = \begin{bmatrix} 0 \\ \Theta\varphi\sigma_l^2(1-\alpha-\delta)^2(n-1) \\ -0.5\Theta n\varphi^2\sigma_l^2(1-\alpha-\delta)^2(n-1) \end{bmatrix}$$

Calculations show that $\det[F_x(x,\ \theta)] > 0$. Now consider the sequence of matrices $F_i(x,\ \theta)$, $i = 1, 2, 3$ which represent $F_x(x,\ \theta)$ but with the ith column replaced by $-F_\rho(x,\ \theta)$. It can be shown that for $n > 1$, $\det[F_1(x,\ \theta)] > 0$, $\det[F_2(x,\ \theta)] < 0$, and $\det[F_3(x,\ \theta)]$ can be of either sign. Thus, since x = (ω, φ, n), Cramer's rule implies $dw/d\rho > 0$, $d\varphi/d\rho < 0$, *and* $dn/d\rho$ is of indeterminate sign. These are the comparative statics derivatives if equilibrium exists without reinsurance. Next, note that if δ = 0 then

$$(1B.4)\quad -F_\alpha(x,\ \theta) = \begin{bmatrix} 0 \\ -\Theta\varphi\sigma_l^2(1-\alpha)[1+(n-1)\rho] \\ 0 \end{bmatrix}$$

and consider the sequence of matrices $F_i(x,\ \theta)$, $i = 1, 2, 3$ which represent $F_x(x,\ \theta)$ but with the ith column replaced by $-F_\alpha(x,\ \theta)$. In this case it can be shown that $\det[F_1(x,\ \theta)] < 0$, $\det[F_2(x,\ \theta)] > 0$, and $\det[F_3(x,\ \theta)] > 0$. Thus, since x = (ω, φ, n), Cramer's rule implies $dw/d\alpha < 0$, $d\varphi/d\alpha > 0$, *and* $dn/d\alpha > 0$. These are the comparative statics derivatives if equilibrium exists under catastrophic risk and proportional reinsurance. Finally note that,

$$(1B.5)\quad -F_\delta(x,\ \theta) = \begin{bmatrix} 0 \\ -\{\bar{l} + 2\Theta\varphi\sigma_l^2(1-\alpha-\delta) \text{ x } [1+(n-1)\rho]\} \\ -n\varphi\{\bar{l} + \Theta\varphi\sigma_l^2(1-\alpha-\delta) \text{ x } [1+(n-1)\rho]\} \end{bmatrix}$$

and consider the sequence of matrices $F_i(x, \theta)$, $i = 1, 2, 3$ which represent $F_x(x, \theta)$ but with the ith column replaced by $-F_\delta(x, \theta)$. In this case it can be shown that $\det[F_1(x, \theta)] < 0$, $\det[F_2(x, \theta)] > 0$, and $\det[F_3(x, \theta)]$ is of indeterminate sign. Thus, since x = (ω, φ, n), Cramer's rule implies $dw/d\delta < 0$, $d\varphi/d\delta > 0$, and $dn/d\delta >$ can be of either sign. These are the comparative statics derivatives, if equilibrium exists with quality risk that are catastrophic and subsidized reinsurance.

Appendix 2: Estimation of Insurable Loss for MPCI and IP

Typically, for either program farmers have the option to choose coverage levels and election prices which will determine the amount of indemnity available.

Insurable Loss Without FHB Risk

The typical MPCI estimates the farmer's expected yield in a given year using four to ten years of his APH. Indemnities are payable to the farmer only in the instant when the actual yield is less than the expected yield (Equation 2A.1).

(2A.1.) $$L_{it} = \text{Max}[0,(\text{APH}ys_{it} - ys_{it})].ps_{it}$$

Where, L_{it} is the insurable MPCI loss per acre without explicit FHB losses, APHys_{it} is calculated APH using historic yields ys_{it}, ys_{it} is the actual yield in region **i** and year t, and ps_{it} is the actual price per bushel received in region **i** and year **t**. The function Max[0,(APHys_{it} - ys_{it})] ensures that no loss is insurable when the producer's actual yield is greater than the APH.

