

CROP INSURANCE AND QUALITY UNCERTAINTY
DUE TO SCAB AND VOMITOXIN

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ABSTRACT

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Quality-related yield and price losses have had significant impacts on producer income and risks. In some instances, quality-related risks have exceeded yield and price losses covered by conventional insurance instruments. Heretofore, mechanisms to deal with these risks have been ex-post and not necessarily effective in terms of third-party risk transfer.

This study develops a framework to incorporate quality-related risk due to scab and vomitoxin in crop insurance programs. Specifically, the study evaluates the impact on the equilibrium coverage levels and risk premiums for suppliers of insurance and barley producers, when these conventional insurance instruments explicitly incorporate quality losses.

The study provide several important implications. First, the methodology illustrates how quality impacts could be incorporated into crop insurance contracts. Second, the study explicitly incorporates the correlation effects of yields and price shortfalls due to quality. Although applied here in the case of malting barley and scab, this approach could be applied similarly in many regions, crops, and quality factors.

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CHAPTER I

INTRODUCTION

Background

Risks due to quality uncertainties are increasingly important in both the farm and agribusiness sectors. Quality-related uncertainties occur at all levels of the supply chain of food crops, livestock, and related products: on-farm, in transportation systems, and during processing. There are frequent recalls due to quality-related contamination in the livestock sector and related industries (USDA-FSIS, 2000) while the contamination of conventionally grown food by genetically modified organisms (GMOs) is also an increasing issue of concern (ACS, 1999). In the case of small grains like barley and wheat, concerns of quality risks have been particularly associated with their production, handling, and processing (Hill et al., 1998). These uncertainties inadvertently lead to the underrating of end products and, in most instances, to major food safety-related concerns.

Quality-related risks have impacted the domestic production and marketing of small grains in the United States. Congress and the United States Department of Agriculture (USDA) have repeatedly used legislative and regulatory tools to improve the quality of the grain delivered to customers overseas (Hill et al., 1998). The authors note, however, that the efforts have led to no significant improvement in grain quality. The factors that contribute to quality shortfalls in small grains in general include moisture content, color, plump, test weight, protein content, level of mycotoxins, and overall weather-related conditions (USGAO, 1999).

In the specific case of wheat and barley, recent studies indicate that farmers in the Midwest have suffered substantial declines in their revenues following the outbreak of scab and vomitoxin in the 1990s (Johnson et al., 1998; USGAO, 1999; Johnson and Nganje, 2000; Koo et al., 2000; Nganje et al., 2001). Scab is the common appellation for the Fusarium Head Blight (FHB) disease while vomitoxin, also called DON (the acronym for *Deoxynivalenol*), is the mycotoxin of scab that renders wheat and barley unfit for human consumption and other end uses at doses greater than 1 ppm (McMullen and Stack, 1999).

The food quality-related and safety concerns of scab and vomitoxin are significant within and outside the United States. The USWBSI (2001) reports that approximately 50 percent of white wheat grown in Michigan in 2000 for use in human food products was rejected for unacceptable levels of DON in the grain at harvest. The same USWBSI (2001) newsletter reports cases of vomitoxin poisoning and related illnesses in China and India. DON from moisture-damaged wheat, for instance, was implicated in a sickness affecting close to 50,000 people in India in 1987.

An important dimension to the effect of scab and vomitoxin on barley is the impact on the quality of the marketable grain. In malting barley, DON is known to cause unacceptable “gushing” in beer production and affects taste profiles. In order to safeguard the taste profiles and allay the fears of toxicity by the public, large U.S. brewers like Anheuser Busch declined from purchasing barley with detectable levels of DON (Johnson and Nganje, 2000). In addition, malting companies and brewers (the traditional buyers of North Dakota’s malting barley), in reaction to scab and vomitoxin damages, have reduced

their reliance on barley supply from the U.S. Midwest and shifted more of their procurement to the western states and Canada. The malting barley imports from Canada, for instance, were estimated to have risen by about 380 percent (USGAO, 1999).

Vomitoxin-contaminated grains are discounted at the level of elevators, leading to reductions in growers' gross revenue. These revenue shortfalls heretofore have not been explicitly covered by the provisions of the Federal Agricultural Improvement and Reform (FAIR) Act, popularly referred to as the "Freedom to Farm bill" of 1996. Under the FAIR Act, assistance is provided to farmers in the form of subsidized crop revenue and yield insurance from a variety of natural causes (Barnett and Coble, 1999) as well as assistance in the form of higher support prices for commodities and transition payment. The provisions for insurance notwithstanding, farmers still remain confronted with risks associated with losses from quality factors like scab and vomitoxin (USGAO, 1999).

Statement of the Problem

Unexpected changes in crop quality have important impacts on producer income and risks. The effects of crop quality risk are the impact on yields and price discounts. In the case of scab and vomitoxin, barley yields have been severely impacted. Price discounts have also been large, due to buyers being averse to grains with greater than nil vomitoxin. These risks have led to substantial reductions in farmers' incomes. Figure 1.1 illustrates the total direct yearly revenue losses to North Dakota farmers due to scab and vomitoxin since 1993, the year of the first major scab outbreak (USGAO, 1999; Nganje et al., 2001).

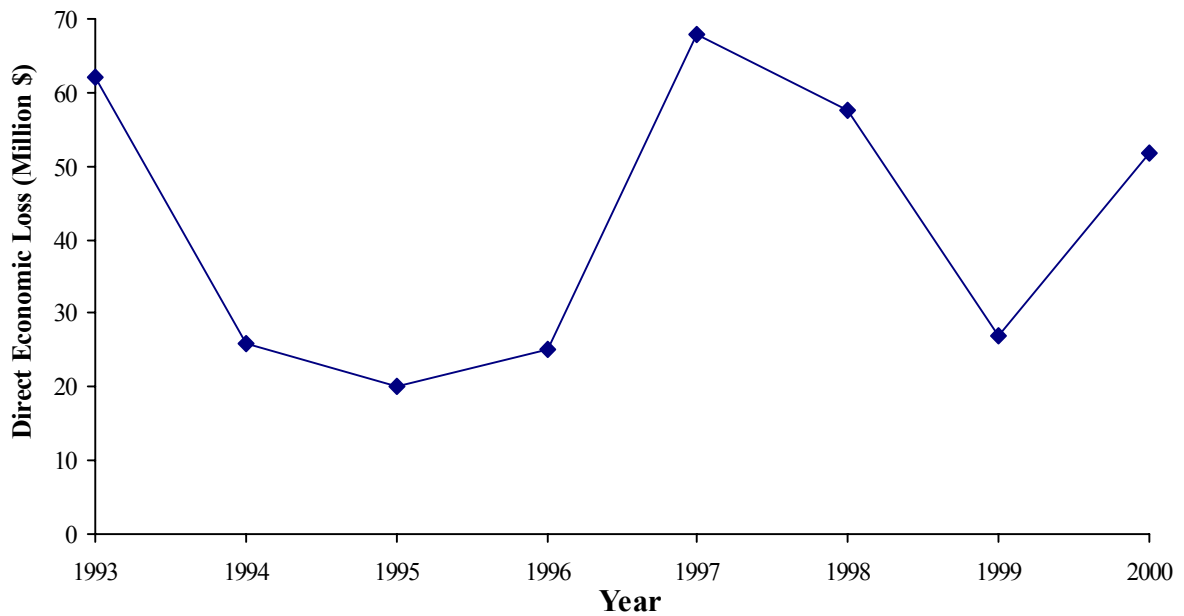


Figure 1.1. Revenue Losses Due to Scab and Vomitoxin in Barley from 1993 to 2000.

It is obvious from Figure 1.1 that the losses to barley farmers in North Dakota due to scab and vomitoxin have been significant over the years. In addition, these losses have equally exhibited a high degree of volatility. The bulk of the losses stem from the fact that grains with quality shortfalls due to vomitoxin are heavily discounted at the farmers' expense. The American Barley Association (ABA) reported, for instance, that, for 1997, only 9 percent of all Midwestern malting barley fell into the premium price category of 0.5 ppm or less (USGAO, 1999).

Although crop insurance programs have escalated in importance as a means to manage risks associated with unexpected events, for barley and wheat, the risks associated with quality which are particularly important have heretofore not been explicitly part of

crop insurance programs. The estimate of crop insurance payments to barley farmers in North Dakota between 1993 and 1997 for scab and vomitoxin-damaged barley covered less than 2 percent of the cumulative losses in barley (about \$200 million dollars), even though losses due to vomitoxin-related price discounts alone accounted for about 30 percent (or \$61 million) of these of losses (USGAO, 1999).

The importance of crop insurance as an important risk management tool to producers, especially in mitigating the increasing risks associated with the 1996 FAIR Act, was emphasized by Leatham et al. (1997). However, quality-associated risks in crops, especially small grains, have thus far 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-related risk. Second, there were some ex-post interpretations of the Crop Revenue Coverage (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, the fact that growers have absorbed these risks internally has resulted in a shift in production. 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 approach has not been a common practice.

In the case of barley and durum wheat, part of the risk of quality deviations is absorbed implicitly by end-users through higher prices. Heretofore, however, the transfer of quality risk has mostly taken 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 always resulted in desirable outcomes. Ultimately, a third-party quality risk transfer in the form of crop quality insurance products could be a desirable alternative for grain producers. It is important, therefore, to envisage how the effects of quality uncertainty due to scab and vomitoxin on barley can be effectively integrated into the existing insurance instruments.

It is also possible to envision that the losses incurred by wheat and barley farmers from the effects of scab and vomitoxin would be alleviated substantially following the results of ongoing research on the use of fungicides and resistant varieties. In the case of barley, for instance, husbandry techniques such as crop rotation, appropriate tillage, seed treatment, staggered planting, and adjusted-combine harvesting have been shown to help in reducing FHB levels (McMullen and Stack, 1999). Nonetheless, there are also strong indications to the effect that scab and vomitoxin are very unlikely to be eliminated in the foreseeable future.

The usefulness of present researched solutions to curb the effects of scab and vomitoxin is limited by their cost as well as by their minimal impact when scab infestations are severe (USGAO, 1999). The USWBSI (2001) highlights most of the ongoing chemical and biological research on scab and vomitoxin by leading plant pathologists. It is noted that most of the research on fungicides used to curb scab are either still to be validated or inconclusive. In addition, there are still constraints in the commercialization of bio-control

products. McMullen and Stack (1999) note further that none of the currently available commercial cultivars are immune to *Fusarium* infection. This background information helps to emphasize the fact that barley growers would continue to be exposed to losses and risks due to scab and vomitoxin for several more years.

Goal and Objectives of the Study

The goal of this study is to develop an insurance model and use it to analyze the impact of quality risks on equilibrium coverage levels and risk premium that suppliers of insurance and producers would be willing to provide when yield and revenue insurance instruments explicitly incorporate quality. Emphasis is laid on the quality risks due to scab and vomitoxin in barley in North Dakota. The specific objectives are

- To develop a model that effectively quantifies insurable losses due to quality shortfall, and employ it in the case of scab and vomitoxin in barley. This model allows the impact of scab and vomitoxin on production and prices to be effectively determined for insurance purposes.
- To develop a model that derives the equilibrium coverage levels and risk premiums for providers of insurance and growers. The empirical analyses explicitly incorporate the risk due to scab and vomitoxin in the Multi-Peril Crop Insurance (MPCI) and Income Protection (IP) programs.
- To conduct sensitivity analysis on farmers' risk aversion and the cost of quality insurance to evaluate farmers' behavior towards the purchase of crop quality insurance instruments.
- To provide guidance and direction in the design of risk-efficient quality insurance

instruments. This involves assessing the policy implications of incorporating quality losses into existing crop insurance instruments to growers, private insurance companies, and the government.

Procedure

The losses due to scab and vomitoxin in barley are modeled as a catastrophic risk following the procedure of Duncan and Myers (2000). Data on scab and vomitoxin are obtained from the annual rop quality surveys conducted in the Midwestern region by Department of Cereal Sciences at North Dakota State University since 1993.

The empirical analysis of the demand for crop quality insurance is based on the utility maximization model. A Mean-Variance (MV) preference function is specified for both the demand and supply of insurance with the assumption of risk averse producers and insurers. In estimating the supply of insurance, the possibility of reinsurance and subsidized reinsurance is incorporated since the current crop insurance policy in the United States is designed to encourage the participation of private insurance firms via reinsurance agreements.

Organization of the Study

The study is divided into five chapters. Chapter II presents a background on barley, scab and vomitoxin, and crop insurance schemes. Chapter II also reviews related studies on crop insurance. Chapter III deals with the Procedures and Methods. This chapter describes the data used for the analyses as well as the key assumptions in the theoretical framework. Chapter IV presents and interprets the Empirical Results. Chapter V summarizes and concludes the study, and provides suggestions for further research.

CHAPTER II

LITERATURE REVIEW

This chapter presents background information on barley, scab, vomitoxin, and crop insurance in relation to the context of the study. Background information on barley is of relevance in quantifying the losses due to scab and vomitoxin while an appraisal of the background information on scab and vomitoxin provides insight on some of the important assumptions to be made when modeling the losses they engender. The chapter also reviews background information on U.S. crop insurance schemes with a view of gaining insight on how to effectively model scab and vomitoxin risk on barley in a framework that fits the existing crop insurance instruments. Selected past research on crop insurance demand and supply, and the related issues of adverse selection, moral hazards, and rating methodologies are equally presented.

Background Information on Barley

An important feature of barley is its distinction between feed and malting barley. Malting barley is used to make malt which is then used to brew beer, while feed barley is used for livestock and poultry. Barley can also be subdivided into six-rowed and two-rowed varieties. The six-row barley varieties recommended for malting by the American Malting Barley Association include Anheuser Busch 1602, Azure, Excel, and Morex while the two-row varieties are Conlion and Triumph (USDA-FCIC, 2001). U.S. malters traditionally require barley of high quality standards which, in the Midwest, is preferably

obtainable from the six-rowed barley. Accordingly, there is a prevalence of six-rowed malting barley planted by U.S. farmers to which certain minimum standards have been defined (USDA-GIPSA, 1999b). Quality requirements are more important for malting barley than for feed barley. Generally, malting barley varieties that fail to reach the prescribed high quality standards can be sold as feed barley (Zhong, 2000).

There are both prescribed official grading and non-grading factors that are essentially considered by the malting industry in the evaluation of the quality of barley (USDA-GIPSA, 1999b). The eight official factors graded on a numerical scale are the test weight, damaged kernels, foreign materials, presence of other grains, skinned and broken kernels, thin barley, sound barley, and suitable malting types. These factors partially reflect the ability of barley to germinate in the malthouse. The non-grading factors of barley include protein content; moisture; color score; and, more recently, vomitoxin content.

This background information on barley is of relevance in this study as will be shown in Chapter III. In quantifying the specific losses to barley farmers due to scab and vomitoxin, cognizance is taken of the fact that both feed and malting barley markets exist. In addition, cognizance is also taken of the fact that not all quality-related losses in barley are attributable to scab and vomitoxin.

Scab and Vomitoxin

Fusarium Head Blight (FHB), or scab, is a fungal disease of small grains. Scab is caused by the fungal species *Fusarium*, the commonest species of which is *F.*

graminearum. In North Dakota, scab is mostly seen on spring wheat, durum wheat, and barley, where it not only causes yield and quality losses, but may be associated with the production of fungal toxins (mycotoxins) that are hazardous to animals (McMullen and Stack, 1999). Clear and Patrick (2001) indicate that FHB has been a recurrent problem in small grains' sector, with infestations dating back a century on corn in North Dakota and Minnesota. Cool, moist weather is conducive for scab during the heading stage of cereal crops (McMullen and Stack, 1999). These conditions occurred in 1993 and the years after, leading to the outbreak of scab in North Dakota and the other Midwestern states.

Vomitoxin, or DON (Deoxynivalenol), is the mycotoxin of scab. Mycotoxins are metabolites produced by pathogenic fungi which play an important role in the development of the host plant (McMullen and Stack, 1999). Vomitoxin is composed essentially of compounds of the class of trichothecenes (USDA-FCIC, 2001) and has been identified as the most important group of mycotoxins associated with scab-infected grains in the Northern Great Plains (McMullen and Stack, 1999). USDA-FCIC (2001) notes that, out of the over 200 mycotoxins identified, vomitoxin and aflatoxin have specifically caused insured grains to be unmarketable. Trichothecenes are toxic to plants and animals alike. As a consequence of scab, therefore, agricultural products like wheat, barley, and maize can be significantly contaminated with trichothecenes and most importantly with vomitoxin. To protect consumers, several countries have established regulations for maximum tolerated vomitoxin levels.

In the United States, scab has had a severe impact on the production of six-row barley in the Midwestern states. Following the scab outbreak in 1993, the presence of

mycotoxins has become an increasingly important factor in the sales of barley and wheat. The USDA-FCIC (2001) indicates that the increasing importance of vomitoxin has been heightened by the advent of a general awareness on grain quality coupled with improved testing procedures, availability of test kits, and animal and human health concerns. The accumulation of deoxynivalenol (DON), associated with FHB, in infected grain makes it undesirable for malting and brewing. It may cause vomiting and feed refusal in small ruminants and, when ingested in high amounts, poses health risks to humans (McMullen and Stack, 1999).

Scabby kernels are considered damaged by U.S. grade standards. It is interesting to note, however, that while vomitoxin can be present in scabbed kernels, the existence of scab does not imply the presence of vomitoxin, nor does the scab kernel count give an accurate measure of the extent of vomitoxin (McMullen and Stack, 1999; Johnson et al., 2001). It is also important to note that vomitoxin-damaged grains are mostly field-infested. Grains that are free of vomitoxin at harvest will not be infested in storage. There is, however, substantial measurement errors of vomitoxin within the commercial marketing system of small grains. A recent study of testing methods by the Grain Inspection Packers and Stockyards Administration (GIPSA) of the USDA indicated that vomitoxin is likely to be distributed erratically, thereby exacerbating measurement problems. In the case of barley, GIPSA concluded that “highly repeatable results may not be achieved with current technology” (USDA-GIPSA, 1999a: p71). This information is of relevance with respect to moral hazard issues associated with crop insurance instruments that explicitly incorporate scab and vomitoxin.

Vomitoxin is regulated by the Food and Drug Administration (FDA). It is treated as an “advisory level,” meaning it is not subject to mandatory limits. However, the FDA reserves the right to take regulatory action against persons who knowingly blend grain containing vomitoxin with clean grain if the resulting mixture is likely to result in an end-product that significantly exceeds the advisory level necessary to protect human and animal health (NGFA, 1993). In 1993, the FDA established advisory limits for DON in food and feed, notably the 1 ppm limit for humans, and 5 ppm for swine and other animals with the exceptions of poultry and cattle (McMullen and Stack, 1999).

The limits for vomitoxin in barley and barley products are actually set by the companies that purchase the grain and malt. Discounts and premiums are applied based on the tested level of vomitoxin. According to Johnson and Nganje (2000), notwithstanding the limitations of commercial testing technology, discounts for DON in malting barley usually begin at 0.5 ppm and have varied in recent years, depending on crop conditions. In the same study, the authors noted that premiums for “no detectable DON” in wheat (practically less than 0.5 ppm) were in the \$0.55-0.60/bu range during 1997-98. Typically, additional discounts of \$0.05 per point are applied for DON levels above 1.0 ppm and up to 4.0 ppm. Barley with DON higher than 4.0 ppm can be sold as feed at a substantial further discount. However, even for feed barley, there are advisory limits for livestock rations, particularly for swine. Table 2.1 shows the average price discount of malting barley from 1995 to 1998 in the Midwest.

Table 2.1. Market Discounts for Vomitoxin, Midwest Six-rowed Barley, from 1995 to 1998

Marketing Year	Weighted Average Discount (\$/bushel)
1995	0.66
1996	0.47
1997	0.79
1998	0.59
Average	0.63

Source: Adapted from Johnson and Nganje (2000).

Quality variability due to factors like vomitoxin creates uncertainty and risks for both grain producers and merchandisers. Grain traders, in order to capture premiums and circumvent this risks, assemble grains from different producing regions with different quality characteristics in order to satisfy the needs of individual buyers. Johnson et al. (2001) note that elevators segregate grains based on quality factors and enhance their margins through blending and conditioning activities. However, whereas traders and elevators can carry out activities which enable them to cushion, to a certain extent, the effects of risks due to quality uncertainties, producers do not have the flexibility to do the same.

Smith et al. (2001) note that the severity of FHB in the Midwest in the past seven years has varied considerably with as much as 51 percent of the crops estimated to be usable (DON level less than 0.5 ppm) in some years to as little as 21 percent usable in other years. Interestingly, the authors also note that not only did years differ for average DON level and percentage of the crop non-detectable in DON, but also the distribution of the harvested crop with respect to DON level varied from year to year. While in some years DON levels ranged from 0 to 13 ppm, in other years, the level in samples ranged from 0 to 50 ppm.

In North Dakota, the level of variability of vomitoxin among the Crop Reporting Districts (CRDs) was estimated by Johnson et al. (2001). The results shown in Table 2.2 were analyzed from detailed data on the incidence of vomitoxin in 1993 within crop producing regions and across the crop production region.

Table 2.2. Average Levels of Vomitoxin in Barley by Crop Reporting District in North Dakota for 1993

ND Crop Reporting District	Mean (ppm)	Std. Deviation (ppm)
ND-NC	0.65	0.69
ND-NE	4.65	2.58
ND-C	1.54	2.31
ND-EC	7.35	4.01
ND-SE	6.58	3.33

Source: Johnson et al. (2001).

Table 2.2 indicates that all the CRDs have average vomitoxin levels that are greater than the advisory levels, particularly in the northeast (ND-NE), the east central (ND-EC) and southeast (ND-SE), which are all CRDs in the eastern part of North Dakota. There was substantial variability both across and within CRDs. Table 2.2 also indicates that, where vomitoxin is more prevalent, its level is subject to greater uncertainty.

Crop Insurance Schemes

The Risk Management Agency (RMA) of the U.S. Department of Agriculture (USDA) designs and rates the crop insurance products which are then delivered and serviced by private sector insurance companies. The RMA also subsidizes premiums that growers pay for federal insurance policies. The main types of insurance programs presently available for U.S. farmers are the Multi-Peril Crop Insurance (MPCI), Group

Risk Plan (GRP), Crop Revenue Coverage (CRC), Revenue Assurance (RA), and Income Protection (IP). The MPCCI and GRP are the traditional yield insurance programs available to U.S. growers. The CRC, IP, and RA, are revenue insurance products that have been introduced for the crop sector in the recent years. Only the MPCCI, IP, and RA are available for barley growers (Rain and Hail Insurance Service, Inc., 2000). None of the insurance categories or their supplements presently provide an explicit form of coverage for unexpected losses associated with quality deviations.

Yield-based Insurance

The Multi-Peril Crop Insurance (MPCI) is the traditional federal crop insurance yield product. Available since 1938, a revised form of the MPCI was introduced in 1980, covering most crops in the United States. MPCI is a yield-based insurance. The current version is typically referred to as the Actual Production History (APH) program.

The critical issue associated with the MPCI is determining what the normal production level is for an insurable farmer. The USDA requires the producer to present actual annual crop yields (usually stated on a bushel per acre basis) for the past four to ten years. This simple average of a producer's annual crop yields over this time period then serves as the producer's actual production history (APH) (Chite, 2000).

The MPCI provides protection against shortfalls in a grower's expected yields (or a predetermined yield known as guarantee). Buschena and Ziegler (1999) noted that, historically producers could insure crop yields of up to 75 percent of average historic yield (with 80 to 85 percent available in limited areas). Losses are paid when the actual yield is

less than the guarantee (Rain and Hail Insurance, Inc., 2000). 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. With the APH scheme, the federal government presently provides low-level protection known as catastrophic (CAT) coverage. Under the CAT protection scheme, growers must experience a yield loss of at least 50 percent to be able to receive an indemnity (Barnett and Coble, 1999).

With the MPCI, the insured farmer can potentially receive an indemnity or loss payment if the actual yield falls short of his insured yield based on the estimated APH. There seem, however, to be an underestimation of farmers' insurable yields using the present method of calculation of the APH, especially in instances of multiple-year crop losses (like in the case of losses due scab and vomitoxin in the Midwest). When producers are affected by multiple years of disasters, the years of little or no harvested production tend to significantly reduce the producer's APH (Chite, 2000). Farm groups in regions that have been stricken with multiple years of natural disasters in recent years (particularly in the Northern Plains and Texas) have complained that the current system of calculating APH discriminates against them and causes them to be assigned crop yields that are below their true production potential. According to Chite (2000), these producers would like to see some accommodation made so that their yields guarantee is not severely reduced by multiple-year crop losses. Moreover, some farmers have complained that a low APH prohibits them from purchasing adequate levels of insurance to cover their costs of production (Chite, 2000). The estimation of the APH in the scab years, in a manner that

addresses this problem, is one of the concerns of this study.

Current USDA regulations prohibit a farmer's APH from falling more than 10 percent in any one year, nor can it rise more than 20 percent from one year to the next. Congressional provisions P.L. 106-224 stipulate that, effective in the 2001 crop year, a floor would be set under a farmer's past and future annual yields so that yields in any year cannot fall below 60 percent. With this provision, even if a producer has a total crop loss in any year, the yield used for the year to calculate the producer's APH will not be lower than 60 percent of the historical average production for the region (Chite, 2000). This provision is stated in the original House-passed bill, which if adopted by the Senate would help, to a certain extent, in resolving moral hazard issues. However, it is arguable if this bill would completely resolve the worries associated with the calculations of the APH involving multi-year losses like is the current case with losses due to scab and vomitoxin in barley.

Revenue-based Insurance Schemes

The U.S. Congressional Budget Office as early as 1983 considered revenue insurance for agricultural products (USCBO, 1983). It was not until 1996, however, that the RMA started offering revenue insurance and also allowing private insurance firms to develop other insurance products which were accepted for subsidization and re-insurance (Buschena and Ziegler, 1999). Under "revenue assurance" the federal government supports farmers at a set percentage of their gross incomes. Hart et al. (2000) indicate that the revenue insurance products have been well received and thus far have provided an

additional extension to the risk management tools available to crop producers.

The revenue insurance products deal with both price and yield risks. The CRC, RA, and IP products all provide protection against growers' gross revenue (product of yield and price). Insurance indemnity payment may be triggered by low yields or low prices, or by the combination of low yields and low prices (Barnett and Coble, 1999). The CRC, RA, and IP are very similar in design but differ primarily in the level of protection offered and the rating methods employed. They are all reinsured and subsidized by the USDA, and use harvest-month futures prices at sign-up and at harvest to compute losses (Coble et al., 2000). In the spring of 1996, the CRC became the first privately developed policy in the insurance industry to be approved for government reinsurance as an alternative to the MPCl. The CRC, however, is not available for barley growers (Stokes, 1997). The IP, on the other hand, 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 MPCl that low prices can adversely affect their overall revenue or profitability even when yields are high.

The IP provides downside price protection for barley farmers by multiplying the APH and the projected county price. The IP program, just like the MPCl, though to a lesser extent, is hinged on the estimation of the APH. With the IP program, yield setting, loss adjustment, and underwriting procedures are based on the current APH program (American Agrisurance, Inc., 2001). Price setting is accompanied by using the average daily futures market closing prices for the insured crop prior to the sales closing date during harvest. The insured unit is taken from the Group Risk Plan (GRP), an insurance

plan that provides protection based on a county index (American Agrisurance, Inc., 2001). Combined, these components form a straightforward product for the protection of a percentage of the farmers' income. However, as with the MPCI, the APH as presently estimated does not explicitly account for the reduction in the production to count when the quality of the appraised and/or harvested production is reduced.

The American Agrisurance, Inc. (2001) web page details how the APH and the prices are obtained for the IP program. The Income Protection dollar guarantee per acre is calculated by multiplying the APH yield times the projected price times the selected coverage level. The APH yield is calculated at the enterprise level (all acreage of the crop in the county) using current APH rules. The projected price is determined from the commodity futures market prior to planting while the coverage level is selected by the insured. An insured's total guaranteed dollar amount of protection is the net acres of the insured crop (acres times share) in the county times the dollar guarantee per acre. Indemnities are due when the insured's share of production to count (harvested and appraised yields) multiplied by the harvest price (as defined in the insurance policy) is less than the Income Protection guarantee.

The price setting for barley is specifically estimated as follows. The projected price is 85 percent of the average final closing daily settlement prices for the current year Chicago Board of Trade (CBOT) September corn futures contracts for each trading day of February of the current year. The harvest price for North Dakota (and other Midwestern states like Minnesota, Montana, and South Dakota) is 85 percent of the average final closing daily settlement prices for the current year CBOT September corn futures contract

for each trading day for the month of August (period of July 15 through August 14 for Idaho, Oregon, and Washington) of the current year.

Demand and Supply of Crop Insurance and Rating Methodologies

Several studies have been conducted on the supply and demand of crop insurance. For instance, Smith and Baquet (1996) used an econometric approach to analyze the demand for crop insurance by individual farms using cross-sectional data on MPCCI purchases from a large, randomly selected sample of wheat farmers in Montana. Their analysis examined both the determinants of participation decision and the level of coverage selected by the farms that did purchase MPCCI as opposed to previous studies which did not use these variables in a simultaneous manner. An important conclusion from this study is that premium rates were found to have no measurable effects on MPCCI participation but reduced coverage levels.

Very few studies have dealt with modeling catastrophic risks. The model by Duncan and Myers (2000) presently provides a solid foundation to model the demand and supply for crop insurance under catastrophic risk. The authors develop theoretical models to show how catastrophic risk may affect the nature and existence of crop insurance market equilibrium. The approach by Duncan and Meyers (2000) has been adopted in this study.

Expected utility maximization is usually the theoretical framework within which the determinants of insurance purchase are examined and is the framework used by Duncan and Myers (2000). If the purchaser is a farmer, the assumed goal is to maximize the expected utility of profits subject to a set of production and market environment

constraints. Pulley (1981) indicated that the Mean Variance (MV) Model was precisely consistent with the expected utility hypothesis only in the special cases of normally distributed security returns or quadratic utility functions. To this extent, most studies on the demand and supply of crop insurance have used the MV approach with assumptions of normality in the distribution of returns and losses. According to Kroll et al. (1984) there are, however, problems with the MV approach that arise from the assumptions about the distribution of returns and from the form of the utility function. However, despite the limitations of the MV model, empirical analysis has shown that the results of MV approximations are very good for some utility functions (Levy and Markowitz, 1979).