Insurable losses for IP with FHB loss are as in Equation 2A.2. In the empirical estimations in this paper, the harvest price is assumed to be the actual cash price at harvest, while the base price, used for the calculation of the revenue guarantee, is assumed to be the forecasted (posted county prices).

(2A.2) $$R_{it} = \text{Max}[0,(\text{APH}ys_{it}.pn_{it} - ys_{it}.ps_{it})]$$

Where $R_{it}$is the insurable IP loss per acre without explicit scab and DON losses, APH$ys_{it}.pn_{it}$ is calculated Guaranteed Revenue for each of year **t,** ps_{it} is the calculated Actual Revenue for each of year **t,** ys_{it} is the actual yield in production region i and scab-affected year **t**, pn_{it} is base price (forecasted) per bushel received in region **i** and year **t**, and ps_{it} is actual price per bushel received in region **i** and scab-affected year **t**. Equation 2A.1 and 2A.2 represent how insurable losses are currently estimated in the MPCI and IP markets.

Insurable Loss With Explicit Consideration of FHB Risk

In a scenario which explicitly incorporates FHB, the potential production loss covered by the MPCI will be as depicted by Equation 2A.3.

(2A.3) $$Ls_{it} = \text{Max}[0,(\text{APH}yn_{it} - ys_{it} + y_g)].ps_{it}$$

Where Ls_{it} is the insurable MPCI loss per acre with scab and vomitoxin, APHyn_{it} is calculated

APH, retaining for each of year **t**, the Max[yn_{it}, ys_{it}], yn_{it} is the normal yield in the absence of FHB in production region **i** and year **t**, yn_{it} is the actual yield in production region **i** and FHB-affected year t, y_g is yield increase attributable to fungicide use (the U.S. Wheat and Barley Scab Initiative has recommended fungicide rate use to help reduce FHB losses), and ps_{it} is the actual price per bushel received in region **i** and FHB-affected year **t**.

The potential revenue loss covered by the IP when FHB is accounted for involves three components. The first two components combined is the traditional insurable revenue loss with FHB. This entails using FHB-adjusted APH, while the base price would be the estimated average normal price of barley had there been no FHB (see U.S. GAO and Nganje et al. for the estimation of these components). The third component is the potential revenue gain or loss as a result of fungicide application. The total insurable revenue loss that explicitly incorporates FHB is estimated as depicted in Equation 2A.4.

$$(2A.4) \qquad Rs_{it} = \text{Max}[0,(\text{APH}yn_{it}pn_{it} - ys_{it}.ps_{it} - Dv_{it})]$$

Where Rs_{it} is the total insurable IP loss per acre with FHB, APH$yn_{it}pn_{it}$ is the calculated guaranteed revenue for each of year **t**, $ys_{it}.ps_{it}$ is the calculated actual gross revenue for each of year **t**, Dv_{it} is the net gains or losses from fungicide application (research results by McMullen have shown that fungicide use does not guarantee increase in quality), yn_{it} is the normal yield in the absence of FHB in production region **i** and year **t**, ys_{it} is the actual yield in production region i and FHB-affected year **t**, pn_{it} is base price (estimated normal price in the absence of FHB) per bushel in region **i** and FHB-affected year t, and ps_{it} is the actual price per bushel received in region **i** and FHB-affected year **t**.

The maximum functions in all equations ensure that no indemnities are paid when the yield or revenue guaranteed is less than the farmer's actual yield or gross revenue. In computing the Dv_{it}, insurance agents can verify whether or not growers implement recommended farming practices. The results of Equations 2A.1, 2A.2, 2A.3, and 2A.4 are presented in Figure 2.