Some studies have compared various revenue insurance plans to the MPCl. Harwood et al. (1994) found the revenue insurance alternatives to be less expensive and more effective at supporting farm income than the yield-based farm policies. Stokes et al. (1997) found in their study on the pricing of revenue insurance that a whole-farm based gross revenue plan is generally less costly than a weighted average of individual crop plans. The budgetary and producer welfare effect of revenue insurance was studied by Hennessy et al. (1997) with the suggested finding that a revenue insurance program would provide greater benefits at lower costs than the 1990 farm program.

Turvey and Amanor-Boadu (1989) examined premium setting for revenue insurance for a representative Ontario cash crop farm. The authors alluded to the problem of assuring a normal distribution when the underlying distribution is non-normal. They indicated that if, for instance, the underlying distribution is positively skewed, then the normality assumption leads to higher premiums.

Crop Insurance, Moral Hazard, and Adverse Selection

Asymmetric information in the agricultural insurance market, particularly adverse selection and moral hazard problems, have been known to provide opportunities for market failure. “Because of asymmetric information, the insurer may not be able to tailor contracts to the individual farmer’s circumstances” (Smith and Baquet, 1996: p.190). With the current MPCCI program, for instance, premium rates are set on a county-wide basis in relation to county-wide losses, which has the tendency to give rise to adverse selection problems. Adverse selection occurs when farmers with higher probabilities of losses face higher expected returns from participation and, therefore, are more likely to participate in the program than farmers with lower probabilities of losses. In addition, the authors indicate that the very structure of the MPCCI constitutes a source of adverse selection problems as farmers’ yields are expected to fall below 75 percent of insured yields for insurance protection to be guaranteed. Thus, operators whose yields rarely or never fall below 75 percent of average yields will not participate in the program.

Moral hazard, on the other hand, occurs when farmers can deliberately influence losses because insurers are unable to monitor farming practices with any degree of precision. Babcock and Hennessy (1996) examine the issue of moral hazard with revenue insurance and conclude that, if coverage levels are kept below 80 percent, then farmers’ input decisions are not greatly affected.

Moral hazard issues can be very significant with any explicit insurance coverage for scab and vomitoxin risk in barley. Moral hazard related concerns on the part of the insured barley grower can be associated with factors like insufficient irrigation (in the case of an

irrigated field), the use of marginally adapted varieties, non weather-related delayed harvest, and inappropriately high plant density. To check these concerns, the USDA-FCIC (2001) LAM Standards Handbook has put forth a set of procedures associated with adequately quantifying the reduction in value (RIV) due to a mycotoxin such as vomitoxin for purposes of insurance coverage. The three-step procedure aims at ensuring a proper testing for the level of vomitoxin contamination, an adequate estimation of the production to count, and a fair market value for the mycotoxin-contaminated grain.

Essentially, the USDA-FCIC (2001) LAM Standards Handbook stipulates that tests for the mycotoxin should be conducted by a reliable testing facility where there is adequate documentation of information like the test date, the test type (qualitative or quantitative), the type and level of mycotoxin established from the test, and the name and location of the testing facility). In addition, the determination of the production to count and the fair market value of the grain should be conducted by an accredited grader licensed under the authority of the U.S. Grain Standards Act or the U.S. Warehouse Act. For instance, in North Dakota, quantitative analysis for several mycotoxins, including DON, is provided by the Veterinary Science Diagnostic Laboratory at North Dakota State University (McMullen and Stack, 1999). Lastly, the RIV should be estimated for sold production, unsold production, and feed production.

With the procedure to avert moral hazard problems clearly spelled out, the USDA-FCIC (2001) LAM Standards Handbook provides further, specific standards under which mycotoxin contaminations should be adjusted for crop insurance coverage. The handbook stipulates that the RIV of insured crops should be considered due to a mycotoxin only if an

economic level of the mycotoxin is present in the grain prior to storage (that is, the grains should be field-infested) and if the presence of the mycotoxin is established to be due to insurable causes. Mycotoxin economic levels are those exceeding the advisory levels and/or feeding restrictions placed by university, research, and/or the FDA.

CHAPTER III

PROCEDURES AND METHODS

The three major challenges in designing actuarial fair insurance schemes are to effectively determine the distribution of price and yield risk, develop a mechanism that explicitly estimates the losses, and evaluate moral hazard and adverse selection problems (Duncan and Myers, 2000; Goodwin et al., 2000; Stokes et al., 1997). These issues become even more critical in developing models to incorporate losses associated with quality risk as is the case with scab and vomitoxin in barley.

Three USDA-funded projects (Johnson et al., 1998; USGAO, 1999; Nganje et al., 2001) have developed methods and procedures to estimate yield and price losses as a result of scab and vomitoxin in wheat and barley. In this chapter, these methods and procedures are briefly summarized and used to develop models to estimate insurable losses for the MPCCI and IP programs with the explicit incorporation of scab and vomitoxin. Demand and supply functions for the MPCCI and IP programs are then developed using the Mean-Variance framework proposed by Duncan and Myers (2000). Finally, an equilibrium model is developed and used to simulate equilibrium coverage levels and premiums in a scenario that incorporates scab and vomitoxin risk and in another scenario that ignores scab and vomitoxin risks. This approach ensures that the impact of incorporating scab and vomitoxin losses in the existing insurance instruments could be effectively assessed.

Estimation of Losses Due to Scab and Vomitoxin

The econometric procedure proposed by Johnson et al. (1998), USGAO (1999), and Nganje et al. (2001) provides a framework to effectively estimate the losses from yield and price effects as a result of scab and vomitoxin. This approach accounts for the fact that, in principle, scab can either raise or lower the net price received by producers. On the one hand, a production shortfall due to scab puts upward pressure on market prices and can lead to higher-than-expected premiums. On the other hand, poor quality due to scab and vomitoxin can induce a larger share of production to be discounted, leading to lower-than-normal prices received by producers despite favorable quoted prices for benchmark grades.

In the estimation of the Reduction in Value (RIV) of grains, the RIVs were separated into the price and quantity effects. Estimates of these effects vary depending on whether actual prices (ps) or conditional prices (pn) are used to value production shortfalls. Actual prices (ps) are prices effectively received by barley farmers in a scab year while conditional prices (pn) are those that farmers would have received in the absence of scab and vomitoxin. The RIV per acre due to scab and vomitoxin for a representative farmer in a given CRD is the difference between the farmer's actual and conditional crop value. The normal or conditional crop value per acre is the product of the price that farmers would have received (pn) and their expected yield under "normal" conditions (yn) (expected yield had there been no scab outbreak). For years of scab outbreak, both yn and pn are unobserved and, therefore, must be estimated.

Estimating RIV from Yield Impacts

To derive yield in the absence of a scab and vomitoxin epidemic, the following regression model was used:

$$(1) \quad y_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 R_{it}^2 + \beta_3 T_{it} + \beta_4 t,$$

where

y_{it} = harvested yield in region i in year t

R_{it} = the difference between average total precipitation and total precipitation during the growing season divided by the standard deviation of total rainfall for region i and year t

R_{it}^2 = the squared value of R_{it} , the precipitation deviation variable

T_{it} = the difference between historical average temperature during the growing season and the average temperature during the growing season divided by the standard deviation of average temperature for region i and year t

t = a time-trend variable.

T_{it} and R_{it} , respectively, measure the closeness of the average temperature and total rainfall of a particular year to its historical average. Values greater than +1 are associated with hot weather or wet months, values less than -1 with dry or cool months, and values between +1 and -1 near the average. These transformed weather variables are used in the regression rather than the actual values because they are more significantly related to yield and contained less multicollinearity (USGAO, 1999b). In addition, the squared precipitation term is justified by the fact that there is an optimum level of precipitation beyond which yields may decrease and the fact that it has been widely used by some

agricultural economists analyzing yields (USGAO, 1999b). The annual time-trend variable (t) represents yield changes due to changes in such things as technology, input use, or farm size. The parameter β_4 is a measure of trend yield growth caused by these changes.

Separate equations were estimated for each CRD, using data for years preceding severe scab outbreak. The results of the estimated coefficients (β s) and model fitness obtained are shown in the Table A.1. The hypothesis that barley yields were homogeneous across farmers in different CRDs was tested using the Chow Test and rejected at the 0.05 level of significance, justifying the use of yield estimates from separate CRDs in the regressions analysis (USGAO, 1999b). The estimated coefficients of the regression models were used to derive estimates of the forecasted yields (yf) that would have occurred in later years (given growing conditions) in the absence of scab. However, scab and vomitoxin do not occur in isolation of other diseases or factors that can potentially reduce crop yields and quality. The percentage of yield losses that a farmer would incur from the sole effects of scab, α_{it} , was estimated with inputs from researchers and extension specialists and then used to calculate conditional yields (yn_{it}), the estimated conditional yields that would have occurred in the absence of scab. The average values of α_{it} are shown in Table A.2. α_{it} was incorporated in the estimation of yn_{it} as shown in equation 2.

$$(2) \quad yn_{it} = \alpha_{it}yf_{it} + (1 + \alpha_{it})ys_{it},$$

where

yn_{it} = conditional yield in the absence of scab for typical farmer i and year t

yf_{it} = predicted yield from the regression equation 1

ys_{it} = actual yield in a scab-affected year

$\alpha_{it} = (0 \leq \alpha_{it} \leq 1)$ is the fraction of a yield shortfall attributable to scab

The conditional yield (yn_{it}) is a weighted average of the regression forecast (yf_{it}) and actual yield (ys_{it}). Figure 3.1 depicts the average actual yield (ys_{it}), forecasted yield (yf_{it}), and the conditional yield (yn_{it}) in one of the CRDs, north eastern North Dakota (ND-NE), included in the study.

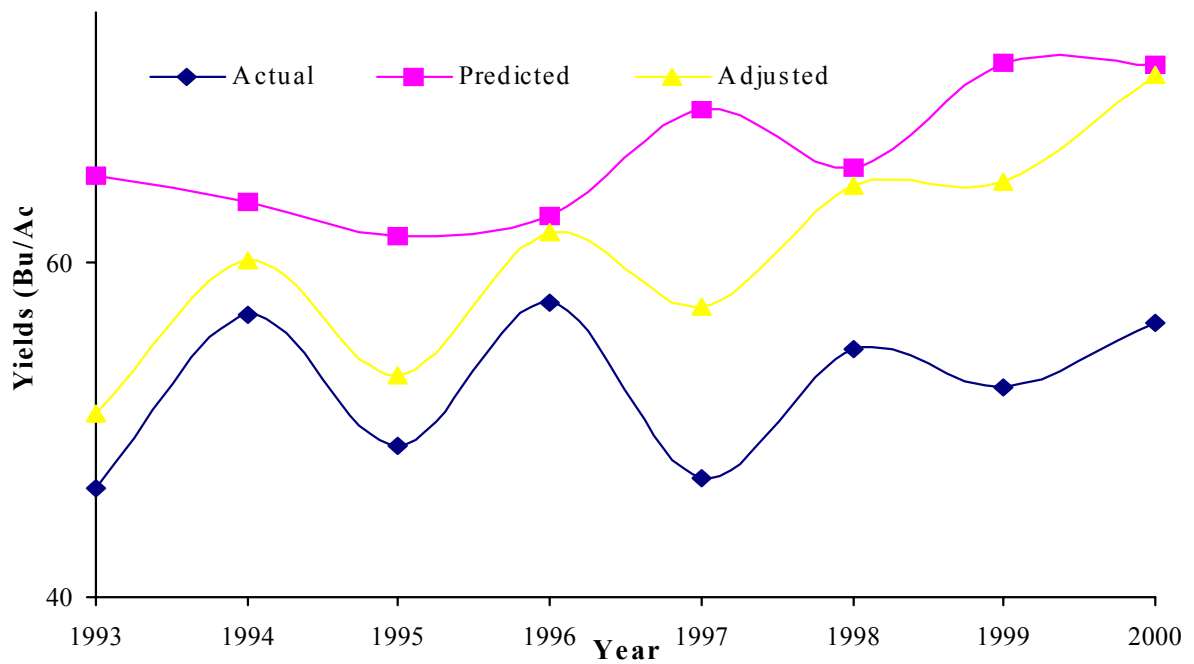


Figure 3.1. Average Actual Yield, Predicted Yield, and Adjusted Yield for ND-NE.

If $\alpha_{it} = 1$ for a typical farmer in a given region and crop year, then conditional yield equals the predicted value, and any estimated yield shortfall ($yf_{it} - ys_{it}$) is attributed entirely to FHB. If $\alpha_{it} < 1$, then the conditional yield lies between the regression forecast and actual yield, and part of the estimated yield shortfall is attributed to other factors. Figure 3.1

reveals that the average barley yield shortfalls in northeastern North Dakota (ND-NE) in 1996, 1998, and 2000 were mostly attributable to FHB while, in the other years, just a minuscule fraction of the shortfall was attributable to scab. For instance, FHB was responsible for 90 percent of the total barley yield shortfall in 1998 while, in 1997, the value of α_{it} was approximately 46 percent (Table A.2).

Estimating RIV from Price Impacts

In estimating the impact of scab and vomitoxin on the net price received by barley producers, two factors were considered: the impact on malting premium and the impact on feed grain prices. USGAO (1999b) proposed a two-step procedure to estimate both malting barley premiums and feed grain prices had there been no scab. Step one involved estimating price equations for both malting barley premiums and feed prices prior to the scab and vomitoxin outbreak. Step two involved using the estimated equations to predict, in the scab years, the malting and feed barley prices that should have been obtained in the absence of the scab epidemic.

In step one, regression analysis was run using historical data on price and production from 1959 through 1992. It was assumed, that since the proportion of malting to total barley production (feed and malting) was fairly stable in the years preceding the scab epidemic, increases in total barley production translated into increases in the proportions of malting barley production. Another consideration was that, while there are differences in barley premiums from region to region, prices are generally transmitted from the malting and brewing industries at a more aggregate market level. To this extent, the

historical association between malting premiums, P_j^m , and total U.S. barley production, Q_j , for each CRD were derived as shown in equation 3.

$$(3) \quad P_j^m = a_0 + a_1 Q_j$$

The regression coefficients are presented in Table A.3. A negative and statistically significant association exists between malting premiums and total barley production at the national level for all the typical farmers in the various regions. To solve the problem of the presence of positive serial correlation across the CRDs, the Yule-Walker regression technique was used to derive the parameter estimates. This technique starts by forming the ordinary least-square estimates of parameters. Next, given the vector of auto-regressive parameters (using the Yule-Walker equations) and the variance matrix of the error vector, efficient estimates of the regression parameters were computed using generalized least squares.

In the feed grain market, corn is the primary feed grain product, accounting for more than 80 percent of total feed grain consumption. It has also been shown that barley feed grain prices are driven primarily by corn prices (USDA-GIPSA, 1999b). In equation 4, the historical association among barley feed grain prices P_j^f , the price of corn, P_c , and total U.S. barley production, Q_j , is specified:

$$(4) \quad P_j^f = a_0 + a_1 P_c + a_2 Q_j$$

To correct for first-order serial correlation, as in the malting premium regression models, the Yule-Walker regression technique was again used for the feed grain models.

The total barley production variable was found to be negative and significant at the 0.10 percent level in all but one of the CRDs. In addition, the corn price was positively related to barley feed grain prices and statistically significant in all the CRD (Table A.4).

The second step of estimating the impact of scab and vomitoxin on the net price received by barley producers involved predicting what malting barley and feed grain barley prices would have been had there been no scab and vomitoxin in the years of and following the outbreak. This step was accomplished by substituting the actual values of barley production and corn prices for the scab years in equations 3 and 4. Malting barley prices were assumed to be the sum of estimated feed grain prices plus estimated malting premiums.

Barley production data are generally furnished in the form of total production and are not separated out for the malting and the feed grain markets. However, it is important to estimate the amount of production in the absence of scab and vomitoxin that would have gone to the malting barley and feed grain markets in each CRD and for each of the years following the scab outbreak. This estimate is of relevance because, in this study, it is assumed that price discounts due to vomitoxin contamination are applied only on the malting barley portion of the market and that no further discounts are applied below the feed barley price. The portions of the crop yield destined to be sold as malting barley and feed grain barley were derived by using actual data on the prices of malting barley, P_M , feed grain barley, P_F , and the total average barley price, P_B . Equation 5 indicates how P_B is derived.

$$(5) \quad P_B = nbar_i^m * P_M + (1 - nbar_i^m) * P_F,$$

where

P_B = weighted average of malting and feed grain price

P_M = actual malting barley price

P_F = actual feed grain barley price

$nbar_i^m$ = proportion of barley sold to the malting market by farmer i

$(1 - nbar_i^m)$ = proportion of barley sold to the feed grain market by farmer i

The overall price of barley, P_B , is a weighted average of the malting and feed grain price. Rearranging terms in equation 5, the proportion of barley sold to the malting market can be expressed as a function of the observed prices as in equation 6.

$$(6) \quad nbar_i^m = (P_B - P_F) / (P_M - P_F)$$

Historical malting and feed grain prices from 1959 through 1992 were used to estimate the proportion of barley sold to the malting market for each year and, consequently, the proportion of barley sold to the feed grain market. The weights obtained represent the proportions of malting barley and feed barley in the market in a typical year before the scab outbreak. Table A.5 shows the overall estimated average weights in CRD.

To estimate the portion of the yield in the absence of scab and vomitoxin that would have gone to the malting barley and feed grain markets for each district in the years following the scab outbreak, the weights in Table A.5 were multiplied by the estimated conditional barley yield (assuming the absence of scab and vomitoxin), yn_{it} .

Estimation of the Insurable Losses with Scab and Vomitoxin Risk

Objective one of this study is addressed under this sub-section. The MPCCI and IP insurance programs were retained for the analysis. The potential loss per acre that would be incurred by a typical farmer in each CRD and insurable under either of the insurance programs was estimated in a scenario excluding the risk due to scab and vomitoxin, and in another scenario incorporating these risks. Emphasis was laid on the potential insurable loss under each program. Conventionally, however, for either program, growers are supposed to choose coverage levels and election prices which then determine the indemnity receivable.

Loss Coverage under MPCCI

The MPCCI, a yield-based insurance, is hinged on the Actual Production History (APH) of the farmer. The traditional MPCCI estimates the grower's expected yield in a given year using four to ten years of his actual verifiable production records (APH yields). Indemnities are payable to the farmer only in the instant when the actual yield is less than the expected yield. In the traditional scenario which does not explicitly incorporate the risk due to scab and vomitoxin, the value of the potential production loss covered by the MPCCI is modeled as depicted in equation 7.

$$(7) \quad Y_{ys_{it}} = \text{Max}[0, (APH_{ys_{it}} - y_{s_{it}})] \cdot ps_{it},$$

where

$Y_{ys_{it}}$ = value of loss per acre covered by the MPCCI in the absence of scab and vomitoxin risks

$APH_{ys_{it}}$ = calculated APH using actual yields, ys_{it}

ys_{it} = actual yield of typical farmer i in scab-affected year t

ps_{it} = actual price per bushel received in region i and scab-affected year t

The function $Max[0, (APH_{ys_{it}} - ys_{it})]$ ensures that there is no insurance coverage when the producer's actual yield is greater than the APH yield. In a scenario which explicitly incorporates the risk due to scab and vomitoxin, the potential value of loss covered by the MPCCI will be as depicted by equation 8.

$$(8) \quad Yyn_{it} = Max[0, (APH_{yn_{it}} - ys_{it})] \cdot ps_{it}$$

where

Yyn_{it} = value of loss per acre covered by the MPCCI with the explicit incorporation of scab and vomitoxin risks

$APH_{yn_{it}}$ = calculated APH, using $Max[yn_{it}, ys_{it}]$

yn_{it} = conditional yield of typical farmer i in the absence of scab

ys_{it} = actual yield of typical farmer i in scab-affected year t

ps_{it} = actual price per bushel received in region i and scab-affected year t

The "Max" attribute in equation 8 ensures that no indemnity is paid when the yield guaranteed is less than the actual yield. $APH_{yn_{it}}$ is estimated using $Max[yn_{it}, ys_{it}]$ so that, in the unlikely event of the estimated conditional yield (yn_{it}) being less than the actual yield (ys_{it}) in a scab year, the latter yield should prevail.

Loss Coverage Under IP

The Income Protection (IP) is a revenue insurance product that protects producers

against reductions in gross income when a crop's price or yield, or a combination of both, declines from early season expectations. The IP equally relies on the APH in estimating the grower's gross revenue. The IP insurance makes indemnity payments when gross revenue falls below the revenue guarantee.

In the empirical estimations in this section, the harvest price was assumed to be the actual cash price at harvest in the scenario that does not explicitly incorporate scab and vomitoxin. The base price used for the calculation of the revenue guarantee was assumed to be 85 percent of the corn price of the previous year. This assumption is based on the historical relationship between corn and barley prices. The estimation of non-scab adjusted IP coverage is as depicted in equation 9.

$$(9) \quad Rys_{it} = \text{Max}[0, (APH)ys_{it}pn_{it} - ys_{it}ps_{it}],$$

where

Rys_{it} = value of revenue loss per acre covered by the IP without explicit incorporation of scab and vomitoxin risks

$APHys_{it}pn_{it}$ = calculated guaranteed revenue for typical farmer i in year t

$ys_{it}ps_{it}$ = calculated actual revenue for typical farmer i in year t

ys_{it} = actual yield in production region i and scab-affected year t

pn_{it} = base price per bushel received in region i and scab-affected year t

ps_{it} = actual price per bushel received in region i and scab-affected year t

In the scenario which explicitly incorporates losses due to scab and vomitoxin, the potential revenue loss covered by the IP involves two components. The first component is the traditional insurable revenue loss adjusted for the explicit incorporation of scab and

vomitoxin risk using scab-adjusted APH, and the forecasted cash price of barley at harvest had there been no scab. The base price, like in the previous scenario, is assumed to be 85 percent of the corn price of the previous year. The second component is the potential revenue loss as a result of ensuing price discounts of malting barley for quality shortfalls due to vomitoxin. The total potential revenue loss that is covered by the IP program in a scenario that explicitly incorporates scab and vomitoxin risk is modeled as depicted in equation 10.

$$(10) \quad Ryn_{it} = \text{Max}[0, (APHyn_{it}pn_{it} - ys_{it}ps_{it} + Dv_{it})],$$

where

Ryn_{it} = value of revenue loss per acre covered by the IP with the explicit incorporation of scab and vomitoxin risks.

$APHyn_{it}pn_{it}$ = calculated guaranteed revenue for typical farmer i in year t

$ys_{it}ps_{it}$ = calculated actual gross revenue for typical farmer i in year t

Dv_{it} = discounted quality loss per acre due to vomitoxin in region i and year t

yn_{it} = conditional yield in the absence of scab in production region i and year t

ys_{it} = actual yield in production region i and scab-affected year t

pn_{it} = base price per bushel in region i and scab-affected year t

ps_{it} = actual price per bushel received in region i and scab-affected year t

The maximum functions in equations 9 and 10, just like in equation 8, ensure that no indemnities are paid when the revenue guaranteed is less than the farmer's gross revenue. In computing the Dv_{it} employed in equation 10, equation 6 was used to estimate the proportion of malting barley for each scab year on which the discount schedule was

applied. It was assumed, as previously indicated, that all the malting barley discounted into the feed category as well as all the initial portion of feed barley for each year had tolerable limits for animal consumption (that is, none of these is further discounted to a zero value due to very high limits of vomitoxin). The price discount schedule was then applied on the weighted proportion of malting barley under each discount category.

Insurance Framework

The expected utility maximization framework is used in the study to develop the equilibrium demand and supply functions for MPC1 and IP with scab and vomitoxin coverage. The framework characterizes the utility of private insurance agents and growers faced with quality risks, and uses it 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 criterion 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, the certainty equivalent, can be expressed as (Serrao and Coelho, 2000):

$$(11) \quad U(W^*) = \int U(W_0 + \tilde{x})f(x)dx ,$$

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

$f(.)$ = is a density function of \tilde{x}

Equation 11 shows what should be the certainty level of wealth without quality risk (in this context) that originates the same utility level as an investment with quality risk.

Equation 11 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, 1987). 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 defined as

$$(12) \quad \phi \approx \frac{1}{2} \left[-\frac{U''(W)}{U'(W)} \right] \text{var}(\tilde{x}),$$

where

ϕ = is the risk aversion parameter

$U'(W)$ = first derivative of the utility of wealth

$U''(W)$ = second derivatives of the utility of wealth

$\text{var}(\tilde{x})$ = is the variance of the risky investment

A comparable measure of risk aversion is relative risk aversion, which is 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. It is assumed barley growers are risk averse such that they will present the following profile:

- they will exhibit constant, decreasing, or increasing risk aversion to crop quality insurance if investments in quality insurance do not significantly affect, increase, decrease their returns, respectively
- they 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 13 as

$$(13) \quad P_a = W^* - W_0,$$

where

P_a = is the asking price or the price that an investor is willing to sell the investment (Serrao and Coelho, 2000). 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).

$$(14) \quad \pi = \mu - P_a,$$

where

π = is the risk premium of an additive investment (in this case quality risk)

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 (2000) was developed to analyze the impact of quality risks on premium levels and to determine the asking price. The exception to the model is that the distribution of losses (quality-related losses in this context) across CRDs is different. Furthermore, the covariance between the average losses incurred by farmers in each CRD and the entire state is not identical. Other studies (Serrao and Coelho, 2000) have used a mathematical programming 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.

In order to focus on the catastrophic nature of scab and vomitoxin risk, the equilibrium model is built around a number of simplifying assumptions similar to those proposed by Duncan and Myers (2000). The insurance market was assumed to be

characterized by a very large number of individual farmers, N , each with known potential income M . Each farmer was assumed to face a stochastic loss, l , which takes the value L with known probability P and *zero* with known probability $(1-P)$. The end-of-period income of each farmer is therefore $M-l$. In order to abstract from problems of asymmetric information, P was assumed to be known by all participants. Furthermore, all the farmers were assumed to face the same marginal probability distribution for l . However, the losses of each pair of farmers may be correlated.

The first assumption for insurance firms was that they were identical and offered contracts to farmers to insure against their loss, l . The existence of the insurance market is fully described by the triple (w, φ, n) , where φ is the coverage level, w is the insurance premium per unit of coverage, and n is the number of contracts held by each insurance firm. φ , the coverage level, lies in the range $[0,1]$ and is quoted as a proportion of the loss. For example, $\varphi = 0.6$ indicates 60 percent of any loss would be reimbursed by the insurance firm. Last, the model is also based on the assumption that the providers of insurance are risk averse, based on uncertainties (monitoring costs and the catastrophic nature of FHB) or the potential moral hazard behavior of growers. They, therefore, have incomplete opportunities to diversify high-quality risks from scab and vomitoxin.

The equilibrium model developed in this study has three parts. The first and second parts of the model respectively derive the demand and supply of insurance. The last part of the model derives a competitive equilibrium that equates demand and supply to derive equilibrium coverage levels and premiums with and without reinsurance.

The Demand for Insurance

The problem facing growers in their quest for insurance coverage is the choice of a coverage level that maximizes their end-of-period incomes given the risks they face. In order to model this situation, the farmers' end-of-period wealth was specified, and a linear mean-variance (M-V) preference function (Robison and Barry, 1987) was used to characterize the demand for insurance. The end-of-period income with the purchase of insurance is given by equation 15.

$$(15) \quad I_d = M - w\varphi_d - (1 - \varphi_d)l.$$

l is the stochastic yield and price loss (l takes the value L with known probability P and 0 with probability $1-P$). l is estimated for MPC1 and IP with and without explicit consideration of scab and vomitoxin losses. The basic assumption that the probability of loss, P , is known by all participants is realistic in this study given the availability of scab and vomitoxin data for representative farmers from CRDs. This assumption enables the model to abstract from problems of adverse selection and moral hazards. The M-V specification of the demand for insurance is given by equation 16.

$$(16) \quad U = M - w\varphi_d - (1 - j_d)\bar{l} - 0.5l(1 - \varphi_d)^2 s_l^2.$$

In equation 12, $\bar{l} = PL$ is the stochastic loss per acre; $\varphi_d \bar{l}$ is the proportion of the loss reimbursed by insurance if there is scab and vomitoxin outbreak; σ_l^2 is variance of loss, and λ is the risk aversion parameter. The first-order condition for the optimal coverage level for crop insurance with quality risk is given by equation 17.

$$(17) \quad -w + \bar{l} + \lambda \sigma_l^2 (1 - \varphi_d) = 0$$

Equation 13 represents the demand for crop insurance at premium w . The second-order condition for a maximum is satisfied because $-\lambda \sigma_l^2 < 0$. Emphasis in this study was laid on coverage levels, φ_d , with the explicit incorporation of quality risks due to scab and vomitoxin. From equation 13, it is expected that the demand for crop insurance will decrease as the premium increases, as well as increase with increasing expected loss; farmers' risk aversion, λ ; and variance of loss, σ_l^2 . The comparative statics results when equation 17 is specified as a vector of equations is presented in the Appendix.

The Supply of Insurance

Equation 18 presents the end-of-period profits for firms selling insurance to representative growers from CRDs and reinsuring some proportion, α , of the policies.

$$(18) \quad I_s = n \varphi_s [(1 - \alpha)(w - c)] - \varphi_s (1 - \alpha - \delta) \sum_{i=1}^n l_i.$$

In equation 18, subscript s refers to the supply of insurance. n is the the number of policies; c is the insurance costs; and $1 - \alpha$ is the proportion of premium left after reinsurance. The insurance company gives up some proportion α , ($0 \leq \alpha < 1$), of its premium to a reinsurer who, in return, accepts the responsibility to pay some proportion $(\alpha + \delta)$ of indemnity with the value of δ satisfying $0 \leq \delta < (1 - \alpha)$. As in the case of the demand for insurance, risk averse insurance firms were assumed to have M-V preferences.

The M-V specification of the supply of insurance is given by equation 19.

$$(19) \quad V_S = n\varphi_S[(1-\alpha)(w-\bar{l}-c) + \delta\bar{l}] - 0.5\Theta n\varphi_S^2\sigma_I^2(1-\alpha-\delta)^2[1+(n-1)\rho].$$

Θ is the risk aversion parameter of the insurer. Θ is different from λ (the risk aversion parameter of the producer) because insurance companies are assumed to be more diversified and larger than barley producers from a CRD. ρ is the correlation coefficients of losses between any two farmers and the measure of the catastrophic nature of the risk insured (scab and vomitoxin outbreaks). ρ is defined and derived in the Appendix. The explicit elaboration of the derivation of The Variance of Insurance Profit is also presented in the Appendix. Following Duncan and Myers (2000), it was assumed for simplicity in this study that ρ is the same for every pair of farmers. Other assumptions for the supply of insurance were that the values of α and δ are set exogenously by government policy.

The insurance firm's short-run problem is to chose a coverage level offer, φ_S , to maximize equation 19, assuming a given premium, w , and number of policies, n . The properties of equation 19 are presented in the Appendix. The number of policies per firm, n (hence, the number of firms), is determined by competition in the insurance market (Duncan and Myers, 2000). Assuming a fixed n and w , the first-order-condition that maximizes equation 19 for the firm is presented in equation 20.

$$(20) \quad (1-\alpha)(w-\bar{l}-c) + \delta\bar{l} - \Theta\varphi_S\sigma_I^2(1-\alpha-\delta)^2[1+(n-1)\rho] = 0$$

Equation 20 represents the short-run supply of insurance at coverage level φ . The relationship $-\Theta\sigma_I^2(1-\alpha-\delta)^2[1+(n-1)\rho] < 0$ shows that the second-order condition

for a maximum is satisfied. From equation 16, the margin between premium received and cost of insurance is $(w - c)$, and there is no subsidy from the reinsurer when $\delta = 0$. It is expected that the short-run supply for insurance will increase with increasing w ; and decrease with increasing \bar{l} (expected loss), ρ (the correlation of loss), and σ_l^2 (the variance of loss). The comparative statics results with equation 20 specified as a vector of equations are presented in the Appendix.

Competitive Equilibrium

It was assumed that, in the long run, insurance firms would maintain a reservation preference level b so that the MV preference function of the firm (equation 19) is equal to b in long-run equilibrium (Appelbaum and Katz, 1986; Duncan and Myers, 2000).

$$(21) \quad n\varphi_S[(1-\alpha)(w-\bar{l}-c)+\delta\bar{l}]-0.5\Theta n\varphi_S^2\sigma_l^2(l-\alpha-\delta)^2[1+(n-1)\rho]-b=0.$$

Duncan and Myers (2000) defined the competitive equilibrium in a model with catastrophic risk and subsidized reinsurance as the premium level, w^* ; coverage level, φ^* ; and number of policies, n^* , for each firm that satisfies equation 17 (the demand for insurance), equation 20 (the short-run supply of insurance by a competitive firm), and equation 21 (the long-run supply of insurance by a competitive firm). The long-run insurance equilibrium is defined here with the assumption of identical firms and farmers facing identical marginal loss distributions. The simultaneous solution of the three equations determines the long-run equilibrium: w^* , φ^* , and n^* . By solving for w in

equation 17 and substituting its value into equation 20, the short-run equilibrium coverage level can be given as in equation 22.

$$(22) \quad \varphi = \frac{(1-\alpha)(\lambda\sigma_l^2 - c) + \delta\bar{l}}{(1-\alpha)\lambda\sigma_l^2 + \Theta\sigma_l^2(1-\alpha-\delta)^2[1+(n-1)\rho]}.$$

For any given n , equation 22 gives the equilibrium coverage level that equates the demand and short-run supply of insurance. Equation 22 is used in this study to empirically derive the effects of the risk from scab and vomitoxin on the equilibrium coverage, φ , for the MPCI and IP programs. Theoretically, it can be observed from equation 22 that the supply for insurance increases with increasing w ; and decreases with increasing expected loss, \bar{l} , correlation, ρ , and variance of loss, σ_l^2 (Appendix). For any given n , equation 22 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 do 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 quality uncertainties due to scab and vomitoxin distinguishes this research from prior studies in this area.

Simulation Procedure and Data

Equation 22 is used to simulate the impacts of quality losses and risk from FHB on the equilibrium coverage level (φ^*) and premiums for MPCCI and IP. Simulations were conducted using @Risk (Palisade Corporation, 2000) for the two insurance programs, MPCCI and IP.

The first task was to determine the correlation matrix (ρ) and use it to determine the catastrophic nature of scab and vomitoxin 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, 2000). In the case of scab and vomitoxin, outbreaks are particularly severe in years with higher rainfall and humidity, and losses have been highly correlated across insureds from different geographical regions.

Step two involved selecting distributions for \bar{l} (insurable loss presented in the Appendix), α (the cost for reinsurance), and δ (subsidy from reinsurance). The simulations were conducted for each program under the three scenarios of no reinsurance, non-subsidized reinsurance, and subsidized 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 uniform distribution was defined for α (the cost of reinsurance) and δ (subsidy from reinsurance). With no reinsurance, the values of α and δ were both equated to zero. In the scenario of reinsurance, the value of α ranged from greater than nil to one. With subsidized reinsurance, the value of δ ranged from nil to $1-\alpha$ and was equated to zero when the reinsurance was non-subsidized.

Assessing the Catastrophic Nature of Scab and Vomitoxin Risk

The coefficient of the correlation of losses between farmers (ρ) was used as the proxy for assessing the catastrophic nature of the scab and vomitoxin risk. A correlation matrix was developed using panel data from 1993 to 2000 for typical farmers from all CRDs in the study area. The mean value of ρ for both the MPCCI and IP insurance programs in the state was computed for losses with and without the incorporation of scab and vomitoxin. ρ was analyzed together with the variance of losses.

Sensitivity Analyses

Sensitivity analyses were conducted for λ (the risk aversion parameter of the farmer) and for the correlation of losses (ρ). With the assumption of risk-averse farmers and insurance suppliers, a risksimtable (assuming values from 0 to 5) in *@Risk* (Pallisade Corporation, 2000) was defined to calibrate the degree of risk aversion for both λ (the risk aversion parameter of the farmer) and Θ (the risk aversion parameter of the insurers).

The sensitivity analysis for the correlation coefficient (ρ) involved defining a risksimtable for ρ from 0 to 1. Only positive values of ρ were considered (Duncan and Myers, 2000) in order to focus on the catastrophic nature of scab and vomitoxin risk. Different values of Θ (the risk aversion parameter of the insurers) were used while simulations were conducted under the following three scenarios: when the insurer is less risk averse than the producer (for $\lambda < \Theta$), when both the insurer and producer are similarly risk averse ($\lambda = \Theta$), and when the insurer is more risk averse ($\lambda > \Theta$).

The final step involved using *@Risk* (Pallisade Corporation, 2000) to simulate

equilibrium coverage levels. The premiums rates at the equilibrium coverage levels were estimated for both the MPCCI and the IP insurance programs, first without incorporating scab and vomitoxin risk and then with the explicit incorporation of these risks.

Data

Data from all barley producing CRDs for North Dakota from 1959 to 2000 were used for the analysis. Data on planted and harvested acres, harvested yield, and production were obtained from the National Agricultural Statistics Service (NASS) of the USDA. The North Dakota Agricultural Statistics Service (2001) and the National Grain and Feed Association (NGFA, 2001), through their websites, specifically provided information on malting barley prices, feed grain barley prices, and average barley yields for the different CRDs from 1959 through 2000. The quality data on scab and vomitoxin levels for the CRDs were obtained from the Cereal Science Department at North Dakota State University. Data on temperature and precipitation from 1950 to 2000 by region were obtained from the web site of the National Climatic Data Center (USDC-NCDC, 2001). The price-discount schedule for vomitoxin in barley was adopted from Johnson and Nganje (2000).

CHAPTER IV

EMPIRICAL RESULTS

This chapter presents the empirical results based on the models developed in Chapter III. First, the conventional losses to barley growers as covered by the MPCCI and IP programs were estimated and compared with a scenario when the programs were adjusted to explicitly cover the losses due to scab and vomitoxin risk. Next, the degree of the catastrophic nature of scab and vomitoxin losses to barley growers under the MPCCI and IP programs were assessed.

Results from the simulation on the effects of scab and vomitoxin losses on equilibrium coverage levels and premiums for the two insurance programs are summarized in a tabular format, allowing for the relevance of reinsurance and subsidized reinsurance to be adequately assessed. The sensitivity analyses of farmers' risk perception and the correlation of losses on the equilibrium coverage levels and premiums for the MPCCI and IP programs are presented in graphical formats.

Loss Estimation and Insurance Coverage

The Average Production History (APH) yields are essential in the estimation of losses for both the yield-based MPCCI program and the revenue-based IP program. The IP program provides coverage for yield and/or price risks. The conventional APH yield, $APH_{y_{it}}$, was estimated and compared with the scab-adjusted APH yield, $APH_{yn_{it}}$ (APH yield that is explicitly adjusted for losses due to scab in years of scab outbreak). A

significant disparity between $APH_{ys_{it}}$ and $APH_{yn_{it}}$ would obviously have implications on the level of coverage provided to barley farmers under the MPCCI and IP programs following the outbreak of scab and vomitoxin in 1993.

The Average Production History (APH) Yield

A four-year-based APH yield was adopted in this study. Figure 4.1 depicts the magnitude of the difference in the scab-adjusted APH yield and conventional APH yield.

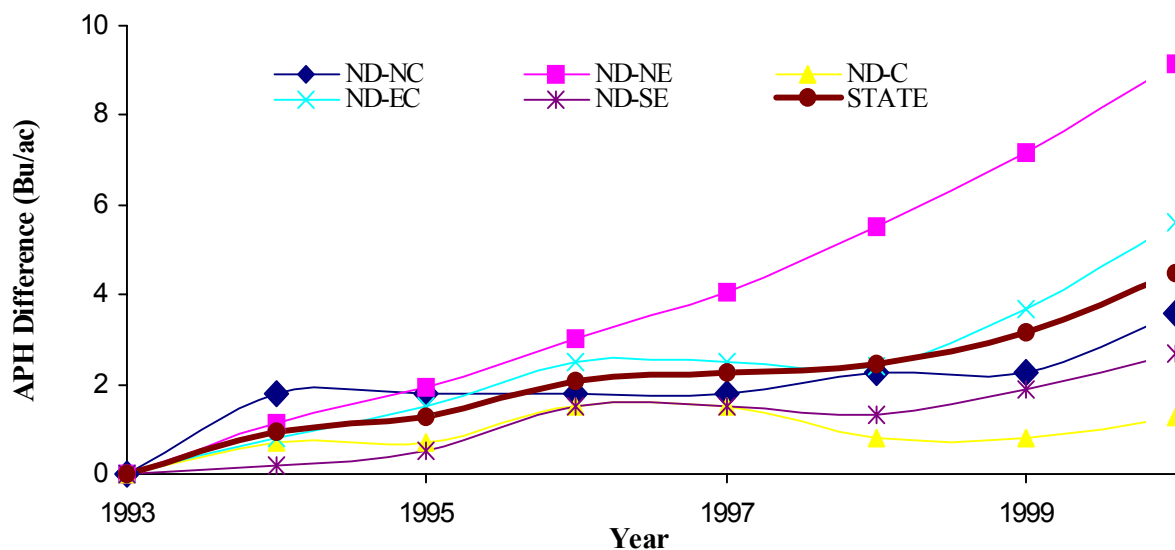


Figure 4.1. Margins of Difference Between Scab-adjusted APH Yields and Conventional APH Yields for the CRDs in North Dakota from 1993 to 2000.

Figure 4.1 represents the additional yield coverage that should have been available to barley farmers in the respective CRDs since 1993 had scab risk been explicitly incorporated in the estimation of the APH yields. Figure 4.1 shows a significant and

increasing margin of difference in the values estimated for APH yields for insurance purposes since 1993 (the year of scab outbreak). The results indicate that, had losses due to scab been explicitly incorporated for insurance coverage to barley farmers in North Dakota, then the estimated APH yields should have been higher, thus providing for better coverage. It is observed that the farmers in some CRDs like the northeastern North Dakota (ND-NE) CRD, were the most affected by the disparity in APH yield estimations for insurance purposes.

Coverage of Losses by MPCI and IP

The average yearly loss per acre was calculated for a typical farmer in North Dakota seeking coverage from both MPCI and IP programs first in the conventional setting and later with the explicit incorporation of losses due to scab and vomitoxin. The potential losses covered by the MPCI and IP programs in both scenarios from 1993 to 2000 are represented in Figures 4.2 and 4.3, respectively. The graphs represent losses for which there would be indemnity payments. In 1995, for instance, a typical farmer with insurance coverage from the IP did not receive any indemnity payments. The insurance coverage is more important when risk due to scab and vomitoxin is factored in the estimation of losses.

Figures 4.2 and 4.3 show that, from 1993 to 2000, a significant proportion of the potential MPCI and IP coverage was largely unaccounted for due to the non-incorporation of scab and vomitoxin risks in the estimation of the losses. Consequently, barley growers were not adequately covered and indemnified by the MPCI and IP in the years following scab and vomitoxin outbreak in North Dakota and in the Midwest by extension.

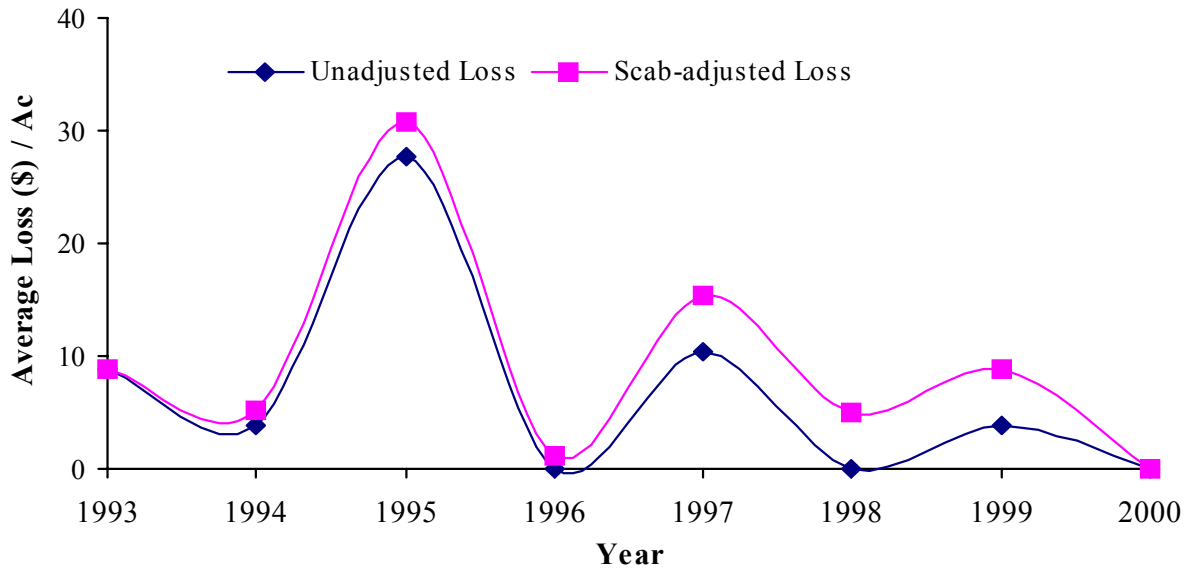


Figure 4.2. Average MPCCI-covered Losses for a Typical Farmer in North Dakota from 1993 to 2000.

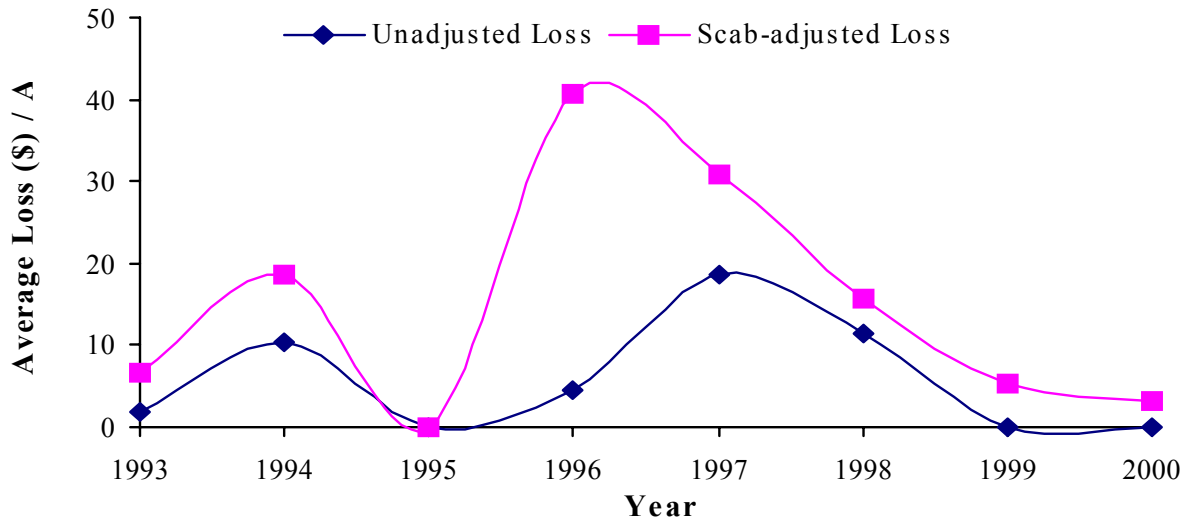


Figure 4.3. Average IP-covered Losses for a Typical Farmer in North Dakota from 1993 to 2000.

The increased risk due to scab and vomitoxin is currently being absorbed by the barley producers (USGAO, 1999). This situation is depicted for the MPCCI program in 1997, 1998, and 1999 (Figure 4.2) and for the IP program in 1994, 1996, and 1997 (Figure 4.3).

The potential for a significant scab outbreak poses a major challenge to insurers, especially if such outbreaks occurred over a wide geographical region. In the proceeding section, the magnitudes of the risk associated with scab and vomitoxin losses are evaluated.

The Catastrophic Nature of Scab and Vomitoxin Risk

In this section, the variance and correlation of the losses to barley farmers covered by both the MPCCI and IP programs are used in assessing the catastrophic nature of scab and vomitoxin risk. Table 4.1 depicts that, when scab and vomitoxin risk are explicitly incorporated in the estimation of the losses that are covered by the IP program, the correlation of the losses, ρ , between farmers increases substantially and is close to 1.

Table 4.1. The Variance and Correlation of Losses Covered by the MPCCI and IP Programs

Insurance Program	Average Loss (\$/ac) Covered	Variance of Loss	Average Correlation of Loss
MPCI _{ns}	8.465	9.1543	0.753
MPCI _s	11.7307	24.6489	0.889
IP _{ns}	8.7413	12.6786	0.5478
IP _s	16.8609	22.1926	0.9036

The subscript *ns* stands for “no scab risk” in the analysis, and *s* stands for “scab and vomitoxin risk.”

MPCI_{ns} and IP_{ns} represent the conventional MPCCI and IP programs (no provision for scab and vomitoxin) while MPCCI_s and IP_s represent the scab-adjusted programs. The correlation coefficient, ρ , is a measure of the catastrophic nature of the losses with a value of zero indicating no catastrophic risk. In principle, crop losses are generally correlated even in the absence of scab and vomitoxin risk. Table 4.1 depicts that the correlation of the losses to barley farmers covered by both the MPCCI and IP programs increases significantly when scab and vomitoxin risks are considered. This increase is expected since scab and vomitoxin risk impacts a larger segment of barley growers whenever there is an unfavorable season. Tables A.6 to A.9 present the correlation matrices for the losses covered by the MPCCI and IP programs from which the average values of ρ presented in Table 4.1 have been derived.

Table 4.1 also shows that, with the IP, the average correlation of losses with scab and vomitoxin is 0.90 as opposed to an average ρ of 0.55 when the estimated IP losses do not explicitly consider scab and vomitoxin risk. The same scenario is seen with the MPCCI program where the average value of ρ increases from 0.75 to 0.89 for the conventional and scab-adjusted scenarios, respectively. These results confirm the hypothesis that scab and vomitoxin risks are more catastrophic in nature than the conventional crop losses to barley farmers. There is a higher and more significant jump in the value of ρ for the IP program than for the MPCCI program, most probably due to the increased risk from vomitoxin discounted prices that are better captured by the IP program when scab and vomitoxin are incorporated in loss estimations. In addition, it can be assumed that all the growers in a scab-affected region are equally exposed to price discounts.

The variance of losses shown in Table 4.1 equally portrays the increased risk to insurers when scab and vomitoxin are an integral part of loss estimations. The variance of loss is seen to increase from 9.15 to 24.65 and from 12.68 to 22.19 for the losses covered by the MPCCI and IP programs, respectively. These results have implications on the risk attitude of the insurers whose responses are translated in the coverage levels they are willing to offer and the premiums they would want to charge from growers.

Impact of Scab and Vomitoxin on the Equilibrium Coverage Levels and Premiums

This section provides the results of the effects of scab and vomitoxin risk and reinsurance on the crop insurance equilibrium measured here by the equilibrium coverage levels and premiums. Simulation analyses were carried out under the scenarios of no reinsurance, reinsurance, and subsidized reinsurance. Prevailing coverage levels for the MPCCI 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 (2002) 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 and \$6.60 for every \$100 of loss in barley (Rate Mate Premium Estimation, 2002). Furthermore, 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.

Table 4.2 presents the results of the base case with the farmers' risk aversion coefficient, λ , set equal to one and equal to θ , the risk aversion coefficient of the insurers.

Table 4.2. Impact of Scab and Vomitoxin Risk on the Equilibrium Coverage Levels and Premiums for the MPCl and IP Programs per CRD

CRD/ State	Insurance Program	No Reinsurance			Non-subsidized Reinsurance			Subsidized Reinsurance		
		Equil. Cov.	StDev	Premium	Equil. Cov.	StDev	Premium	Equil. Cov.	StDev	Premium
ND-NC	MPCl _{ns}	0.1774	0.0065	27.6652	0.3674	0.1889	23.9099	0.7298	0.2823	16.7445
	MPCl _s	0.1738	0.0053	49.8212	0.3643	0.1904	41.8781	0.7181	0.2790	27.1272
	IP _{ns}	0.2272	0.0101	23.9971	0.4261	0.1828	20.5085	0.7839	0.2646	14.2441
	IP _s	0.1749	0.0030	39.6216	0.3665	0.1921	34.5426	0.6991	0.2655	25.7287
ND-NE	MPCl _{ns}	0.1793	0.0051	22.2673	0.3731	0.1912	19.3562	0.7209	0.2712	14.1314
	MPCl _s	0.1739	0.0053	37.8421	0.3620	0.1884	32.1976	0.7139	0.2792	21.6330
	IP _{ns}	0.2284	0.0088	36.5571	0.4295	0.1841	30.5804	0.7898	0.2615	20.1725
	IP _s	0.1749	0.0029	52.9462	0.3679	0.1932	45.5538	0.6997	0.2649	32.8435
ND-C	MPCl _{ns}	0.1797	0.0051	8.6414	0.3707	0.1883	7.8468	0.769	0.2710	6.4068
	MPCl _s	0.1750	0.0046	15.6300	0.3664	0.1902	13.7393	0.7089	0.2727	10.3570
	IP _{ns}	0.2217	0.0145	15.6409	0.4170	0.1817	13.6955	0.8045	0.2911	9.9363
	IP _s	0.1745	0.0034	17.7339	0.3654	0.1911	16.0212	0.6988	0.2661	13.03.8
ND-EC	MPCl _{ns}	0.1797	0.0046	26.9125	0.3725	0.1911	23.2239	0.7176	0.2717	16.6191
	MPCl _s	0.1748	0.0044	59.4147	0.3645	0.1900	49.6775	0.7120	0.2752	31.8436
	IP _{ns}	0.2303	0.0077	14.9459	0.4329	0.1860	13.0338	0.7727	0.2563	9.8259
	IP _s	0.1740	0.0035	51.4173	0.3647	0.1908	44.3847	0.7040	0.2695	31.8667
ND-SE	MPCl _{ns}	0.1801	0.0046	7.1099	0.3725	0.1894	6.5068	0.7177	0.2706	5.4248
	MPCl _s	0.1752	0.0046	10.4109	0.3669	0.1922	9.3147	0.7091	0.2710	7.3578
	IP _{ns}	0.2225	0.0150	6.0858	0.4190	0.1811	5.5708	0.80.18	0.2869	4.5672
	IP _s	0.1733	0.0044	27.4428	0.3614	0.1890	24.3696	0.7087	0.2741	18.6957
ND	MPCl _{ns}	0.1792	0.0004	17.5423	0.3712	0.0010	15.4191	0.7206	0.0018	11.5554
	MPCl _s	0.1746	0.0005	31.281	0.3648	0.0019	27.2714	0.7124	0.0022	18.7680
	IP _{ns}	0.2260	0.0037	18.5548	0.4249	0.0067	16.0331	0.7885	0.0137	11.4224
	IP _s	0.1743	0.0006	35.1848	0.3652	0.0023	30.9492	0.7020	0.0040	23.4733

The subscript *ns* stands for “no scab risk” in the analysis, and *s* stands for “scab and vomitoxin risk” while the abbreviation Equil. Cov. refers to the “Equilibrium Coverage Levels” and StDev refers to “Standard Deviation.”

The results of the effects of scab and vomitoxin on the equilibrium coverage and premiums as presented in Table 4.2 are analyzed separately followed by a joint summary. Although presented for the state level (ND), the same inferences can be made at the CRD levels. Tables A.10 and A.11 present the summarized results at the state level for the

MPCI and IP programs for different relationships between λ , the farmers' risk aversion coefficient, and θ , the risk aversion coefficient of the insurers.

The analyses and inferences following Table 4.2 are true for the three scenarios ($\lambda > \theta$, $\lambda = \theta$, and $\lambda < \theta$) presented in Tables A.10 and A.11, with the exception that, with $\lambda < \theta$, the equilibrium coverage level is lower while the premium charged is higher

Effects on Equilibrium Coverage Level (φ)

It is worth recalling here that the conventional coverage levels for RMA-subsidized MPCIs and IP programs range from 65 to 85 percent. Table 4.2 shows that, in the absence of reinsurance, the equilibrium coverage levels fall below the present recommended 65-85 percent range. As expected, having subsidized reinsurance leads to a significant increase in the coverage levels. For instance, with the incorporation of scab risk and vomitoxin risk, the state-level coverage levels with no reinsurance increase from 17.46 percent to 71.24 percent, and from 17.43 percent to 70.20 percent for the MPCIs and IP, respectively.

Comparing the rate of increase of the coverage levels (Table 4.2) as a consequence of reinsurance and subsidized reinsurance reveals very little disparity between the $MPCI_{ns}$ (the conventional MPCIs program) and $MPCI_s$ (scab and vomitoxin adjusted MPCIs). For instance, the increased margin of coverage level from no reinsurance to subsidized reinsurance is 54.14 percent (17.92 to 72.06 percent) for the $MPCI_{ns}$ as opposed to 53.78 percent (17.46 to 71.24 percent) for the $MPCI_s$. The same analysis holds true for the IP_{ns} (the conventional IP program) and the IP_s (scab and vomitoxin adjusted IP) with increased margins 56.25 percent (22.6 to 78.85) and 52.77 percent (17.43 to 70.20), respectively.

As expected, Table 4.2 also shows that the equilibrium coverage levels (φ) for both the MPCCI and IP programs are lower when losses due to scab risk are explicitly covered. However, the decrease appears to be more substantial with the IP coverage than with the MPCCI coverage. For instance, with non-subsidized reinsurance, φ decreases from 42.49 percent (with non scab risk) to 36.52 percent (with scab risk) for the IP program, giving a margin of decrease of 6 percent. For the MPCCI program, the margin of decrease for the same scenario is only 0.6 percent (decrease from 37.12 to 36.48 percent). These results are consistent with the coverage of losses by the MPCCI and IP programs as illustrated in Figures 4.2 and 4.3, respectively. The bigger margin of losses covered by the IP program as a result of scab and vomitoxin is responsible for the marked decrease in coverage levels in this program as opposed to the MPCCI program. Furthermore, it is shown in Tables 4.1 and 4.2 that the dollar difference in losses due to scab and vomitoxin covered by the IP program, \$8.12 (\$16.86 minus \$8.74) is greater than that covered by the MPCCI, \$3.26 (\$11.73 minus \$8.47).

Table 4.2 also depicts that growers are required to pay higher premiums to obtain insurance coverage within the recommended 65-85 percent range when scab and vomitoxin risks are explicitly incorporated. This impact on premiums is shown to be equally important for the MPCCI program for which scab risk seemed to have a minimal effect on the reduction of the coverage level. The analysis of Table 4.2 with respect to the impact of scab and vomitoxin on the premium rates insurers would charge is presented in the following subsection.

Effects on Premiums (w)

For both the MPCCI and IP programs, Table 4.2 shows that, as expected, reinsurance leads to a decrease in the potential premium that is charged. For the MPCCI_s (scab-adjusted MPCCI program), levels fall from \$31.93 per acre when there is no reinsurance to \$27.27 per acre when there is reinsurance with a further drop to \$18.77 per acre when the reinsurance is subsidized.

The premiums for MPCCI and IP are higher and almost double in magnitude when losses due to scab risk are explicitly incorporated. The premium charged with no reinsurance for IP_s (the scab-adjusted IP program) is \$35.18 per acre as opposed to \$18.55 per acre for IP_{ns} (the conventional IP program). In the case of the MPCCI program, the premium charged with no reinsurance for MPCCI_s (the scab-adjusted MPCCI program) is \$31.93 per acre as opposed to \$17.54 per acre for MPCCI_{ns} (the conventional MPCCI program). The results show that, for scab to be effectively covered by the existing insurance instruments, the growers will have to pay far higher premiums. The resultant higher premiums, however, raise concerns regarding the growers' willingness to bear the almost 100 percent increase rate for scab and vomitoxin coverage compared to the traditional coverage.

The results suggest the relative importance of subsidized reinsurance for scab and vomitoxin coverage as opposed to the conventional coverage. For instance, reinsuring and subsidizing the IP program in the absence of scab risks (IP_{ns}) lead to a decrease in the premium charged from \$18.55 per acre to \$11.42 per acre (a net reduction of \$7.14 per acre). The same analysis when scab risk is incorporated (IP_s) lead to a net decrease of

\$11.71 per acre. With subsidized MPCl, the analysis gives a net decrease of \$5.99 for the MPCl_{ns} and a net decrease of \$13.16 for the MPCl_s.

The results of this study are consistent with the conclusions of Duncan and Myers (2000) regarding catastrophic risks when the effects of scab and vomitoxin risk on the equilibrium coverage level and premiums are weighted together. In this case, scab and vomitoxin risk are seen to decrease the equilibrium coverage levels and increase premiums. The decrease in coverage levels is shown to have a lesser significance with the MPCl coverage as opposed to its effect on the IP coverage, but the increase in premiums, on the other hand, is very significant for both insurance programs. Subsidized reinsurance is seen to increase the equilibrium coverage levels (to the 65 to 85 percent range) and decrease the premiums. Notwithstanding the effects of reinsurance and subsidized reinsurance in decreasing premium amounts, the premiums expected of growers to effectively cover for scab and vomitoxin risks appear to be very high, which may cause an unwillingness to pay by the growers, thereby leading to a possible breakdown of the insurance market.

The foregoing analysis is suggestive of the fact that subsidized reinsurance might not be enough to stabilize the insurance market when scab and vomitoxin risk are explicitly incorporated in the conventional insurance instruments. The stability of such a market will also rely heavily on how both the growers and insurers perceive the opportunities of insuring against quality-related risks. One way of looking at the situation is by conducting sensitivity analyses to assess the effects on the equilibrium coverage levels and premiums of changes in the risk perception of the growers and insurers.

Sensitivity Analyses

A major concern related to any crop insurance market is how farmers value risk, scab, and vomitoxin; and whether they are willing to pay a third party to manage this risk. In theory, farmers would be willing to pay a higher risk premium if they perceive that they have a higher probability of incurring yield and/or revenue loss as a result of scab and vomitoxin.

Another major challenge is a good understanding of the properties of the expected loss (the variance of loss and the spread). In the case of scab and vomitoxin, a major concern about the expected loss is its correlation across geographical regions and between farmers. This correlation indicates not only the degree of the catastrophic nature of the losses, but to an even bigger scale, it affects how grain elevators determine price discounts. For instance, grain elevators tend to be more rigorous with testing scab levels and the level of discounts charged if they perceive that scab was more widespread in a particular year. Furthermore, it could be envisioned that two farmers in different CRDs with the same level of scab-infested grains may receive different discounts if one is located in a CRD where scab is not perceived to be very problematic for a given year.

To empirically address these issues, sensitivity analyses were conducted to assess the behavior of the equilibrium coverage levels and premiums to changes in the level of farmers' risk attitude (measured by λ) and the degree of correlation of losses (ρ).

Sensitivity of Equilibrium Coverage Levels and Premiums to Growers' Risk Aversion (λ)

The two graphs in Figures 4.4 and 4.5 indicate the sensitivity of the equilibrium coverage levels and premiums to changes in the farmers' risk aversion parameter (λ) when MPCI and IP programs are adjusted to incorporate scab and vomitoxin risk, respectively. As expected with the MPCI and the IP programs, the more risk averse the farmer is (as λ increases), the higher the equilibrium coverage level and the premium for the three scenarios of no reinsurance, non-subsidized re-insurance, and subsidized reinsurance. For all values of λ , subsidized reinsurance gives higher coverage levels and lower premiums.

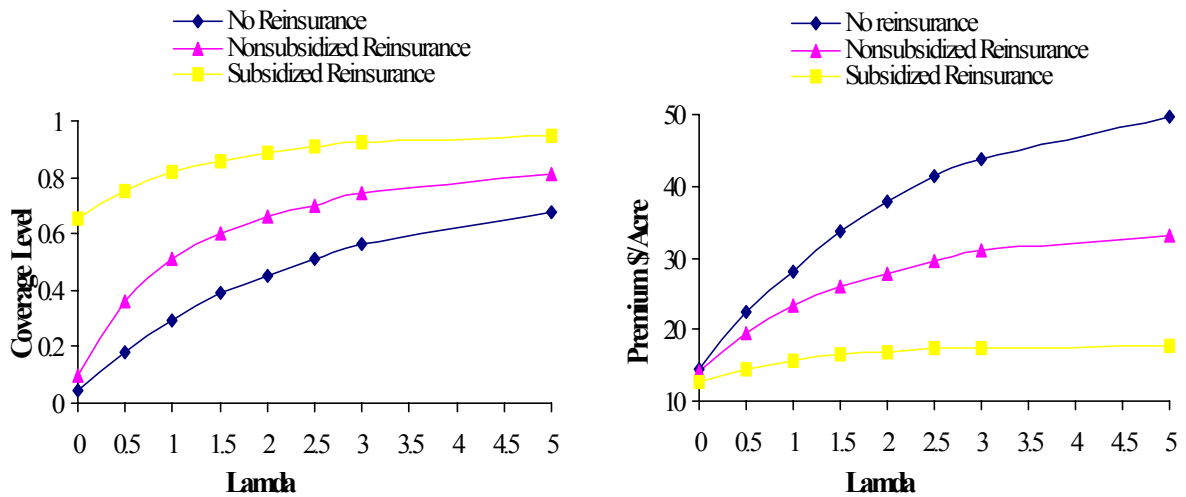


Figure 4.4. Effects of Farmers' Risk on MPCI Coverage Levels and Premiums when Scab and Vomitoxin Risk is Greater than Zero.

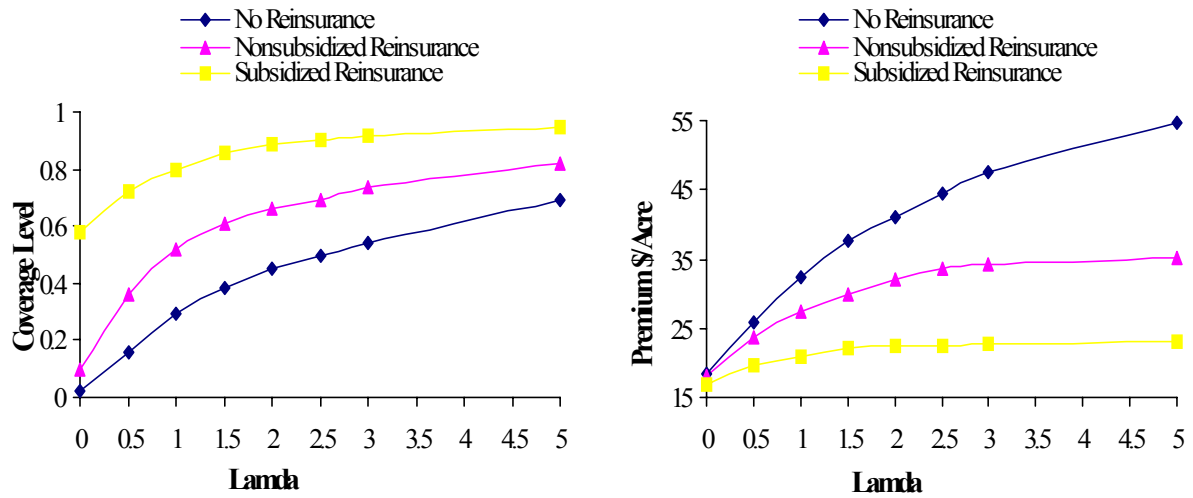


Figure 4.5. Effects of Farmers' Risk on IP Coverage Levels and Premiums when Scab and Vomitoxin Risk is Greater than Zero.

Both Figures 4.4 and 4.5 help to emphasize the relevance of reinsuring and subsidizing the existing insurance programs if the losses due to scab and vomitoxin have to be effectively covered by the existing insurance instruments. The results indicate that subsidized reinsurance (and possibly premiums) will be required to attain the 65 to 85 percent coverage level. The curve for subsidized reinsurance stabilizes when $1 < \lambda < 2$, for a coverage level range of 65 to 85 percent. The plot of the premium levels with subsidized reinsurance depicts corresponding lower values of premiums for $1 < \lambda < 2$. The other two curves (no reinsurance and non-subsidized reinsurance) increase exponentially within the same range for both the coverage levels and premium even for values of $\lambda > 2$.

Sensitivity of Equilibrium Coverage Level and Premiums to the Correlation of Losses (ρ)

The graphs in Figures 4.6 and 4.7 indicate the sensitivity of the equilibrium coverage levels and premiums to changes in the degree of correlation of losses (ρ) for the MPCCI and IP programs, respectively. As expected, when both programs are adjusted to explicitly cover scab and vomitoxin risks, the higher the degree of correlation of the losses (as ρ increases), the lower the coverage levels and the higher the premium for the three scenarios of no reinsurance, non-subsidized reinsurance, and subsidized reinsurance. The inverse relationship between the coverage level and premiums with regards to the response in changes in the values of ρ can be understood from the standpoint that insurers faced with highly correlated risks will be less than willing to participate in the insurance market and would normally charge higher premiums.

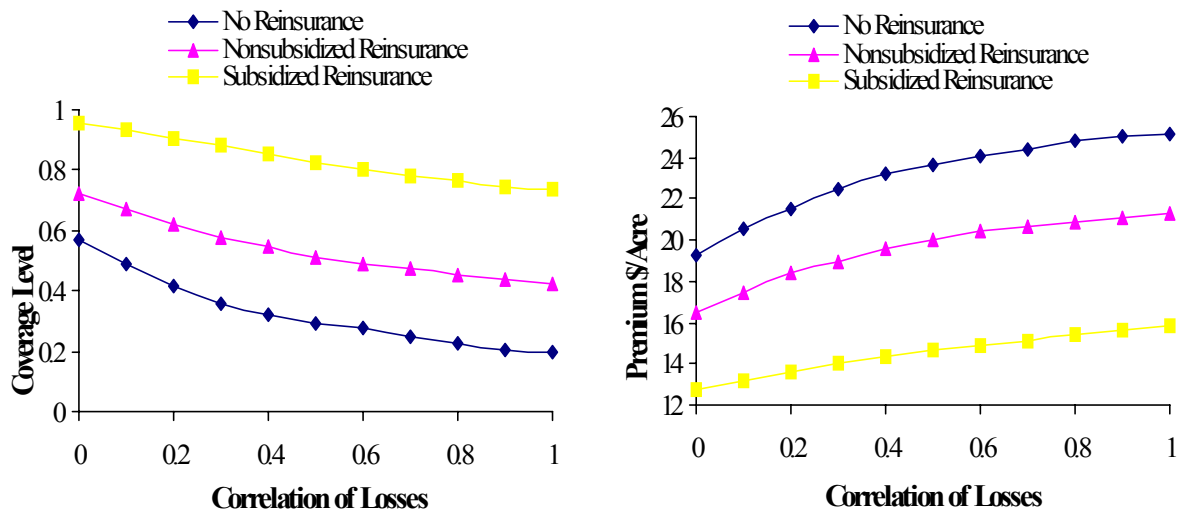


Figure 4.6. Effects of Correlation of Losses on MPCCI Coverage Levels and Premiums with Scab and Vomitoxin Risk Greater than Zero.

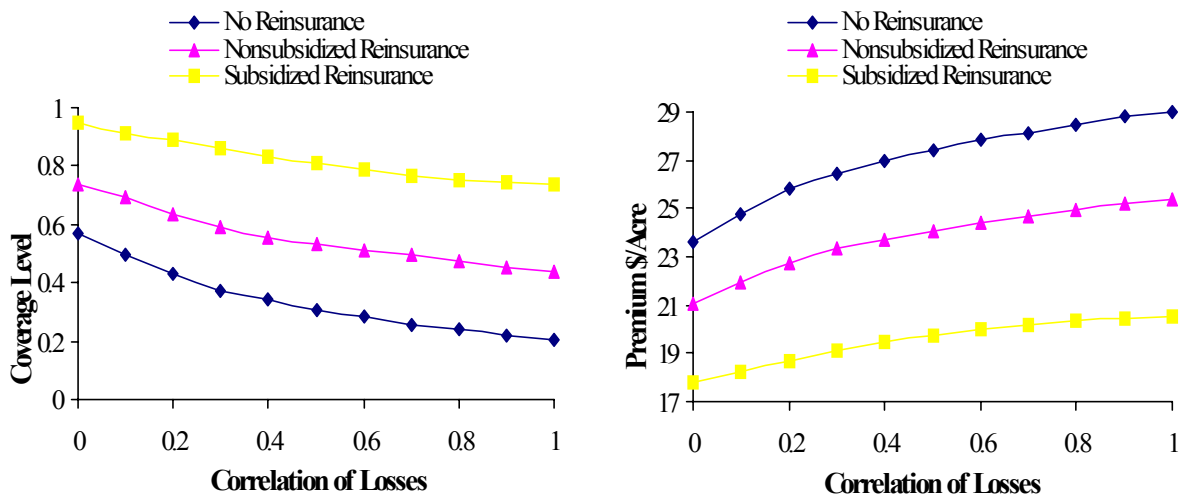


Figure 4.7. Effects of Correlation of Losses on IP Coverage Levels and Premiums with Scab and Vomitoxin Risk Greater than Zero.

Figures 4.6 and 4.7 further emphasize the importance of subsidized reinsurance if quality risk like scab has to be incorporated in the MPCCI and IP. For both programs, the correlation of losses with scab and vomitoxin is greater than 0.8. From Figures 4.6 and 4.7, it is seen that, with correlations of 0.8 and above, a coverage level of 60 percent and above can be attained only with subsidized reinsurance. Even at a very absolute value of ρ equal to 1 (very widespread losses and highly correlated losses), no reinsurance and subsidized reinsurance give coverage levels which are greater than 50 percent. Again, the resultant high coverage levels point to the fact that the likelihood of insurance market failure with scab and vomitoxin risk is very high given the high degree of correlation of the losses between barley farmers. Only with subsidized reinsurance are the equilibrium coverage levels high enough. Meanwhile, although the premiums charged are relatively

low at higher values of ρ for subsidized reinsurance, the values still appear to be high for barley growers. Therefore, willingness to pay for premiums is an issue for scab and vomitoxin third-party coverage even when the insurance is subsidized. From the outset, a federal government policy to specifically subsidize premiums for scab and vomitoxin coverage in a systematic manner is highly indicated.

CHAPTER V

SUMMARY AND CONCLUSIONS

Unexpected changes in crop quality are known to have important impacts on producer income and risks. Following the outbreak of scab and vomitoxin in the Midwest, barley yields have been severely impacted. In addition, price discounts have been large due to food safety-related concerns associated with vomitoxin contamination. Recent studies (Johnson et al., 1998; USGAO, 1999; Nganje et al., 2001) have documented substantial declines in revenues of wheat and barley farmers in North Dakota and the Midwest due to scab and vomitoxin. However, despite the escalation in the importance of crop insurance as a means to manage risks associated with unexpected events, there has not been any effective insurance coverage for barley farmers against scab and vomitoxin risks. The USGAO (1999) estimated that only 2 percent of the cumulative scab and vomitoxin related losses to barley farmers between 1993 and 1997 were indemnified under the existing crop insurance programs. This low protection is 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.

This study developed an equilibrium crop insurance model in a framework that explicitly incorporates quality-related risk in crop insurance programs. Specifically, the study developed a framework to effectively estimate the insurable losses to barley farmers due to scab and vomitoxin under the Multi-Peril Crop Insurance (MPCI) and Income Protection (IP) programs. The second specific objective of the study was to determine

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 by analyzing the impact of the quality-related losses on the equilibrium coverage levels and premiums of the MPCCI and IP programs. Last, the study conducted 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 analysis provided important and timely implications for the design and management of crop insurance that explicitly covers risks due to quality shortfalls. Quality-related insurance instruments are of relevance because risks of quality losses are increasingly important and, in many cases, such as with scab and vomitoxin in the barley crop, have exceeded losses from traditional sources of price level and yield risks.

The analysis of the yield-based and revenue-based losses to barley farmers reveals that the conventional MPCCI and IP programs have not been effective mechanisms to manage the losses related to scab and vomitoxin risk. On the one hand, the study showed that the Actual Production History (APH) yields on which the MPCCI and IP programs are hinged are underestimated in the present context of scab and vomitoxin risks. There is a significant disparity between estimated conventional APH yield and the APH yield that has been explicitly adjusted to account for scab and vomitoxin related losses. Second, the incorporation of scab and vomitoxin risk in the estimation of losses to barley farmers leads to an increase in the size of the insurable losses for the MPCCI and IP programs. The direct consequence of the increase in insurable crop losses is that, from 1993 to 2000, a significant

proportion of the potential MPCl and IP coverage for barley farmers in North Dakota was undermined due to the non-incorporation of scab and vomitoxin risks in the estimation of the losses. By extension, it can be envisioned that barley farmers in North Dakota and the Midwest have not been adequately indemnified by the MPCl and IP programs since 1993, the year of the first major scab and vomitoxin outbreak.

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 scab and vomitoxin. However, coverage levels are significantly lower than the 65 to 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. 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.

The implementation of effective crop quality insurance programs has several advantages for barley producers in North Dakota and in the United States. The farmers, through crop quality insurance, get to transfer a part of their quality risk to insurance companies, thereby reducing the underlying risk to barley production. This risk transfer 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, 2002) 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.

The methodology used in the study illustrates how quality risks could be incorporated into crop insurance types of contracts. Heretofore, mechanisms to deal with these risks have been ex-post and not necessarily effective in terms of third-party risk transfer. Although applied here in the case of scab and vomitoxin in barley, the methodology could be applied similarly in many regions and crops. Furthermore, even though the estimation of insurable loss in this study follows RMA quality loss adjustment guidelines, which are intended to minimize moral hazard tendencies, the potential moral hazard issues associated with quality insurance instruments is an area where further research is needed.

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APPENDIX

Table A.1. Barley Yield Equation Parameter Estimates by Crop Reporting District

State / CRD	Intercept	Trend	Temperature Deviation	Precipitation Deviation	Precipitation Deviation squared
ND - NC**	25.87* (9.06)	0.72* (5.64)	-3.89* (-3.31)	4.1* (3.72)	-2.65* (-2.47)
ND - NE	24.43* (8.48)	1.15* (9)	-3.41* (-2.47)	3.26* (2.72)	-2.31 (-1.65)
ND - C	21.28* (7.73)	0.93* (7.02)	-4.56* (-3.44)	5.37* (4.25)	-1.27 (-1.34)
ND - EC	27.2* (10.01)	1.17* (9.09)	-3.57* (-2.67)	2.96* (2.33)	-2.27 (-2.14)
ND - SE	26.43* (9.66)	0.92* (7.01)	-2.87* (-2.07)	5.49* (3.56)	-3.6 (-3.83)

Numbers in the parentheses are t-values.

** Indicates error structure corrected for first order auto-correlation.

Source: Adapted from USGAO (1999).

Table A.2. Fraction of Barley Yield and Area Loss (α_{it}) Attributable to Fusarium Head Blight by Crop Reporting District

Year	ND-NC	ND-NE	ND-C	ND-EC	ND-SE
1993	1	0.24	0.26 - 0.43 ⁺	0.17 - 0.28 ⁺	0.19 - 0.31 ⁺
1994	1	0.32 - 0.65 ⁺	1	0.18 - 0.30 ⁺	0.19 - 0.32 ⁺
1995	0.26 - 0.52 ⁺	0.34	0.16 - 0.32 ⁺	0.15 - 0.31 ⁺	0.15 - 0.30 ⁺
1996	0.84 - 1.00 ⁺	0.64 - 0.93 ⁺	1	0.66	0.75 - 1.00 ⁺
1997	0.43 - 0.87 ⁺	0.40 - 0.53	0.45 - 0.68 ⁺	0.11 - 0.26 ⁺	0.19 - 0.38 ⁺
1998	0.73	0.9	0.47	0.8	0.93
1999	0.35	0.63	0.4	0.6	0.56
2000	0.75	0.96	0.81	0.86	0.43

*Where ranges are given the arithmetic means were used.

Source: Extension Specialists and USGAO (1999).

Table A.3. Malting Barley Premium Parameter Estimates by Crop Reporting District

State / CRD	Independent Variable	
	Intercept	Total production (Q_T)
ND - NC	0.88** (3.68)	-0.0015** (2.78)
ND - NE	1.42** (6.16)	-0.0026** (-5.29)
ND - C	1.07** (4.48)	-0.0018** (3.54)
ND - EC	2.05** (6.85)	-0.0039** (-6.07)
ND - SE	1.07** (4.23)	-0.0018** (-3.18)

Numbers in the parentheses are t-values.

** Indicates parameter is statistically significant at the 0.05 level or higher.

Source: Adapted from USGAO (1999).

Table A.4. Feed Grain Barley Parameter Estimates by Crop Reporting District

State / CRD	Independent Variable		
	Intercept	Corn Price (P_C)	Total production (Q_T)
ND - NC**	0.24 (1.19)	0.78* (17.75)	-0.0009* (-2.07)
ND - NE	0.28 (1.48)	0.75* (18.18)	-0.0008* (-2.10)
ND - C	0.21 (1.19)	0.77* (19.81)	-0.0007** (2.00)
ND - EC	0.22 (1.13)	0.75* (17.42)	-0.0006 (-1.39)
ND - SE	0.21	0.78* (17.49)	-0.0007** (-1.76)

Note: Numbers in the parentheses are t-values.

*Indicates parameter is statistically significant at the 0.05 level or higher.

**Indicates parameter is statistically significant at the 0.10.

Source: Adapted from USGAO (1999)/

Table A.5. Estimated Average Malting and Feed Grain Weights by Crop Reporting District, 1959 to 1992

Barley Market	ND-NC	ND-NE	ND-C	ND-EC	ND-SE
Malting (nbar\mi)	0.71	0.68	0.62	0.79	0.6
Feed Grain (1 - nbar\mi)	0.29	0.32	0.38	0.21	0.4

Source: Adapted from USGAO (1999).

Table A.6. Correlation Matrix of Losses Covered by the MPCl with Scab and Vomitoxin Risk

	ND-NC	ND-NE	ND-C	ND-EC	ND-SE
ND-NC	1				
ND-NE	0.836440782	1			
ND-C	0.947790153	0.864845	1		
ND-EC	0.874457473	0.928799	0.876181	1	
ND-SE	0.840859781	0.861308	0.941549	0.924256	1
Average	0.889648595				

Table A.7. Correlation Matrix of Losses Covered by the MPCl Without Scab and Vomitoxin Risk

	ND-NC	ND-NE	ND-C	ND-EC	ND-SE
ND-NC	1				
ND-NE	0.59316	1			
ND-C	0.83746	0.79983	1		
ND-EC	0.62668	0.90519	0.78385	1	
ND-SE	0.58487	0.83796	0.73446	0.82638	1
Average	0.75298				

Table A.8. Correlation Matrix of Losses Covered by the IP with Scab and Vomitoxin Risk

	ND-NC	ND-NE	ND-C	ND-EC	ND-SE
ND-NC	1				
ND-NE	0.943169337	1			
ND-C	0.922619868	0.917556	1		
ND-EC	0.810776548	0.883724	0.918605	1	
ND-SE	0.834763309	0.916004	0.905123	0.984132	1
Average	0.903647374				

Table A.9. Correlation Matrix of Losses Covered by the IP Without Scab and Vomitoxin Risk

	ND-NC	ND-NE	ND-C	ND-EC	ND-SE
ND-NC	1				
ND-NE	0.851316	1			
ND-C	0.797615	0.61861941	1		
ND-EC	0.411299	0.46731506	0.65047	1	
ND-SE	0.155431	0.28445473	0.3196	0.922039	1
Average	0.547816				

Table A.10. Impact of Scab and Vomitoxin Risk on the Equilibrium Coverage Levels and Premiums for the MPCI Program

Nature of risk	No Reinsurance			Non-subsidized Reinsurance			Subsidized Reinsurance		
	Equil Cov.	StDev	Premium	Equil Cov.	StDev	Premium	Equil Cov.	StDev	Premium
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

0¹ ($\lambda > \Theta$), 0² ($\lambda = \Theta$), and 0³ ($\lambda < \Theta$).

Table A.11. Impact of Scab and Vomitoxin Risk on the Equilibrium Coverage Levels and Premiums for the IP Program

Nature of risk	No Reinsurance			Non-subsidized Reinsurance			Subsidized Reinsurance		
	Equil Cov.	StDev	Premium	Equil Cov.	StDev	Premium	Equil Cov.	StDev	Premium
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

0¹ ($\lambda > \Theta$), 0² ($\lambda = \Theta$), and 0³ ($\lambda < \Theta$).

The Variance of Insurance Profit [Adapted from Duncan and Myers (2000)]

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

In this study, it is assumed that all the random variables have the same marginal distribution, and the covariance between any two random variables is positive and identical; as such, the correlation coefficient between any two of the random variable is

$$\rho_{ij} = \frac{\text{Cov}(l_i, l_j)}{\sigma_l^2}$$

Substituting ρ into the variance expression then gives the result used in equation (15)

$$\text{Var}\left(\sum_{i=1}^n l_i\right) = n\sigma_l^2 [1 + (n-1)\rho]$$

Properties of the Firm Preference Function [Adapted from Duncan and Myers (2000)]

The equilibrium firm preference function, $V(n; \theta)$, can be written as

$$\begin{aligned} V(n; \theta) = & n\varphi(n) \{ (1 - \alpha)[w(n) - \bar{l} - c] + \delta\bar{l} \} \\ & - 0.5\Theta n[\varphi(n)]^2 \sigma_l^2 \times (1 - \alpha - \delta)^2 [1 + (n-1)\rho]. \end{aligned}$$

Collecting terms then gives

$$\begin{aligned} V(n; \theta) = & n\varphi(n) \{ (1 - \alpha)[w(n) - \bar{l} - c] \\ & + \delta\bar{l} - \Theta \varphi(n) \sigma_l^2 (1 - \alpha - \delta)^2 \times [1 + (n-1)\rho] \} \\ & + 0.5\Theta n[\varphi(n)]^2 \sigma_l^2 (1 - \alpha - \delta)^2 \times [1 + (n+1)\rho]. \end{aligned}$$

In equilibrium, equation (16) implies that the term in braces, $\{.\}$, is zero, which leaves

$$V(n; \theta) = 0.5\Theta n[\varphi(n)]^2 \sigma_i^2 (1 - \alpha - \delta)^2 \times [1 + (n+1)\rho],$$

where $\varphi(n)$ is given by equation (18). The properties of $V(n; \theta)$ are derived as follows:

- $V(n; \theta) = 0$ is trivial

$$- \frac{dV(n; \theta)}{dn} = \frac{\partial V}{\partial n} + \frac{\partial V}{\partial \varphi} \bullet \frac{\partial \varphi}{\partial n} = \frac{\partial V}{\partial n} \quad \text{because, in equilibrium, } \partial V / \partial \varphi = 0$$

Thus, $\frac{dV(n; \theta)}{dn} = 0.5\Theta[\varphi(n)]^2 \sigma_i^2 (1 - \alpha - \delta)^2 \times (1 - \rho + 2n\rho) > 0$, and $V(n; \theta)$ is

monotonically increasing.

$$\begin{aligned} - \lim_{n \rightarrow \infty} V(n; \theta) &= \lim_{n \rightarrow \infty} 0.5\Theta n[\varphi(n)]^2 \sigma_i^2 \times (1 - \alpha - \delta)^2 \times [1 + (n+1)\rho] \\ &= \lim_{n \rightarrow \infty} 0.5\Theta n[\varphi(n)]^2 \sigma_i^2 \times (1 - \alpha - \delta)^2 (1 - \rho) \\ &\quad + \lim_{n \rightarrow \infty} 0.5\Theta n^2 [\varphi(n)]^2 \sigma_i^2 \times (1 - \alpha - \delta)^2 \rho \end{aligned}$$

It can be shown that, as $n \rightarrow \infty$, $\varphi \rightarrow 0$. Since $[\varphi(n)]^2$ is of second order, it will go to

zero faster than $n \rightarrow \infty$. The first limit is, therefore, zero. The second limit depends on

$$\begin{aligned} &\lim_{n \rightarrow \infty} n^2 [\varphi(n)]^2 \\ &= \lim_{n \rightarrow \infty} \left(n^2 [(1 - \alpha)(\lambda \alpha \sigma_i^2 - c) + \delta \bar{l}]^2 \right) \\ &\quad / \left(\{(1 - \alpha)\lambda \sigma_i^2 + \Theta \sigma_i^2 (1 - \alpha - \delta)^2 \times [1 + (n - 1)\rho]\}^2 \right) \\ &= \lim_{n \rightarrow \infty} [(1 - \sigma)(\lambda \sigma_i^2 - c) + \delta \bar{l}]^2 \end{aligned}$$

$$\begin{aligned} & \left[\frac{(1-\alpha)\lambda\sigma_l^2 + \Theta\sigma_l^2(1-\alpha-\delta)^2}{n} + \frac{\Theta\sigma_l^2(1-\alpha-\delta)^2(n-1)\rho}{n} \right]^2 \\ &= \frac{[(1-\alpha)(\lambda\sigma_l^2 - c) + \delta\bar{l}]^2}{[\Theta\sigma_l^2(1-\alpha-\delta)^2\rho]^2} \end{aligned}$$

Thus, we have

$$\begin{aligned} \lim_{n \rightarrow \infty} V(n; \theta) &= \left(0.5\Theta\sigma_l^2(1-\alpha-\delta)^2\rho \times [(1-\alpha)(\lambda\sigma_l^2 - c) + \delta\bar{l}]^2 \right) \\ & \quad / ([\Theta\sigma_l^2(1-\alpha-\delta)^2\rho]^2) \\ &= \frac{[(1-\alpha)(\lambda\sigma_l^2 - c) + \delta\bar{l}]^2}{2\Theta\rho\sigma_l^2(1-\alpha-\delta)^2} \end{aligned}$$

Setting $\alpha = \delta = 0$ gives a limiting value assuming no reinsurance. Setting $\alpha > 0$ (reinsurance but no subsidization) again leads to a limiting value.

Comparative Statics Results [Adapted from Duncan and Myers (2000)]

Equations (13) to (15) can be rewritten as a vector of equations

$$F(x, \theta) = 0,$$

where $x = (\omega, \varphi, n)$

and $\theta = (c, \bar{l}, \Theta, \lambda, \sigma_l^2, \rho, \alpha, \delta)$ are the exogenous variables.

Assuming the conditions of the implicit function theorem are satisfied, then, at an equilibrium, $x = G(\theta)$ is an implicit function defined by $F[G(\theta), \theta] = 0$ and characterized by $F_x(x, \theta) \cdot G_\theta(\theta) = -F_\theta(x, \theta)$, 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 (13) to (15) and rearranging terms, we see that

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

Furthermore,

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

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 i th 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 $x = (\omega, \varphi, n)$, Cramer's rule implies $dw/d\rho > 0$, $d\varphi/d\rho < 0$, and $dn/d\rho$ is of indeterminate sign. These derivatives are the comparative statics equations if equilibrium exists under catastrophic risk without reinsurance.

Next note that, if $\delta = 0$, then

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

and consider the sequence of matrices $F_i(x, \theta)$, $i = 1, 2, 3$ which represent $F_x(x, \theta)$ but with the i th 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 $x = (\omega, \varphi, n)$, Cramer's rule implies $dw/d\alpha < 0$, $d\varphi/d\alpha > 0$, and $dn/d\alpha > 0$. These derivatives are the comparative statics equations if equilibrium exists under catastrophic risk and proportional reinsurance.

Finally note that

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

and consider the sequence of matrices $F_i(x, \theta)$, $i = 1, 2, 3$ which represents $F_x(x, \theta)$ but with the i th 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 $x = (\omega, \varphi, n)$, Cramer's rule implies $dw/d\delta < 0$, $d\varphi/d\delta > 0$, and $dn/d\delta >$ can be of either sign. These derivatives are the comparative statics equations if equilibrium exists with catastrophic risk and subsidized reinsurance.